The Brightest Stars, expanded version

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PREFACE: Scope and purpose of this essay

This online essay is an extended version of the essay in the printed-edition Handbook, containing all the material of its printed-edition accompaniment, but adding material of its own. The accompanying online table is likewise an extended version of the printed-edition table, *(a)* with extra stars (after providing for multiplicity, as we explain below, the brightest MK-classified 325, allowing for variability, where the printed edition has about 30 fewer, allowing for variability: our cutoff is mag. ~3.55), and *(b)* with additional remarks for the duplicated stars. We use a dagger superscript (†) to mark data cells for which the online table supplies some additional information, some context, or a caveat.

The online essay and table try to address the needs of three kinds of serious amateur: amateurs who are also astrophysics students (whether or not enrolled formally at some campus); amateurs who, like many in RASC, assist in public outreach, through some form of lecturing; and amateurs who are planning their own private citizen-science observing runs, in the spirit of such "pro-am" organizations as AAVSO. Additionally, we would hope that the online project will help serve a constituency of sky lovers, whether professional or amateur, who work with the heavens in an unambitious and contemplative spirit, seeking to understand at the eyepiece, or even with the naked eye, the realities behind the little that their limited circumstances may allow them to see. (This is the same contemplative exercise as is proposed for the Cyg X-1 black hole, with its gas-dumping supergiant companion HD226868, in the Handbook "Expired Stars" essay: with a small telescope, or even with binoculars, we first find HD226868, and then take a moment to ponder in awe the accompanying unobserved realities of gas-fed hot accretion disk, event horizon, and spacetime singularity.)

Our online project, started as a supplement to the 2017 Handbook, is still far from what might be considered a complete state. We cannot claim to have fully satisfied the needs of our various constituencies. Above all, we cannot claim to have covered all the appropriate points from stellar-astronomy news in our "Remarks" column, important though news is to amateurs of all three types. We would hope in coming years to remedy our deficiencies in several ways, most notably by relying more in our writing on recent primary-literature journal articles, with appropriate explicit citations.

In our citations, we favour the now-prevalent astrophysics "bibcode" formalism. The formalism is documented in simbad.u-strasbg.fr/guide/refcode/refcode-paper.html, and again in section 1.2.3 (headed "Bibliographic Identifiers") in adsabs.harvard.edu/abs_doc/help_pages/data.html.

A bibcode can be transformed into the display of a more human-readable bibliography entry, often with clickable hyperlink to an underlying online full-text, all-illustrations PDF publication, in various ways. We illustrate some possibilities by taking an extreme case, namely our bibcode reference to the classic 1910 Joel Stibbins *Astrophysical Journal* paper that reports the electric-photometry discovery of a secondary minimum in the Algol light curve. Old though the paper is, it is nevertheless available online. The bibcode (as we state again in our "Remarks" for the Algol entry in our table) is 1910ApJ....32..185S. A browser display with hyperlink to the desired full-text, all-illustrations PDF is available from the Centre de Données Stellaires (CDS) server (probably in Strasbourg) as simbad.u-strasbg.fr/simbad/sim-ref?bibcode=1910ApJ....32..185S. If something has gone wrong—and experience suggests that things can go wrong, even when a bibcode appears to casual inspection to be correctly typed, at any rate in some such semi-autonomous-agent computing environment as Microsoft Office—then one can recover through CDS as simbad.u-strasbg.fr/simbad/sim-fid if the star of interest and year of publication are known. In this particular case, recovery involves giving simbad.u-strasbg.fr/simbad/sim-fid some convenient identifier, for instance the IAU-promulgated name "Algol" or the Bayer identifier "beta Per." In the Algol-specific input form generated, one next asks, in the "References" section of the form, for all references from 1910 to 1910. The duly displayed bibcode, 1910ApJ....32..185S, for the sole 1910-through-1910 reference, is shown as a clickable hyperlink. Upon further clicking, the hyperlink eventually yields the PDF. A similar browser display is available from a (probably North American) ADS-NASA server as ui.adsabs.harvard.edu/abs/1910ApJ....32..185S/abstract. As a fourth possibility, the PDF is retrievable through a self-evident set of steps that starts by copying and pasting the bibcode into the “Bibliographic Code Query” box at the paper-workflow, as distinct from the more obviously accessible paperless-workflow, online form ui.adsabs.harvard.edu/paper-form. This fourth method has the advantage that multiple bibcodes can be entered within a single query. As a fifth possibility, which in our view cannot be guaranteed to work (but there seem to be intermittent problems with the fourth possibility as well; and in general, servers should not be presumed fully reliable, in any discipline) is simply to put 1910ApJ....32..185S naively into a general Google search, and to explore the ensuing chain of hyperlinks: in the case of at least a heavily cited paper, one is likely soon enough to reach an abstract at ADS-NASA or some similar authority, with accompanying PDF.

The bibliographic support of simbad.u-strasbg.fr/simbad and ui.adsabs.harvard.edu, as the principal tools for our primary-literature searching, is herewith gratefully acknowledged, as are *Wikipedia* (in exact-science topics, generally careful and up to date), *Sky & Telescope*, the web materials of Prof. James Kaler, and at a more technical level, several key sources of data: the Washington Double Star Catalog (WDS), the JMMC Measured Stellar Diameters Catalogue (JMDC), the BeSS database (operated at LESIA, Observatoire de Meudon, France: basebe.obspm.fr), and AAVSO. Helpful at AAVSO are not only the general graphing facility and the general AAVSO record of observations, but also a more recent offering, the VSX online database.

Thanks are additionally due both to the RASC family in North America and to the Tartu Observatory dark-sky (Tõravere) campus in Estonia for encouragement and support. At the dark-sky campus, particular mention should be made of conversations regarding photometry, notably with Dr. T. Eenmäe and Dr. I. Kolka.

It has been necessary in the photometry section (“Section 6”) to make an unusually large number of judgement calls or professions of uncertainty. In the interferometry section (“Section 7”), the work has been constrained by the author’s being only in the early phases of an envisaged multi-year private study of Fourier methods, including a study of interferometric aperture-synthesis imaging. It seems for this reason particularly advisable for the author to stress that the various inevitable errors and omissions in this work (notably in Sections 6 and 7, but also in the other sections, and in the table) are his sole responsibility, and to stress his desire to receive feedback. Feedback is best communicated in e-mail, to toomas.karmo@gmail.com, using some such hard-to-miss subject line as “RASC brightest-stars online: some deficiencies noted; some recommendations.”

SECTION 1: Selection bases for our 317 nominal “bright stars,” strictly 325 MK-classified bright stars

Of our selected 317 nominal stars, five call for extra comment pertinent to this mag. ~3.55 naked-eye selection criterion. (1) κ (kappa) CMa (at RA ~6h50) brightened in the 1960s or 1970s, just managing to meet the cutoff, and has remained bright. This change was unfortunately not noted in the RASC Handbook until 2019. Should κ CMa now once again fade, we propose to keep listing it for at least a few years, since it is a variable of the γ Cas type (and may therefore be liable to yet further episodes of brightening during the 21st century; in general, the γ Cas variables, whether temporarily bright or temporarily faint, are desirable targets for ongoing, regular, citizen-science spectroscopy, and even naked-eye monitoring, being closely associated with the amateur-relevant “Be phenomenon,” which we discuss at the end of Section 5 in this essay). (2) We discontinued listing L_2 Pup (at RA ~07h14) in the 2017, 2018, and 2019 Handbooks. Since then, however, we have reverted to our pre-2017 policy, since L_2 Pup is a semi-regular pulsator, occasionally bright. (3) T CrB A (at RA ~16h00) has shown nova behaviour, brightening from its current very faint state (mag. ~10 or ~9) to mag. 2.0 in 1866 and to mag. 3.0 in 1946. The Handbook has for years or decades listed T CrB A in its brightest-stars table. We propose to continue listing it, since its history suggests the possibility of a 21st-century outburst. (4) The Mira-type variable χ Cyg A (at RA~19h50) was considered by visual observers to surmount our brightness threshold in 2006, 2008, and 2013, even while not being assessed as quite this bright by CCD observers in those three years. From January 2023 Handbook work onward, we regard χ Cyg A as a star (just barely) meriting inclusion. (5) The supergiant μ Cep A, “Herschel’s Garnet Star” (at RA~21h44) occasionally surmounts our brightness threshold, being (e.g.) as bright as mag. 3.4 in a V-passband CCD observation from 2022 June 28. From January 2023 Handbook work onward, we therefore regard μ Cep A as a star (more than just barely) meriting inclusion.

Two omissions from our selection of 317 nominal stars also call for comment. (1) While mindful of the fact that η Car brightened greatly, attaining even mag. 0 for a few years from 1837 onward, we omit it from our table since there is no firm prognosis of a 21st-century repetition of that outburst. In April 2024, η Car was being reported as at mag. 3.9 or 4.0 in the V passband, and February 2022 as at mag. 4.1 in the V passband. In January

2021, η Car was being variously reported visually as at mag. 4.3 and 4.5. In all these cases, then, η Car was decidedly fainter than our naked-eye cutoff, although 2024 presents some brightening in relation to 2022 and 2021. The star was not reported by AAVSO visual observers as any brighter than mag. 3.9 in the second half of 2020. (2) P Cyg temporarily surmounted the Sample S brightness threshold around the year 1600, and perhaps again on one or two occasions later in the 1600s. The entire available AAVSO record, however, reaching back to 1891, shows P Cyg at all times no brighter than mag. 4.0. The AAVSO archive shows that in May 2024 and December 2022, P Cyg was being observed with photometric equipment in the V passband as at mags. 4.8 and 4.7.

We may now explain in what sense the set of 317 is nominal. In a strict accounting, the selection is a set of 317 objects that are in naked-eye terms "bright stars," i.e. are bright, unresolved point sources of starlight. Three kinds of situation need to be distinguished here, as we move from naked-eye impressions to underlying physical realities:

(1) In some cases (to cite an example at random, β Tau (Elnath)) what is to the naked eye a point source actually is, so far is as known, a solitary star.

(2) Very common is a situation in which a bright star is a component in a multi-star system, with the other member(s) making either a very small or a negligible contribution to the naked-eye retinal signal. An instance of the former type of pairing is γ And A, from which at a distance of just over 9″ lie two fainter stars, γ And B and γ And C, themselves separated by a mere 0.2″, and so faint that the BC pairing shines at around mag. 5. This has the consequence that BC makes just a modest contribution to the overall γ And ABC naked-eye neuron response. An instance of the latter type of pairing is α CMa A (Sirius), with α CMa B a white dwarf shining at mag. 8.5, in other words shining so feebly as to play essentially no role in the signal generated by the naked-eye retina. This binary constitutes a not trivial, and yet also at the present favourable time a not hopeless, project for the small telescope. (Apoastron was in 2019, and the greatest observational angular separation, at 11.3″, in 2023.) Since our table is officially a table of bright stars, we take care, at any rate in our various table revisions from early 2021 onward, to write in our first table column "γ And A" (not "γ And AB" or "γ And"), and "α CMa A" (not "α CMa AB" or "α CMa"). Helpfully, the naming rules promulgated since around 2016 at IAU, and reflected in our concluding "Remarks" column, stipulate, in parallel with our first-column decision, that a name such as "Sirius" applies to a star such as α CMa A, rather than to the binary system α CMa AB.

(3) In eleven other cases, the naked-eye point, shining at mag. ~3.55 or brighter, is the combined light of two binary-system components, each individually bright enough to count as a "bright star"—perhaps with each component exceeding our mag. ~3.55 cutoff, but also perhaps with one or both components just a little fainter than our mag. ~3.55 cutoff, and yielding a "star" brighter than mag. ~3.55 upon combining the light.

These eleven, so-to-speak awkward, cases (awkwardly forcing us to write the binary designations "AB" or "Aa,Ab" in the first column) are the following:

- β Phe AB (with each of A, B individually around mag. 4, yielding an aggregated naked-eye impression of mag. 3.2)
- γ Per Aa,Ab (with each of Aa, Ab a little brighter than mag. 4, yielding an aggregated naked-eye impression of mag. 2.91)
- α Aur Aa (Capella), Ab (with each of Aa, Ab very close to mag. 0)
- β Aur Aa (Menkalinam), Ab (with magnitudes nearly equal, yielding an aggregated naked-eye impression a little brighter than mag. 2)
- ζ CMa Aa,Ab (magnitudes nearly equal, at 3.6 and 3.8; this very tight binary is not as yet well observed, with as of at any rate 2022 March 2 just 4 WDS-documented measurements, from 2019 and 2020)
- γ Vir A (Porrima), B (magnitudes nearly equal, and with each individually very close to our mag. ~3.55 cutoff, yielding an aggregated naked-eye impression a little brighter than mag. 3)
- β Cen Aa (Hadar), Ab (magnitudes nearly equal, with each individual star much brighter than our mag. ~3.55 cutoff)
- η Oph A (Sabik), B (with B at mag. 3.5)
- λ Sco Aa (Shaula), Ab (with even Ab well above our cutoff, at mag. ~2.8)

- ζ Sgr A (Ascella), B (with B at mag. 3.5)
- π Sgr A (Albaldah), B (a poorly documented pairing, with the faint outlier C also poorly documented: WDS implies that B is of nearly the same magnitude as A, with each of these two stars very close to our mag. ~3.55 cutoff)

It is tempting to consider the η Peg system to be a twelfth case, requiring entry as "η Peg Aa (Matar), Ab." But since Ab is decidedly fainter than our mag. ~3.55 cutoff, and Aa only slightly fainter than that, we are obliged instead to enter this case simply as "η Peg Aa (Matar)," drawing attention in the table "Remarks" column to the fact that our stated magnitude of 2.93 is for the combined light. Somewhat like the η Peg system is the o (omicron) Leo system, where o Leo Aa (Subra) is very close to mag. 3.5, and where o Leo Ab is, while fainter than mag. 3.5, nevertheless bright enough to make a non-trivial contribution to the overall visual impression. Before 2021, our table unfortunately had the erroneous information that o Leo Aa,Ab is a binary system in which the components are of equal magnitude. Also somewhat like the η Peg system is θ Tau Aa, shining a bit below our magnitude cutoff at 3.74, and rising to just above the cutoff in the combined light of θ Tau Aa,Ab (where Ab is well below our cutoff, at mag. 4.86).

We thus have a table of nominally 317 stars, yielding on a more refined, i.e. less nominal, analysis 317 + 11 = 328 bright stars. With 3 exceptions, each of the 328 has a known (at worst, an uncertainty-flagged) MK temperature type and MK luminosity class (with the Sun, of course, better observed than any of the others). (The case of ζ CMa Aa,Ab is admittedly rather indeterminate. Here we have a longstanding MK type, from decades before the 2019 discovery of binarity. Should it be assumed now that the type applies only to ζ CMa Aa, or should it be understood as approximately correct also for ζ CMa Ab? Since the magnitude difference is small, around 0.2 mag., and since the stars are likely to be of the same age, as products of co-genesis from an ISM molecular cloud, we take the latter option.) The final result is accordingly a set of 328 –3 = 325 bright stars of known MK classification.

SECTION 2: General characteristics of our 325 MK-classified bright stars

Our 325-element sample is found to lie in a region, around 3000 ly in radius, essentially confined to the sandwich-filler, or "thin disk," part of the overall galactic disk, within the Orion Arm. Of the few Sample-S interlopers born outside the sandwich filling, and now temporarily passing through it on orbits oblique to the thin disk, the best known is α Boo (Arcturus). It is convenient here to use the term "Population P" for the ensemble of non-brown-dwarf, non-white-dwarf stars in the much larger, 3000-ly radius, subdisk-of-the-thin-disk from which our (tiny) Sample S is drawn. This P-region is itself only a (tiny) fraction of the overall galactic thin-disk region of stars, ~50,000 ly in radius. The various pages at atlasoftheuniverse.com are a useful resource for visualization of the Orion Arm, furnishing both a zooming-out to the wider galactic context and a zooming-in to detailed features within the Arm.

Sample S, being formally defined by an apparent-magnitude cutoff as opposed to a distance cutoff, is itself far from statistically representative of Population P. *(a)* In P, the O stars are vanishingly rare. A tabulation by Glenn Ledrew, in *JRASC* **95** (2001), pp. 32ff (2001JRASC..95...32L) suggests an O-star frequency within P of just 0.00003%. By contrast, O stars comprise a hefty ~2% of S. A similar overrepresentation occurs for the B, A, F, G, and K stars, with Ledrew's tabulation suggesting that these MK temperature types might have a respective frequency within P of 0.1%, 0.6%, 3.2%, 8.0%, and 12.9%. By contrast, the first three of these five rare types comprise ~30%, ~20%, and ~10%, respectively, of S, and the last ~20% of S. *(b)* In P, something on the order of 76% or 78%—different authorities are perhaps mildly discrepant—must be M stars. (Ledrew's tabulation, in particular, suggests an M-star frequency of 78.2%.) Only a few of these (the Ledrew tabulation suggests 0.04%) have evolved to beyond the Main Sequence stage of stable-core hydrogen fusion. By contrast, the M stars comprise just ~5% or ~10% of S. All of them have evolved beyond the Main Sequence, having started their lives as types hotter than M or K.

The statistically anomalous character of S is further illustrated by the fact that in S, in each of the Big Six MK temperature types hotter than M, the numerical majority comprises the stars that have ended stable-core hydrogen fusion (and so have, as a generally reliable rule—we return below to a necessary caveat regarding reliability—evolved out of MK luminosity class V into one of the brighter MK luminosity classes IV, III, II, or I). In Ledrew's tabulation, the percentages of evolved stars in F, G, and K, as a percentage of the overall respective F, G, and K populations, are just 2.0%, 2.5%, and 3.8%. Consistently with this, the 1991 Gliese-Jahreiss catalogue of the nearest 1000 stars (containing, admittedly, not only the local OBAFGKM VI, V, IV, III, II, and I stars, but also at least many of the local white dwarfs) assigns less than 1% of its population to MK luminosity classes IV, III, II, or I.

Sample S—so rich in varieties of star statistically infrequent within Population P—harbours physical extremes. Although the extremes are for the most part not written into our table, they can be studied easily from such sources as Prof. James Kaler's stars.astro.illinois.edu/sow/sowlist.html.

At least 58 of our 325-star set each radiate, across the full spectrum from X-ray through UV and optical to IR and radio, at least as much power as is radiated by 10,000 Suns. Possibly the most dramatic is ζ Ori, with a bolometric luminosity of 375,000 Suns—making ζ Ori notable not within S alone, but even within the overall galaxy. Several others are not far behind, among them ζ Pup (360,000 Suns, suggests Kaler, as of July 2008 revising his earlier, circa-1999, suggestion of ~750,000 Suns). We believe that just two stars in Sample S, nearby τ Cet and nearby α Cen B, radiate more feebly than our Sun, each at about half of the Sun's bolometric luminosity.

The principal determinant of stellar luminosity, for any given phase in stellar evolution, is mass, with even small variations in mass translating into large variations in energy output. The exceptional luminosities of ζ Ori and ζ Pup, in particular, are a consequence of their exceptionally high respective masses, 20 $M_\odot$ and 40 $M_\odot$. (Kaler now suggests 40 $M_\odot$ for ζ Pup, while having previously suggested 60 $M_\odot$. He additionally notes from the literature the lower suggested value of 22.5 $M_\odot$.)

Theory does predict, although our small Sample S does not succeed in illustrating, the possibility of masses up to the Eddington stellar-mass limit, somewhere above 100 $M_\odot$, and even of some "super-Eddington" stars. (Eddington's limit is by definition attained when luminosity rises so high as to make the outward radiation push, tending to tear a star apart, exceed the inward gravitational pull.)

Rotation periods in Sample S vary from far in excess of our Sun's to far short of our Sun's (which we may here take as a nominal 27 d; refined treatments of solar rotation provide for rotation-period variations both with solar latitude and with solar depth). Spectroscopy yields for γ Cep a period of 781 d, i.e. of 2.14 y. Kaler suggests that the respective rotation periods of α Hya and ε Crv could be as long as 2.4 y and 3.9 y. Perhaps our slowest rotator, however, is α Ori, now (cf 2009A&A...504..115K) assigned the period of 8.4 y. At the other extreme, Kaler suggests for ζ Aql A, α Aql, and ζ Lep, respectively, 16 h, at most 10 h, and around 6 h.

Radii (as distance from centre to outermost opaque layer, perpendicular to the axis of stellar rotation) are typically greater than the solar radius. Two notable instances of stellar expansion—in other words, of notably tenuous stellar atmosphere—are α Sco (with a radius of 3.4 au, not far short of the Sun-Jupiter distance) and α Ori (with a radius of 4.1 au or 4.6 au from interferometry, or alternatively 3.1 au or 3.4 au from luminosity-temperature deductions). A still more notable, but also very hard-to-determine, case is "Herschel's Garnet Star," μ Cep A, with radius variously estimated as 4.5 au, 5.6 au, 6.6 au, or 7.7 au. Results in these extreme cases depend strongly on the wavelength selected for evaluating opacity. Observations within Population P do indicate, although our Sample S does not succeed in illustrating, the possibility of still more-extreme stellar radii, to values approaching ~10 au.

The broad range of temperatures (a topic whose MK conceptual subtleties we examine in subsection 4.1, below) is reflected in the fact that all of the Big Seven temperature-type bins in the traditional MK temperature sequence are well occupied, however statistically skewed (as we have argued above) is the distribution in the MK Big Five luminosity-class bins. At the MK temperature extremes are the hot ζ Pup (O5; 42,000 K) and the cool Miras, most famously o (omicron) Cet (M5–M10; a typical temperature for this variable is variously suggested as ~2000 K or ~3000 K).

Interesting spectral anomalies in Sample S include the "Be phenomenon" and "shell spectrum" stars, as discussed at length in our final subsection.

SECTION 3: Initial user guide to the columns in our 317-entry table

In our first column, we use the flags "+nP" (n = 1, 2, ...) for companions of sub-stellar mass, such as have been found outside our Solar System, in an accelerating sequence of discoveries, from the 1990s onward, that has now reached even the tiny Sample S. Such companions are typically planets but could in principle also be brown dwarfs. We do not attempt here to define formally the difference between a planet and a brown-dwarf companion.

In this same column, we apply the WDS naming scheme for multiplicity, both in the case of true binarity and in the case of mere optical doubles (in all but eleven awkward cases, as noted in section 1 above, putting into the first column just the name of the brightest WDS-catalogued component; but we additionally try to supply particulars, at any rate in the online table, for binary and mere-optical companions brighter than mag. 10, in the "Remarks" column, while for the most part regarding binary and mere-optical companions fainter than this limit), using underlining, as discussed in Section 4 below, to flag instances in which a binary system possesses a published orbital solution.

Apparent Visual Magnitude (**m**$_V$ = V): Apparent magnitudes, with "v" appended for large-amplitude variables, are from *HIPPARCOS*. In the case of variable, we take as authoritative the ranges (where possible, in V), and also the periods, published in the online AAVSO(VSX) database. Our reasoning here is that AAVSO has critically appraised and filtered data originally presented in more upstream sources, such as the primary (journal-article) literature. Our "V" is the usual "V" of UBV photometry, as introduced by H.L. Johnson and W.W. Morgan in 1953ApJ...117..313J (and as subsequently extended, by Cousins, to UBVRI). The (yellow) V filter corresponds roughly to the response of the eye. We retain, without having attempted our own independent error analysis, the assertion of our Handbook predecessor R.F. Garrison (working essentially before *HIPPARCOS*) that the "probable error" of each of our cited V values is at most 0.03 mag. (in other words, that of the actually and potentially available V measurements from the world's duly competent photometry facilities, at least half will lie within 0.03 mag. of our own cited V values). Some small inaccuracies in magnitudes may be present in cases of combined light: readers needing confirmation may check our values against WDS, or where possible against the magnitude-specifying atlas pages of AAVSO. (By the nature of its mission, AAVSO is constrained to supply in its cartography not only details of variables, but also magnitudes of stars that are constant, and that can be used by amateur photometrists as comparison stars and check stars.)

Spectral Classification (**MK Type**): The "MK temperature type" (O, B, A, F, G, K, M) is given first, followed by a finer subtype (0–9) and an "MK luminosity class" (Roman numerals I–V, with "a" or "b" added occasionally to indicate slightly brighter or fainter stars within the class). As we discuss in detail in subsection 4.1 below, O stars are the hottest, M stars coolest; Ia stars are termed the most luminous "supergiants"; III stars are termed "giants"; and V stars are termed "dwarfs." V stars form the largest class in the cosmos, comprising the observational Main Sequence (MS) (as a region in two-dimensional MK-luminosity-class-versus-MK-temperature-type classification space). Other MK symbols include "e" for hydrogen emission; "f" for broad, non-hydrogen emission in hot stars; "m" for strong metallic absorption; "n" or "nn" for unusually broad absorption; "p" for peculiarities; "s" for a mixture of broad and sharp lines; and ":" for a minor uncertainty. (The flags "n" and "nn" are a signature of rotation. It seems that historically "n" and "nn" signified "nebulous," as references to the photographic-plate appearance of a rotationally broadened absorption line.) Where a single star (e.g. α CMa A) is given two types, with the second flagged "m," the first is the type that best characterizes the hydrogen lines, the second the type that best characterizes the metal lines.

MK classifications are in some cases controverted. We have inherited our own types for the most part from the judgements of our predecessor R.F. Garrison, who, as a principal authority in MK classification, drew both on what he judged to be the best of the literature and on some of his own unpublished classifications. As of 2021 Jan. 13, we have made a modest beginning at flagging the cases of controverted MK phenomenology (in our online, but not in our printed-edition, "Remarks" column), in two ways: *(a)* Where the literature suggests a real difficulty in MK classification, we draw attention to the difficulty, discussing it in a few words; *(b)* Where we have not found reason in the literature to suspect an MK-classification uncertainty, but nevertheless find our assigned MK type diverging (even in a small way) from the type assigned as of epoch 2021.5 in the official United States Naval Observatory and HM Nautical Almanac Office publication *Astronomical Almanac*, Section H (bright stars), we document the divergence, without further discussion.

Parallax (**π**), *Proper Motion* (**μ**), and *Position Angle* (**PA**): Parallaxes, in milliarcseconds (mas), proper-motion vector norms (″/y), and vector position-angles (degrees, from N through E) are derived from the *HIPPARCOS* 2007 data reduction, with a few exceptions. It may be hoped that in future years more precise parallaxes will be forthcoming from the *Gaia* mission, which has now found an engineering solution significantly easing its initial restriction to the fainter stars. (Detector overload had been feared.) Like *HIPPARCOS*, *Gaia* has to cope with the special challenges posed in measuring to high precision (*i*) the parallax of a (orbitally wobbling) star possessing a gravitationally bound, and not necessarily well documented, companion, and (*ii*) the parallax of a star with perturbed photosphere, and consequently with displaced photocentre (as when a tight binary system contains a bright mass-transfer stream).

Absolute Visual Magnitude (**M**$_V$) and *Distance in Light-Years* (**D**): Absolute magnitudes and distances are determined from parallaxes, except where a colon follows the absolute magnitude; in these cases, both quantities are determined from a calibration of the spectral classification. The absolute magnitude is left uncorrected for interstellar absorption. The appropriate correction is typically ~+0.06 mag. per 100 ly outside the (admittedly very-far-from-spherical) Local Bubble, i.e. beyond ~100 ly. A special difficulty, not fully grasped by this author, arises in the case of the controverted ε Aur system distance (for which we now use *Gaia* DR2, additionally supplying references to the recent literature).

We take account of uncertainties in parallaxes by stating the derived distances, in ly, to no more than the appropriate number of significant figures (rounding where necessary). In cases where rounding would itself be misleading, we use a tilde as an indicator of imprecision.

Radial Velocity (**V_{rad}**): Radial velocities are from BSC5. "SB" indicates a spectroscopic binary, an unresolved system whose duplicity is revealed by periodic Doppler oscillations in its spectrum and for which an orbit is possibly known. If the lines of both stars are detectable, "SB2" is used; "+" and "–" indicate, respectively, motion away from and toward the observer. "V" indicates a variable velocity in a star not observable as a spectroscopic binary. (In most "V" cases, the orbit is unknown.)

Remarks: Remarks include data on variability, spectra, observed angular diameters, interferometric aperture-synthesis imaging, particulars of any companions, and (for the most part, only in our online table) prominent bits of observational-astronomy news. We are often a little casual with rounding, stating physical quantities for a given star (as, to take a random example, the angle between the α Cen AB orbital plane and the plane of the sky) to a lower precision than is now available from the primary literature. In a departure from our practice prior to 2017, we now give star names in all and only those cases in which star names are formally promulgated in the International Astronomical Union (IAU) star-naming project, as launched in 2016 at www.iau.org/public/themes/naming_stars. Readers requiring further information on names could start with the individual star descriptions in stars.astro.illinois.edu/sow/sowlist.html. Richard Hinckley Allen's 1899 book *Star Names: Their Lore and Meaning* has been much cited over the decades. More recent scholarship, with due professional attention to Arabic philology, is, however, presented in Paul Kunitzsch and Tim Smart, *Short Guide to Modern Star Names and their Derivations* (Wiesbaden, 1986), and (by the same pair of authors) *Dictionary of Modern Star Names: A Short Guide to 254 Star Names and their Derivations* (Cambridge, MA, circa 2006). In the **Remarks** column, a **boldface** star name indicates a navigation star.

The "Remarks" vary greatly in their depth of coverage. As a rough general rule, the more heavily a star other than our own Sun is cited in the primary literature, the greater is its astrophysical significance, and correspondingly the longer is its "Remarks" entry.

It is of some interest to document here the relative frequencies with which our various night-time stars are cited. We use as our metric the number of citations over an arbitrary, but long, period (from the beginning of 1973 to the end of 2023) recorded in the SIMBAD (simbad.u-strasbg.fr/simbad) database. We follow SIMBAD in not attempting to separate components of tight doubles (so, for instance, considering the citation count for α CMa as a system, rather than the individual citation counts for α CMa A and α CMa B. To facilitate "Remarks" lookups in our long table, we supply an approximate RA value in each case.

We first list, in decreasing order of citation frequency, the instances which in our selected period have been cited 500 or more times:

* RA~18h37 α Lyr (Vega) (2429 times)
* RA~14h41 α Cen (2207 times;
  SIMBAD gives 1213 citations for α Cen A (Rigil Centaurus), 994 for α Cen B)
* RA~14h16 α Boo (Arcturus) (2139 times)
* RA~16h38 ζ Oph (1721 times)
* RA~07h40 α CMi (Procyon) (1697 times)
* RA~05h56 α Ori (Betelgeuse= (1514 times)
* RA~02h20 o Cet (Mira= (1352 times)
* RA~06h46 α CMa (Sirius) (1344 times)
* RA~22h58 α PsA (Fomalhaut) (1181 times)
* RA~01h48 τ Cet (1174 times)
* RA~04h37 α Tau (Aldebaran) (1097 times)
* RA~03h09 β Per (Algol) (1090 times)

* RA~05h18 α Aur (Capella) (1082 times)
* RA~08h05 ζ Pup (Naos) (1070 times)
* RA~00h58 γ Cas (1051 times)
* RA~07h46 β Gem (Pollux) (986 times)
* RA~08h10 γ Vel (832 times)
* RA~16h37 τ Sco (Paikauhale) (795 times)
* RA~19h51 α Aql (Altair) (780 times)
* RA~13h26 α Vir (Spica) (752 times)
* RA~16h22 σ Sco (Alniyat) (741 times)
* RA~18h51 β Lyr (Sheliak) (741 times)
* RA~05h37 ε Ori (Alnilam) (736 times)
* RA~10h09 α Leo (Regulus) (724 times)
* RA~03h55 ζ Per (710 times)
* RA~05h33 δ Ori (Mintaka) (690 times)
* RA~16h01 δ Sco (Dschubba) (661 times)
* RA~05h36 ι Ori (Hatysa) (660 times)
* RA~00h50 η Cas (Achird) (654 times)
* RA~16h00 T CrB (651 times)
* RA~03h25 α Per (Mirfak) (648 times)
* RA~22h30 δ Cep (647 times)
* RA~16h30 α Sco (Antares) (625 times)
* RA~13h55 η Boo (Muphrid) (620 times)
* RA~21h29 β Cep (Alfirk) (601 times)
* RA~05h39 ζ Tau (Tianguan) (595 times)
* RA~17h47 μ Her (594 times)
* RA~05h15 β Ori (Rigel) (588 times)
* RA~02h50 α UMi (Polaris) (587 times)
* RA~20h42 α Cyg (Deneb) (582 times)
* RA~00h26 β Hyi (556 times)
* RA~12h57 α CVn (Cor Caroli) (553 times)
* RA~03h44 δ Eri (547 times)
* RA~00h14 γ Peg (Algenib) (541 times)
* RA~23h40 γ Cep (Errai) (541 times)
* RA~06h23 β CMa (Mirzam) (534 times)
* RA~02h09 α Ari (Hamal) (526 times)
* RA~19h53 η Aql (521 times)
* RA~11h50 β Leo (Denebola) (506 times)
* RA~13h48 η UMa (Alkaid) (505 times)
* RA~23h04 β Peg (Scheat) (503 times)
* RA~04h29 ε Tau (Ain) (500 times)

We next list, simply in increasing order of RA, the instances which in our selected period have been cited between 100 and 499 times, inclusive. These are stars which would seem not be of deep astrophysical interest, and on the other hand would seem not to have been grossly neglected in the literature:

* RA~00h09 α And (Alpheratz) (406 times)
* RA~00h09 β Cas (Caph) (440 times)
* RA~00h27 α Phe (Ankaa) (137 times)
* RA~00h40 δ And (280 times)
* RA~00h41 α Cas (Schedar) (293 times)
* RA~00h44 β Cet (Diphda) (477 times)

….

* RA~01h09 η Cet (201 times)
* RA~01h10 β And (Mirach) (481 times)
* RA~01h27 δ Cas (Ruchbah) (225 times)
* RA~01h29 γ Phe (130 times)
* RA~01h38 α Eri (Achernar) (442 times)
* RA~01h54 α Tri (Mothallah) (258 times)
* RA~01h55 β Ari (Sheratan) (328 times)
* RA~01h56 ε Cas (Segin) (166 times)
* RA~01h59 α Hyi (201 times)

….
* RA~02h05 γ And (Almach) (260 times)
* RA~02h10 β Tri (185 times)
* RA~02h44 γ Cet (Kaffaljidhma) (157 times)

….
* RA~03h03 α Cet (Menkar) (387 times)
* RA~03h06 γ Per (196 times)
* RA~03h06 ρ Per (266 times)
* RA~03h44 δ Per (260 times)
* RA~03h48 η Tau (Alcyone) (440 times)
* RA~03h59 γ Eri (Zaurak) (164 times)
* RA~03h59 ε Per (434 times)

….
* RA~04h01 λ Tau (300 times)
* RA~04h15 α Ret (116 times)
* RA~04h29 θ Tau (Chamukuy) (374 times)
* RA~04h34 α Dor (132 times)
* RA~04h51 π^3 Ori (Tabit) (470 times)
* RA~04h58 ι Aur (Hassaleh) (235 times)

….
* RA~05h03 ε Aur (Almaaz) (479 times)
* RA~05h06 ε Lep (152 times)
* RA~05h09 η Aur (Haedus) (296 times)
* RA~05h09 β Eri (Cursa) (182 times)
* RA~05h14 μ Lep (257 times)
* RA~05h25 η Ori (316 times)
* RA~05h26 γ Ori (Bellatrix) (419 times)
* RA~05h27 β Tau (Elnath) (301 times)
* RA~05h29 β Lep (Nihal) (220 times)
* RA~05h33 α Lep (Arneb) (236 times)
* RA~05h34 β Dor (321 times)
* RA~05h36 λ Ori (Meissa) (304 times)
* RA~05h40 α Col (Phact) (209 times)
* RA~05h41 ζ Ori (Alnitak) (350 times)
* RA~05h48 ζ Lep (277 times)
* RA~05h48 κ Ori (Saiph) (490 times)
* RA~05h51 β Col (Wazn) (130 times)

….
* RA~06h01 β Aur (Menkalinan) (331 times)
* RA~06h01 θ Aur (Mahasim) (243 times)
* RA~06h16 η Gem (Propus) (219 times)
* RA~06h21 ζ CMa (Furud) (145 times)
* RA~06h24 μ Gem (Tejat) (318 times)
* RA~06h24 α Car (Canopus) (411 times)

* RA~06h38 ν Pup (131 times)
* RA~06h39 γ Gem (Alhena) (412 times)
* RA~06h45 ε Gem (Mebsuta) (342 times)
* RA~06h46 ξ Gem (Alzirr) (178 times)
* RA~06h48 α Pic (154 times)
* RA~06h50 τ Pup (101 times)
* RA~06h50 κ CMa (253 times)
* RA~06h59 ε CMa (Adhara) (433 times)

….

* RA~07h02 σ CMa (Unurgunite) (158 times)
* RA~07h04 o^2 CMa (275 times)
* RA~07h09 δ CMa (Wezen) (269 times)
* RA~07h14 L_2 Pup (207 times)
* RA~07h18 π Pup (100 times)
* RA~07h21 δ Gem (Wasat) (209 times)
* RA~07h25 η CMa (Aludra) (318 times)
* RA~07h28 β CMi (Gomeisa) (326 times)
* RA~07h30 σ Pup (116 times)
* RA~07h36 α Gem (Castor) (257 times)
* RA~07h50 ξ Pup (Azmidi) (176 times)
* RA~07h57 χ Car (140 times)

….

* RA~08h08 ρ Pup (Tureis) (252 times)
* RA~08h17 β Cnc (Tarf) (295 times)
* RA~08h31 ο UMa (Muscida) (232 times)
* RA~08h45 δ Vel (Alsephina) (182 times)
* RA~08h48 ε Hya (Ashlesha) (211 times)
* RA~08h56 ζ Hya (209 times)

….

* RA~09h00 ι UMa (Talitha) (236 times)
* RA~09h09 λ Vel (Suhail) (206 times)
* RA~09h11 a Car (123 times)
* RA~09h13 β Car (Miaplacidus) (205 times)
* RA~09h17 ι Car (Aspidiske) (132 times)
* RA~09h22 α Lyn (184 times)
* RA~09h23 κ Vel (Markeb) (140 times)
* RA~09h28 α Hya (Alphard) (391 times)
* RA~09h34 θ UMa (360 times)
* RA~09h42 ο Leo (Subra) (138 times)
* RA~09h46 l Car (280 times)
* RA~09h47 ε Leo (283 times)
* RA~09h57 φ Vel (104 times)

….

* RA~10h08 η Leo (290 times)
* RA~10h14 ω Car (111 times)
* RA~10h18 q Car (131 times)
* RA~10h17 ζ Leo (Adhafera) (193 times)
* RA~10h18 λ UMa (Tania Borealis) (167 times)
* RA~10h21 γ Leo A (Algieba) (199 times)
  (SIMBAD 1973-through-2023 citation count for γ Leo A,
  not for the total γ Leo AB system;
  SIMBAD tallies γ Leo B separately,
  with a 1973-through-2023 citation count of 93)

* RA~10h23 μ UMa (Tania Australis) (274 times)
* RA~10h33 p Car (196 times)
* RA~10h43 θ Car (313 times)
* RA~10h47 μ Vel (173 times)
* RA~10h50 ν Hya (168 times)

….
* RA~11h03 β UMa (Merak) (374 times)
* RA~11h05 α UMa (Dubhe) (345 times)
* RA~11h10 ψ UMa (227 times)
* RA~11h15 δ Leo (Zosma) (239 times)
* RA~11h15 θ Leo (Chertan) (312 times)
* RA~11h19 ν UMa (Alula Borealis) (167 times)
* RA~11h34 ξ Hya (252 times)
* RA~11h36 λ Cen (120 times)
* RA~11h55 γ UMa (Phecda) (309 times)

….
* RA~12h09 δ Cen (272 times)
* RA~12h11 ε Crv (142 times)
* RA~12h16 δ Cru (Imai) (189 times)
* RA~12h16 δ UMa (Megrez) (236 times)
* RA~12h17 γ Crv (Gienah) (203 times)
* RA~12h27 α Cru (Acrux) (115 times)
  (SIMBAD 1973-through-2023 citation count for α Cru A,
  not for the total α Cru AB system;
  SIMBAD tallies α Cru B separately,
  with a 1973-through-2023 citation count of 59)
* RA~12h31 δ Crv (Algorab) (191 times)
* RA~12h32 γ Cru (Gacrux) (261 times)
* RA~12h35 β Crv (Kraz) (240 times)
* RA~12h38 α Mus (132 times)
* RA~12h42 γ Cen (102 times)
* RA~12h42 γ Vir (Porrima) (360 times)
* RA~12h47 β Mus (106 times)
* RA~12h49 β Cru (Mimosa) (282 times)
* RA~12h55 ε UMa (Alioth) (389 times)
* RA~12h56 δ Vir (Minelauva) (242 times)

….
* RA~13h02 ε Vir (Vindemiatrix) (481 times)
* RA~13h20 γ Hya (166 times)
* RA~13h21 ι Cen (199 times)
* RA~13h25 ζ UMa (Mizar) (248 times)
* RA~13h35 ζ Vir (Heze) (173 times)
* RA~13h41 ε Cen (220 times)
* RA~13h50 ν Cen (172 times)
* RA~13h50 μ Cen (395 times)
* RA~13h56 ζ Cen (158 times)

….
* RA~14h05 β Cen (Hadar) (323 times)
* RA~14h07 π Hya (134 times)
* RA~14h08 θ Cen (Menkent) (226 times)
* RA~14h20 ι Lup (100 times)
* RA~14h33 γ Boo (Seginus) (209 times)
* RA~14h36 η Cen (303 times)

* RA~14h43 α Lup (195 times)
* RA~14h43 α Cir (347 times)
* RA~14h46 ε Boo (Izar) (134 times)
* RA~14h51 β UMi (Kochab) (283 times)
* RA~14h52 α Lib (Zubenelgenubi) (182 times)
* RA~14h59 β Lup (161 times)

….

* RA~15h00 κ Cen (171 times)
* RA~15h02 β Boo (Nekkar) (221 times)
* RA~15h05 σ Lib (Brachium) (170 times)
* RA~15h16 δ Boo (315 times)
* RA~15h18 β Lib (Zubeneschamali) (276 times)
* RA~15h20 γ TrA (118 times)
* RA~15h21 γ UMi (Pherkad) (118 times)
* RA~15h22 δ Lup (197 times)
* RA~15h24 ε Lup (164 times)
* RA~15h25 ι Dra (Edasich) (366 times)
* RA~15h35 α CrB (Alphecca) (398 times)
* RA~15h36 γ Lup (156 times)
* RA~15h45 α Ser (Unukalhai) (425 times)
* RA~15h50 μ Ser (103 times)
* RA~15h56 β TrA (148 times)

….

* RA~16h00 π Sco (Fang) (324 times)
* RA~16h01 η Lup (144 times)
* RA~16h06 β Sco (Acrab) (491 times)
* RA~16h15 δ Oph (Yed Prior) (321 times)
* RA~16h19 ε Oph (Yed Posterior) (214 times)
* RA~16h24 η Dra (Athebyne) (249 times)
* RA~16h31 β Her (Kornephoros) (272 times)
* RA~16h42 ζ Her (339 times)
* RA~16h43 η Her (238 times)
* RA~16h50 α TrA (Atria) (232 times)
* RA~16h51 ε Sco (Larawag) (200 times)
* RA~16h53 μ^1 Sco (Xamidimura) (240 times)
* RA~16h58 κ Oph (260 times)

….

* RA~17h09 ζ Dra (Aldhibah) (215 times)
* RA~17h11 η Oph (Sabik) (225 times)
* RA~17h13 η Sco (135 times)
* RA~17h16 α Her (Rasalgethi) (345 times)
* RA~17h16 π Her (200 times)
* RA~17h16 δ Her (Sarin) (167 times)
* RA~17h23 θ Oph (268 times)
* RA~17h27 β Ara (126 times)
* RA~17h27 γ Ara (257 times)
* RA~17h31 β Dra (Rastaban) (357 times)
* RA~17h32 υ Sco (Lesath) (159 times)
* RA~17h33 α Ara (219 times)
* RA~17h35 λ Sco (Shaula) (353 times)
* RA~17h36 α Oph (Rasalhague) (416 times)
* RA~17h38 ξ Ser (131 times)

* RA~17h38 θ Sco (Sargas) (111 times)
* RA~17h43 κ Sco (210 times)
* RA~17h44 β Oph (Cebalrai) (408 times)
* RA~17h57 γ Dra (Eltanin) (499 times)

….

* RA~18h00 ν Oph (195 times)
* RA~18h07 γ^2 Sgr (Alnasl) (139 times)
* RA~18h19 η Sgr (131 times)
* RA~18h22 δ Sgr (Kaus Media) (164 times)
* RA~18h22 η Ser (331 times)
* RA~18h25 ε Sgr (Kaus Australis) (196 times)
* RA~18h28 α Tel (120 times)
* RA~18h29 λ Sgr (Kaus Borealis) (256 times)
* RA~18h47 φ Sgr (106 times)
* RA~18h56 σ Sgr (Nunki) (243 times)
* RA~18h59 ξ^2 Sgr (115 times)
* RA~18h59 γ Lyr (Sulafat) (236 times)

….

* RA~19h04 ζ Sgr (Ascella) (148 times)
* RA~19h06 ζ Aql (Okab) (300 times)
* RA~19h07 λ Aql (209 times)
* RA~19h08 τ Sgr (148 times)
* RA~19h11 π Sgr (Albaldah) (119 times)
* RA~19h13 δ Dra (Altais) (249 times)
* RA~19h26 δ Aql (204 times)
* RA~19h31 β Cyg (Albireo) (188 times)
* RA~19h45 δ Cyg (Fawaris) (220 times)
* RA~19h47 γ Aql (Tarazed) (372 times)
* RA~19h59 γ Sge (225 times)

….

* RA~20h12 θ Aql (179 times)
* RA~20h22 β Cap (Dabih) (172 times)
  (SIMBAD 1973-through-2023 citation count for the β Cap Aa,Ab system,
  not for the total β Cap Aa,Ab,B system:
  SIMBAD tallies the ~mag. 6 star β Cap B separately,
  with a 1973-through-2023 citation count of 139)
* RA~20h23 γ Cyg (Sadr) (474 times)
* RA~20h27 α Pav (Peacock) (259 times)
* RA~20h39 α Ind (125 times)
* RA~20h46 η Cep (364 times)
* RA~20h47 ε Cyg (Aljanah) (428 times)

….

* RA~21h14 ζ Cyg (299 times)
* RA~21h19 α Cep (Alderamin) (297 times)
* RA~21h32 β Aqr (Sadalsuud) (369 times)
* RA~21h45 ε Peg (Enif) (366 times)
* RA~21h48 δ Cap (Deneb Algedi) (226 times)
* RA~21h55 γ Gru (Aldhanab) (122 times)

….

* RA~22h07 α Aqr (Sadalmelik) (372 times)
* RA~22h09 α Gru (Alnair) (269 times)
* RA~22h11 θ Peg (Biham) (168 times)
* RA~22h11 ζ Cep (222 times)

* RA~22h19 α Tuc (122 times)
* RA~22h30 δ Cep (647 times)
* RA~22h42 ζ Peg (Homam) (267 times)
* RA~22h44 β Gru (Tiaki) (185 times)
* RA~22h44 η Peg (Matar) (156 times)
* RA~22h49 ε Gru (119 times)
* RA~22h50 ι Cep (222 times)
* RA~22h51 μ Peg (Sadalbari) (269 times)
* RA~22h55 δ Aqr (Skat) (139 times)

….

* RA~23h05 α Peg (Markab) (283 times)

Finally, we list, in decreasing order of citation frequency, instances which in our selected period have been cited no more than 99 times. This population merits attention, since it might conceivably include some stars which are under-observed:

* RA~15h14 ζ Lup A (99 times)
* RA~17h49 ι^1 Sco A (97 times)
* RA~17h00 ζ Ara (95 times)
* RA~09h32 N Vel (92 times)
* RA~17h51 G Sco (Fuyue) (78 times)
* RA~01h07 β Phe (77 times)
* RA~08h23 ε Car (Avior) (77 times)
* RA~03h47 γ Hyi (75 times)
* RA~20h47 β Pav (68 times)
* RA~09h48 υ Car (65 times)
* RA~12h28 α Cru (Acrux) (87 times)
* RA~02h59 θ Eri (Acamar) (35 times)

SECTION 4: Supplementary user guide, concerning our treatment of double-star astrometry

4.1: General background remarks on double-star astrometry

4.1.1: Introductory remarks; prevalence of binarity in System S:

The observer at the eyepiece seeks physical understanding. Here is a speck of starlight, and here at medium power, around 10″ (around a quarter-Jupiter or a fifth-Jupiter) away is another, with perhaps an intriguing tint difference between pure white and yellowish white, over and above a notable magnitude difference: how far away is each of these two stars, and what stages have they attained in their respective lives, and how do their masses and photospheric temperatures differ?

When the specks are paired, as in this imagined example, a further question arises, however, no less important than the ones already mentioned. Are these two physically unrelated stars, neighbours on the two-dimensional celestial sphere through coincidence (with one star perhaps twice or five times as far from Earth as the other, but perhaps with the stars even at rather similar distances from Earth)? Or is it, on the contrary, the case that each star experiences the gravitational attraction of the other so strongly as to keep the pair in a mutual orbit, constraining them to move through galactic space as a binary system?

Most stars in our galaxy, and in particular most stars in that portion of our galaxy that is our nearby Population P, not only are red dwarfs in the stable core-hydrogen-fusion phase of their lives but are solitary. (Our own galaxy is a barred spiral. In elliptical galaxies, red dwarfs are still more common, and solitary stars therefore presumably likewise still more common.) However, binarity becomes more prevalent as stellar mass increases. In our Sample S, high-mass stars predominate, and binarity is correspondingly more evident within Sample S than in the overall Population P.

4.1.2: Hierarchically organized systems; contrast with clusters:
A situation by no means rare in binarity-rich Sample S is the many-star system hierarchically organized, with binarity at each hierarchy level. One of the good instances is the six-star system whose combined light becomes, in a compact amateur atlas, the starlight point α Gem, and whose most prominent star is Castor (with the ancient name "Castor" since 2016, under IAU rules, designating just a single star, but before that ruling often used loosely, as a name marking merely the overall naked-eye point of light).

We may have, for instance, stars w and x in a mutual orbit (with w describing an ellipse about the wx centre of mass C_{wx}, and x for its part also describing an ellipse about C_{wx}, but with some remote star y experiencing the entire wx system as essentially a point mass). In an appropriately chosen rest frame, y describes some rather wide, rather slow orbit in tandem with the wx pair. In this situation, C_{wx} moves in an ellipse about the wxy centre of mass C_{wxy}, and y for its part also moves in an ellipse about C_{wxy}. There can now be a still more remote star z, experiencing the wxy trio as essentially a point mass. In such a case, C_{wxy} will, in an appropriately chosen rest frame, describe an ellipse around C_{wxyz}, and z will for its part also describe an ellipse about C_{wxyz}.

Here "appropriateness of choice" consists in taking some inertial frame of mass in which the centre of mass for the given pairing is held at rest. For present purposes, it is enough first to confine our discussion to classical Newtonian mechanics (neglecting the general relativity analysis of gravitation as a geometrical feature of spacetime), and then within this confined framework to further bypass a conceivable deep conceptual problem, saying—simply and loosely—that an inertial frame anchored on some point in space is one in which that point is held at rest (for instance, by being made the origin of Cartesian coordinates for that frame), and in which additionally the frame is "stipulated not to rotate." (A deep question, extraneous to our own limited purposes in this Handbook article, does admittedly arise even in the confined Newtonian-mechanics framework: with respect to what physical standard is it asserted that a given frame "does not rotate"? Without venturing into details here, we remark that in our Handbook view, the deep question—historically prominent in the Leibniz-Clarke correspondence—can be given a conceptually satisfactory answer, by defining "does not rotate" in terms of "absence of centrifugal pseudo-forces violating Newton's force-as-product-of-mass-and-acceleration principle.")

Still further geometries are possible in the case of four stars. In particular, as an alternative to the situation just described, $wxyz$ could instead be a double double, with wx a tight pair, and yz a tight pair, and with these two tight pairs sufficiently distant from each other to make each experience the other as essentially a point mass (with, in this case, C_{wx} and C_{yz} describing, in an appropriate choice of rest frame, elliptical orbits about C_{wxyx}).

Does an intricate system of, say, eight stars, organized into a four-level hierarchy as "{{{{1,2},{3,4}},{5,6}},{7,8}}" or into a six-level hierarchy as "{{{{{{1,2},3},4},{5,6}},7},8}" differ in kind, or only in degree, from a stellar cluster (be it an open cluster, such as the Hyades, or a globular, such as M13)? We argue that the difference is one of kind.

In developing our argument, we first run through some formal preliminaries.

Consider any pair of point masses P, Q in three-dimensional space, subject to any arbitrary assemblage of forces, and never occupying the same location in space at the same time, and with their respective masses constant through time. For each member of the pair, in any frame of reference, its velocity at any instant (no matter how simple or intricate may be the assemblage of acting forces) is perpendicular to its angular momentum at that instant. We call this the "Basic Momentum-Geometry Fact."

For any binary point-mass system P, Q (perhaps experiencing some very intricate assemblage of forces, some of them exerted somehow by bodies other than P and Q), call a force experienced by P or by Q "central" if and only if it is either parallel or antiparallel to the vector from P to Q. Newtonian gravitation in an isolated two-body system is a central force, as also are electrostatic forces of attraction and repulsion for isolated two-body systems in particle physics. (More concretely, P experiences in the astronomical or particle-physics isolated-binary-system case a force exerted by Q, acting along the P–Q line, whereas Q experiences an equal and opposite force exerted by P.) If, as is the case for an isolated two-point-mass gravitational or electrostatic system, P experiences at every moment nothing but the one central force exerted on it by Q, and Q experiences nothing but the equal-and-opposite central force exerted on it by P, then (via a one- or two-line proof in differential vector calculus) the angular momentum vector of P is constant and the angular momentum vector of Q is constant. But then, by the "Basic Momentum-Geometry Fact," each of P and Q describes, in any inertial frame in which C_{PQ} is at rest, a curve confined to a plane.

In astronomy, gravitating bodies are often close to possessing a spherically symmetric mass distribution. It is provable (with a many-line argument; Newton held up publication of *Principia* by a couple of decades until he at last had the proof) that such bodies behave as point masses.

With these formal preliminaries complete, we now give our argument.

In a hierarchical system, each component (whether a single star, a pair of stars, a double double, or a lone outlier in tandem with a tight double, …) experiences as non-negligible only a central force exerted by its nearest companion. It therefore describes, in any inertial centre-of-mass frame for that binary within the hierarchy of nested binaries, a curve that is confined to a plane. In an arbitrary stellar cluster, on the other hand, the described curves are not in general plane curves, but can be so-to-speak warped ("twisted," "skewed").

We add here that warped-curves cases might arise even in systems simpler than open clusters and globular clusters, including groupings that are not stable: one example of such a small, unstable, grouping is the handful of stars at the heart of the Orion Nebula, whose four brightest members constitute the Trapezium (and whose very brightest member shines at mag. 5.1, less than two magnitude steps below some of our own "Brightest Stars").

4.1.3: Two-body systems and the conic sections, and orbiting as a kind of oblique falling:

None of this argument makes any assumptions about the mathematical form of the central force. It is, however, probable (again as a non-trivial theorem, requiring a multi-line proof) that in the special situation in which the central force obeys an inverse-square law (as is the case for gravitation, and indeed also for the electrostatics dominant in particle physics), the curve is not only confined to a plane, but assumes the specially simple form of a conic section. The section is a hyperbola if the central force happens to be repulsive and is a hyperbola or parabola or ellipse if the central force happens to be attractive. The hyperbola case is illustrated in the mechanics of our Solar System by those comets that are moving too quickly to be captured into closed-curve orbits around the Sun. Ellipses are of course common in celestial mechanics: for an isolated binary in an inertial centre-of-mass frame, there is a plane P such that each of the two components describes an ellipse in P with the centre of mass at one focus, with the two components always on opposite sides of the centre of mass, and with the more massive component moving in the smaller of the tandem ellipses, and the tandem ellipses being of the same shape even if quite different in size (being, that is, figures in P that are similar-even-if-not-congruent). That conic section that is the parabola is, on the other hand, from the point of view of real-life celestial mechanics, a mere mathematical idealization, constituting the so-to-speak infinitely thin boundary between the cases of the hyperbola and the cases of the ellipse. More formally, a parabolic trajectory is realized in an inertial centre-of-mass rest frame of an isolated two-point-mass system when and only when the relative speed of the two masses exactly equals the least upper bound of those various relative speeds, relative to the centre of mass, which are low enough to yield an ellipse.

The soccer ball, as a projectile on the sports ground, constitutes a two-body system with Earth. It is often stated, as an approximation, that the impelled ball describes a parabola. Here, however, the truth is that the trajectory is a segment of an ellipse, minutely divergent from a parabola, and that the trajectory would become a perfect parabola if the gravitational field on the sports ground were, contrary to fact, to be of constant direction. (Take the Earth to be a sphere of perfectly spherical mass distribution: then the gravitational field across the soccer ground, exerted by Earth on the ball, changes everywhere in direction, pointing everywhere in the soccer ground to that single point that is the Earth's centre.)

In the limiting case in which a soccer ball is impelled almost directly upward, and so falls almost directly downward, the trajectory becomes a segment of some almost-degenerate ellipse, with its minor axis of almost negligible length. Since Earth is so overwhelmingly more massive than the soccer ball, the common centre of mass of the Earth-ball system nearly coincides with the centre of the Earth, and the Earth's ellipse around the centre of mass becomes correspondingly of sub-sub-atomic dimensions. (Admittedly, this is the situation in a Newtonian setting. It will be interesting to see what becomes of such entailed sub-sub-atomic ellipses if, at some future era, general relativity becomes successfully unified with quantum mechanics.) Upon reflecting on this sportsground example as an extreme case, it can rather soon be seen (we omit details) that a binary system in stellar astronomy is a case of falling—in which, however, the two bodies fall toward each other in such a way as to stray a little off the line at any instant connecting them, and so are destined never to meet up. If the falling is at all times only a little off the instantaneous connecting line, the ellipse is severely elongated (has an "eccentricity" just slightly less than 1; in our brightest-stars table "Remarks," we write "*e*" in our occasional reports of known orbit geometries); if, on the other hand, the falling is at each instant as far off the instantaneous connecting line as geometrically possible, so that at each instant each body is moving perpendicularly to what is at that instant the inter-body connecting line, then the ellipse is a circle (with e=0).

4.1.4: Binary systems and the determination of individual masses:

For foundational astrophysical reasons, much effort has historically been, and is still now being, expended on documenting binary stars. This work was pioneered with the filar micrometry of William Herschel (1738–1822) and (more systematically) F.G.W. von Struve (1793–1864). The work took on fresh vigour with the late-Victorian advent of radial-velocity spectroscopy, as spectrograms began to be measured under the microscope for Doppler shifts. Since 1980 or so, it has taken on still greater vigour with the rise of interferometry.

Always, from the pioneering filar micrometry onward, the astrophysical motivation has been the same. Once a full orbital solution for a binary system of known distance is determined, the individual masses of the two components are known—both *(a)* as multiples of Solar System quantities and *(b)* in the absolute Système international d'unités (SI) laboratory unit, which is the kilogram. Here a "full orbital solution" is a set of half a dozen geometrical parameters, or "orbital elements," in essence angles, describing the ellipticity of the orbit and its orientation in three-dimensional space (including its angle of inclination with respect to the plane of the sky). With these, plus a determination of the distance to the binary system, the orbital trajectory of the binary (in any inertial centre-of-mass rest frame) is fully described, in particular with the length of its semimajor axis determined in the laboratory SI unit of metres.

It is, admittedly, an intricate task to proceed to the orbital elements from the little that is available at the telescope. In the case of traditional filar microscopy, orbital elements are in principle obtainable from some years or decades of raw astrometry, with each night supplying just the angular separation of the components and their position angle (as an angle in the half-open interval [0°, 360°), taken from sky north through east, south, and finally west; in our table "Remarks," we write "PA"). Also in principle obtainable are orbital solutions for binaries of known distance in which there is no filar-micrometer astrometry, and also no other (for instance, interferometer-procured) astrometry, but in which the plane of the orbit happens to be exactly perpendicular to the plane of the sky, and in which spectroscopic Doppler-shift measurements have over many successive observing sessions supplied the changing radial velocities of each of the two components. Although the situation in which the plane of a binary orbit is exactly perpendicular to the plane of the sky is seldom, if ever, realized in observational work, the situation is approximated to usable precision by cases in which the two stars are found to eclipse each other (as with, e.g. β Per Aa1 (Algol) and β Per Aa2). Finally, an orbital solution may be obtained from a combination of (perhaps imperfect) astrometry and (perhaps imperfect) spectroscopy.

Let it, in any case, now be taken that a binary system of known distance has had its orbital elements determined, by some means or other.

The solution to problem *(a)* (individual stellar masses to be determined as multiples of Solar System quantities) rests on the fact that there exists a "universal gravitational constant" G, such that for any two-body system of constant point masses m_1 and m_2, in the gravitationally bound, elliptical-orbit case the sum m_1+m_2 obeys, under Newton's generalization of Kepler's Third Law, the equality "$m_1+m_2 = (4\pi^2\, a_{1,2}{}^3)/(G\, P_{1,2}{}^2)$" (with $a_{1,2}$ the length of the semimajor axis of the orbit (in any convenient inertial rest frame of the m_1,m_2 centre of mass), and $P_{1,2}$ the m_1,m_2 orbital period). The law as stated here is independent of units: masses could be measured in kilograms, or in any other convenient units; the distance, which is $a_{1,2}$, could be measured in metres, in light-seconds, or in any other convenient units; and time could be measured in any convenient units. Let, now, M_{EM} and $M_\odot$ be the respective masses of the Earth-Moon binary and the Sun. It then follows as a special case, and under the (in practice sufficiently good) idealization of the Earth-Moon binary and the Sun as an isolated system of two point masses that $M_{EM}+M_\odot = (4\pi^2\, a_{\mathrm{EM},\odot}{}^3)/(G\, P_{\mathrm{EM},\odot}{}^2)$ (where $P_{\mathrm{EM},\odot}$ is the orbital period, in any convenient inertial rest frame of the centre of mass of those two entities, which are the tight Earth-Moon binary and the Sun, of that wide binary, which is the Earth-Moon centre-of-mass and the Sun). Equating the ratio of the left-hand sides of this pair of equations with the ratio of the right-hand sides of this pair of equations, and additionally equating $a_{\mathrm{EM},\odot}$ to the physical quantity 1 au as defined since 2012 in the SI unit of metres at IAU (this equating, while not exact, is an excellent approximation), we have $(m_1+m_2)/(M_{EM}+M_\odot) = (a_{1,2}/1\ \mathrm{au})^3/(P_{1,2}\ /\ 1\ \mathrm{y})^2$. Conveniently, however, M_{EM} is to one significant figure a mere 3-millionths the mass of the Sun. This justifies replacing, for most ordinary astrophysical purposes, $M_{EM}+M_\odot$ with $M_\odot$, yielding as a final, good approximation, the following solution to problem *(a)*: $m_1+m_2 = M_\odot\, (a_{1,2}/1\ \mathrm{au})^3/(P_{1,2}\ /\ 1\ \mathrm{y})^2$.

It remains to determine not just m_1+m_2 in terms of the quantities 1 au, 1 y, but the individual stellar masses m_1, m_2 in terms of this pair of quantities. This, however, is a comparatively modest further step. Once the orbit of the binary system, in some convenient centre-of-mass inertial rest frame, is given, the mass ratio m_1/m_2 can be found by comparing the respective dimensions of the two similar-though-in-general-not-congruent ellipses (the smaller ellipse for the larger of the two masses) traced around the common centre of mass in any convenient inertial centre-of-mass rest frame. With m_1+m_2 known and m_1/m_2 known, the individual values of m_1 and m_2 follow.

Problem "*(a)*" has thus been solved without recourse to a laboratory determination of the troublesome constant *G*. It is for problem "*(b)*" (determination of m_1, m_2 individual values in kilograms) that *G* itself is needed. Work on the laboratory problem has been proceeding for a little over two centuries. Google or YouTube searches under such terms as "Cavendish experiment apparatus" reveal the possibilities for repeating, under a constrained high-school budget or a frugal lone hobbyist's budget, the result published by Henry Cavendish in 1798, and falling within around 1% of the now-accepted value. As the current state of the art, where expense is surely not spared, www.pnas.org/content/113/36/9949 cites a *Phys. Rev. Lett.* year-2000 determination of *G* to an uncertainty of 0.0014%. Even this modern level of precision compares unfavourably with the precision attainable for, e.g. the electron charge-to-mass ratio, the speed of light, the electrical permittivity of free space, and the magnetic permeability of free space. Nevertheless, *G*, while continuing to be something of a laboratory embarrassment, is sufficiently well known to facilitate work in those areas of astronomy (notably in planetary science) where actual kilogram masses are useful. Already in Cavendish's day, for instance, it was determined (we here rephrase Cavendish's result in modern terminology, while conserving its substance) that the mass-per-unit-volume of Earth is higher than the mass-per-unit-volume of ordinary rock (planet Earth 5515 kg/m^3, but basalt and granite merely ~3000 kg/m^3), and that therefore the rocks familiar to geology are not representative of Earth's deeper interior. SI-unit density determinations, resting on the determination of masses in kilograms, are now needed not in geophysics alone but in exoplanet work, for instance for supporting hypotheses regarding a given exoplanet's composition (gas, in the manner of Jupiter? or something more dense, in the manner of Earth?).

4.1.5: Some further reading:

Tutorial resources on the Web include a conspicuously thorough source of pages from an author of the *Cambridge Double Star Atlas* (2009, second edition 2015), Bruce MacEvoy (the colleague author for this book is the celestial cartography authority, Wil Tirion), at www.handprint.com/ASTRO/index.html.

SUBSECTION 4.2: Our notational conventions in table "Star Name" column for double-star astrometry

Our treatment of double stars follows the WDS naming rules, but with additionally our own (purely Handbook-local) underline-flagging convention.

Suppose, as a hypothetical case, that a certain bright naked-eye point source has been familiar from Johann Bayer's 1603 atlas onward as "omega FooBaris," or ω FBr. Suppose ω FBr to have been discovered by some 1830's filar micrometrist to be a tight double, with components separated on the celestial sphere by an angular distance of 0.7″. It does not matter whether the pair is a binary or a mere line-of-sight coincidence: in either case, at the 1960's launch of WDS, the pairing is catalogued as ω FBr A and ω FBr B.

Now suppose, as a refinement of this basic scenario, that around 1910, ω FBr A was found by some specroscopist to be a spectroscopic binary (in our penultimate-column notation, to be an "SB"), and that nothing further was known about ω FBr A until 1974. What are the 1973 WDS implications of the 1910 discovery? Under WDS rules, ω FBr A had at that early stage in the development of WDS to be ω FBr A (not ω FBr Aa, ω FBr Ab), since as of 1973 its components had not been measured in the celestial-sphere terms of PA and angular separation.

Stellar interferometry was launched in a modest way in the 1920s. It is perhaps reasonable to say that a "Second Generation" of optical interferometers was ushered in by the team of Robert Hanbury Brown, operating the Narrabri Stellar Intensity Interferometer from 1963 to 1974. Suppose, then, that in 1974 some interferometer, such as Narrabri, succeeded in resolving ω FBr A into two components, say at a measured separation of 0.1″. At this stage, the WDS multiplicity catalogue was at last able (and under its self-imposed rules was required) to refer not to "ω FBr A" but to ω FBr Aa and ω FBr Ab.

Finally, suppose that in the current, arguably "third," generation of optical interferometry, some such instrument as CHARA or NPOI or VLTI, perhaps working in the year 2020 or 2030 or 2040, measures ω FBr Ab itself as a (very tight, very rapid) binary, with the separation even at apastron found to be just a few tens of milliarcseconds. At this stage, WDS is able (and under its self-imposed rules is required) to refer not to ω FBr Aa and ω FBr Ab but, rather, to ω FBr Aa, ω FBr Ab1, and ω FBr Ab2.

In the leftmost column of our table, we indicate with underlining that a published orbital solution is asserted to exist in WDS. In our notation, "ω FBr Aa" signifies the existence of a published orbital solution for ω FBr Aa and {ω FBr Ab1, ω FBr Ab2} (where the star ω FBr Aa experiences the outlying pair of stars ω FBr Ab1, ω FBr Ab2 as essentially a point mass), whereas "ω FBr Aa" signifies in our notation the existence of a published orbital solution for the entire {ω FBr Aa, ω FBr Ab1, ω FBr Ab2} three-star system, considered as a point mass, in its wide and slow orbit with the remote ω FBr B. In various cases in which this notation is, whether definitely or at least arguably, unclear in its intent, we explain in the "Remarks" what is and is not available in the published ω FBr orbital-solutions literature.

Although the presence of underlining in our leftmost column is a safe indication that a given double is a binary, the absence of underlining is not a safe indication that a given double is a mere line-of-sight coincidence. In some cases lacking underlining, it is a known fact that the given double is a binary (typically with some very wide, slow, orbit, that will defy mathematical modelling until some further centuries or millennia of astrometry become available); in other such cases, it is a known fact that the given double is a mere line-of-sight coincidence (for instance, because either the parallaxes or the proper motions of the two stars are severely discrepant); and in very many other such cases, the answer to the question "Binary, or not?" is currently unknown. Although we do not here try to flag the first and the second of these three possibilities in our leftmost column, WDS does try to track the current state of knowledge with its own (duly elaborate) flagging system.

SECTION 5: Supplementary user guide, concerning the more detailed interpretation of our MK-classification column

5.1: Conceptual underpinnings of the MK classification system

In strict conceptual accuracy, the MK temperature types are a purely phenomenological record of which elements are present *(a)* in which stages of ionization, and *(b)* at what densities (in other words, under what local strength of the local downward-directed gravitational field) in the photosphere of the given star.

Decades before the 1943 Morgan-Keenan-Kellman publication of the full two-dimensional MK scheme, it had already been found possible to set up the phenomenological spectral types under our heading "*(a)*" in a single orderly OBAFGKM sequence, in which individual types gave way smoothly to their neighbouring types. (This process was itself not quite straightforward. First came a simple Harvard "A, B, C, D, ..." scheme. This was followed by the realization that "A," for example, linked smoothly in its phenomenology with "B" and "F," with some of the old alphabet having to be altogether dropped or repurposed. In working out this ordering, it was found necessary by the Harvard pioneers to subdivide the OBAFGKM categories, for instance in the sense of "G rather similar to F" and "G rather similar to K" and "G about equidistant between F and K." Hearnshaw's *Analysis of Starlight*, now in its second edition as 2014anst.book.....H, is the definitive history both of the MK scheme and of its predecessors.)

It was then not a matter of definition, but of astrophysical discovery (cf, e.g. the already-cited 2014anst.book.....H, or again 1994AJ....107..742G, or again the detailed MK reference-work exposition 2009ssc..book.....G), that the OBAFGKM sequence corresponded to a temperature-ordered sequence of stellar groupings, running from the hottest photospheres to the coolest, with each of the various subdivisions within each of the O, B, A, F, G, K, and M types corresponding to a particular temperature range.

With the 1943 introduction of the two-dimensional MK scheme, the luminosity classes I, II, III, IV, V likewise had strictly a phenomenological, not an astrophysical, definition (proceeding now from our heading "*(b)*," as opposed to the "*(a)*" that yielded O, B, A, F, G, K, and M). It was then once again conceptually speaking not a matter of definition, but of astrophysical discovery, that the I-through-V sequence corresponded to a luminosity-ordered sequence of stellar groupings, running from the most luminous to the least luminous.

Admittedly, this conceptual picture, for the history of work under our heading "*(b)*," is idealized. It was evident on the theoretical front even some decades before 1943 that the "*(b)*"-heading phenomenological features highlighted in 1943 by the developers of the MK taxonomic system and signalling differences in photospheric gas densities (i.e. to differences in the strength of the local downward-pointing gravitational field) in fact correspond to differences in stellar luminosities. The developers of the MK taxonomy thus had a theoretical motivation for their definitions of classes I, II, III, IV, and V, resolutely phenomenological though their definitions were required to be, under observational-astrophysics methodology—the MK system now serves as a paradigm of successful taxonomy, even for fields outside astronomy. A classification system is defined in terms of mere phenomenological fieldwork, and yet in the expectation (successfully realized in the case of MK) that the phenomenological classification bins will in due course be discovered by the theoreticians to correspond to relevant, important, physical differences in the materials observed. (Parallels might be suggested with, e.g. 18th- or 19th-century medicine: whereas *(i)* the old clinical-phenomenology definition of "tertian fever" and "quartan fever," in terms of the observed duration of body-temperature anomalies, have been found in physiology theory not to correspond to useful fundamental realities at the level of microbiology, *(ii)* the gross empirical observation, as with the pre-Victorian stethoscope, of heartbeat anomalies has been found to correspond to useful fundamental realities at the level of cardiac neuroanatomy.)

When the MK system was introduced, it was already evident that if the classes I through V signalled a progressive decrease in stellar luminosities, then they had to signal a corresponding progressive decrease in stellar radii. The temperature of a given photosphere determines the amount of energy that photosphere radiates per unit time per unit of photosphere area. Consequently, if two stars in the same temperature type are found to differ in luminosity class, the one in the brighter luminosity class must have a larger total photosphere area, and so must be of greater radius.

It was therefore natural to adopt theory-informed, but nevertheless in official terms purely mnemonic, labels for the phenomenologically conceived luminosity classes, with I called for convenience the "supergiants," II the "bright giants," III the "giants," and IV the "subgiants." V had to be given some mnemonic label opposed to "giant," with "dwarf" consequently pressed into service, and "subdwarf" used for the underluminous class VI (important in studies of congenital metallicity, but irrelevant to our own Sample S). (It is admittedly troublesome that the terms "white dwarf"—and nowadays also "brown dwarf"—prove necessary in other contexts, with the "white dwarfs" and the now-celebrated "brown dwarfs" radiating at luminosities far below even classes V and VI.)

5.2: MK classification and stellar evolution: preliminary remarks

In 1943, when the MK system was introduced, stellar-evolution theory was not yet on a sound footing. Only the broad outline, that a star may be expected to increase in photospheric radius after completing the fusion of hydrogen in its innermost portion, was at that point known. With the theoretical nuclear-physics advances of the 1950s and 1960s, and with the advent of increasingly detailed computer modelling from the 1960s onward, it became possible to map the elaborate excursions (we outline these in subsections 5.7 and 5.8 below) that evolving stars perform in the two-dimensional luminosity-class-versus-temperature-type phenomenologically defined MK plane (the "observational HR diagram"). In particular, it is now known that every star in the phenomenological class V in our 325-star set from our 317-entry table is still performing stable fusion of hydrogen in its innermost portion. (We repeat that this class V is best termed, with correct deference to the MK classification conceptual underpinning, not simply the "Main Sequence" (MS), but the "observational MS"—as at p. 342 of the authoritative 2006ima..book.....C.) Further, membership in the phenomenological class IV is a good (though even in our small 325-star set not an infallible) indicator that stable hydrogen fusion in the innermost portion is over, with the subject star now having performed at least some part of its (in general, elaborate) later-life excursions over the MK phenomenological plane.

The distribution of the set of 325 stars across MK luminosity classes I through V accordingly turns out to be a reasonable indication of the evolutionary spread of the set.

It follows that the naked-eye bright-star night sky is a different place from the daytime sky, with its lone proximate class-V star. Something on the order of a mere fifth of our 325 MK-classified bright nighttime stars (for the most part stars in luminosity class V) resemble the Sun (the sole daytime object in our set of 325 MK-classified bright stars) in stably burning hydrogen at their centre. Even most of these are far hotter than the Sun and are consequently destined to spend less time than the Sun in this process of stable burning. All the rest have in one way or another moved beyond that stage, as shown by their luminosity classes—with the nocturnal 324 falling overwhelmingly into classes III and IV, but with classes I and II also rather well populated.

5.3: MK classification and stellar evolution: starbirth and MS

A star has at birth (i.e. has upon condensing sufficiently from its local ISM cloud to begin hydrogen fusion) four key characteristics. If the star happens not to be in the disturbing environment of some proximate star (most notably, in the disturbing environment of a binary companion so close as to transfer matter) then these four characteristics jointly entail its various other characteristics, for each point in its entire subsequent career. Prominent among those other characteristics are the duration of overall life, and at each point in the overall life additionally those time-varying key characteristics, which are radius, luminosity, and its photosphere effective temperature. Here, then, are the "Governing Four": *(a)* birth-epoch mass (the more massive stars are also the hotter, the more luminous, and the shorter-lived); *(b)* birth-epoch elemental composition (the most important aspect of composition is simply the birth-epoch "metallicity"—i.e. the extent to which, thanks to the specific properties of the local gestating ISM cloud, the subject star contains at the time of birth any elements, in whatever detailed proportions, heavier than hydrogen and helium); *(c)* absence or (possible) presence of inherited fossil magnetism, from (possible) magnetism in the gestating ISM cloud; and *(d)* birth-epoch speed of rotation.

Of the four listed properties, the first is the most important, accounting, along with the accidental circumstances of distance-from-Earth and time-elapsed-since-gestation, for essentially all the stellar variety that the unaided eye can discern.

Regarding the accidental circumstance of time-elapsed-since-gestation, a parenthetical caveat, relevant even to interpreting the casual naked-eye experience, is needed: stars condensed from the same ISM cloud are of the same age. This is the case not only with binaries but also, more dramatically, with associations (such as the dramatic naked-eye association in the northern sky whose most familiar members comprise β UMa (Merak), γ UMa A (Phecda), δ UMa A (Megrez), ε UMa A (Alioth), and ζ UMa Aa (Mizar), in other words comprise all but the first and last of the seven Big Dipper stars).

In contrast with mass and present age, congenital elemental composition does not vary greatly across our set of 325 MK-classified bright stars. The pronounced chemical differences across the set of 325 (evident from the notations for chemical peculiarities in many of the 325 bright-star MK types in our 317-entry table) are due, rather, to processes of stellar aging, notably *(i)* gravitational settling and radiational lofting of selected elemental species in cases in which the outer layers are quiet (in particular, not rotationally disturbed), and *(ii)* processes known as "Dredge-Up" (discussed again in subsection 5.8, below), when convection in an evolving star raises such elements as carbon or nitrogen into the photosphere from the buried thermonuclear furnaces.

We will not attempt to discuss congenital magnetism. But we do remark that, like chemical peculiarities, magnetism can develop and change as a star ages (with, for instance, convection in outer layers, under rotation, producing a dynamo, and with the dynamo in turn generating the kind of looping-field locally dipolar magnetic structures present in the Sun, and hinted at in the small telescope by the Sun's appearance through a hydrogen Balmer-α filter).

The fourth property in our list, congenital rotation, is a consequence of the vagaries of possible motions in the gestating ISM. The local part of the condensing gas was likely to have some kind of coordinated spin, and this spin tended to increase, under conservation of angular momentum, as the gas became more and more condensed—even though some angular momentum also was possibly shed via gas outflows, as the condensation proceeded toward starbirth.

We will not discuss congenital rotation further. We do, however, remark that the rotation speed of a solitary, undisturbed star is once again a property that can evolve as the given star ages, under the combined influence of its evolving mass distribution (although the mass of all but the hottest stars remains rather constant until late in life, after cessation of core hydrogen fusion the mass gets distributed over larger radii, forcing (under conservation of angular momentum) an increase in rotation period and its (possibly, as already noted, evolving) magnetism.

The process of change has two aspects. On the one hand, as an aging star evolves out of luminosity class V into IV, III, and in the case of congenitally massive stars even into II or I, increases in its radius cause (because angular momentum is conserved) a slowing of rotation.

On the other hand, and quite apart from this general slowing-through-bloating, a spin-braking mechanism exists within class V for those stars that succeed in generating the right kind of local, looping, dipole magnetic-field structures. The mass shed by such a star in winds, although modest, is nevertheless constrained by magnetic fields not to orbit the star freely, but to rotate at the about the same angular velocity as the star itself. Under conservation of angular momentum, this so-called "magnetic braking" then slows the rotation. In the overall galactic population of V stars, those cooler than MK temperature type F5 are capable of achieving magnetic braking, and those hotter than F5 are not. The F5 type thus constitutes a so-called "rotation break" within class V.

In our set of 325 MK-classified bright stars, all but 6 of the class V stars lie on the hot side of the break. The brightest V-class stars in Earth's sky have to be either the most luminous, and therefore the hottest, or those nearest to Earth. The scarcity of V-class bright stars on the slow side of the rotation break therefore indicates that it is the first of these two brightness-promoting characteristics that predominates, in our overall set of 325.

Although we here largely neglect stars in the disturbing environment of other proximate stars, we do have to remark parenthetically that in the case of a close binary, rotation (like also chemical composition) can be affected by processes of mass transfer. This is very notably the case with one of the more heavily studied stars in the 325-member set, α Leo A (Regulus). Here the rapid rotation is the result of a now-completed spinning-up process, involving a copious mass transfer, from the now diminutive, and therefore now observationally elusive, pre-white dwarf. In the "Remarks" for α Leo A in the table, we point out that this elusive companion, having for decades escaped observation, is at last reported in 2020ApJ...902...25G as detected spectroscopically.

The F5 "rotation break" within MK luminosity class V is ultimately due to, and is nearly coincident with, a transition (as one proceeds along the observational MS from the hottest stars to the coolest, i.e. as one advances in the sense OBAFGKM) from stars in which the hydrogen fusion is predominantly the work of the carbon-nitrogen-oxygen (CNO) cycle to stars in which the hydrogen fusion is predominantly the work of the proton-proton chain. The point at which the two processes deliver, per unit of fusion-depth mass, roughly equal energy-per-unit time is at or near a total stellar mass of 1.2 $M_\odot$.

To what extent are the four key properties reflected in the MK type of a young star (in observational terms, a star found to lie in MK luminosity class V)?

(a) Mass is well correlated with MK temperature type, in the sense that the OBAFGKM progression within class V proves to be a progression from the most massive stars to the least massive. This fact is itself far from obvious. It was, however, established in the early decades of the 20th century by spectrally classifying the elements of binary systems, of known distance, in which the orbit is not so tight as to allow the disturbing feature of mass transfer, and yet in which the orbit is tight enough, and consequently fast enough, to permit determination of orbital geometry and orbital period. For such binaries, individual masses can be determined from Newtonian mechanics.

(b) Birth-epoch elemental composition is not really reflected in the observationally assigned MK class. We have already remarked that the elemental-composition flags present in many of the 325 bright MK types are due, if not to "Dredge-Up" in the case of an aging star, then to segregation of elements through gravitational settling and radiative lofting (processes that can occur even for a young star, provided its atmosphere is quiet, as in cases where rapid rotation is absent).

(c) The MK scheme does not attempt to flag magnetism, even though magnetism is observed spectroscopically, through the Zeeman splitting of emission and absorption lines when a magnetic field is strong.

(d) Rotation can be inferred in favourable cases, but not in all cases, from the presence of the MK-type flags "n" and "nn." In a favourable case, a rapidly rotating star is seen more or less equator-on, causing its emission and absorption lines to be Doppler-broadened (since half of the photosphere is rapidly receding from the spectrograph, and the other half rapidly approaching it). In, however, the unfavourable case in which the star is seen more or less pole-on, there is no rotational broadening. A particularly well-known example of a rapid pole-on rotator (with "n" and "nn" therefore absent from the observed MK type) is α Lyr A (Vega).

We might add by way of background that it is only in recent decades that the detection of pole-on rotators has become feasible at all. If the star is close and bright enough, interferometry, while powerless to detect the shape deformation of a pole-on rapid rotator, may nevertheless succeed in picking up the equatorial darkening that accompanies rotational flattening (in the pole-on case, as an anomalous darkening, over and above the normal "limb darkening," toward the edges of the interferometrically discerned stellar disk, at whose centre is the Earth-facing stellar pole).

5.4: MK classification and stellar evolution: rotation largely neglected here

It is now helpful to outline the various possibilities for stellar evolution, as experienced by that majority of stars in the 325 MK-classified set that are already in MK luminosity classes IV, III, II, or I, as opposed to the "observational MS," which is class V. But an initial caveat is needed: we here largely neglect the disturbing influence of stellar rotation, important though that influence is.

Regarding rotation, we do remark at this point that rotation can produce flows of matter along lines of stellar longitude ("meridional flows"), and that where such flows extend some significant distance into the stellar interior, they help replenish the supply of hydrogen, as a thermonuclear fuel, in the stellar depths. The effect of rotation is in general to somewhat shift the evolutionary track of a star on the phenomenological MK plane (by promoting mixing of stellar layers that would otherwise be more sharply separated) without radically changing the shape of the track.

Difficulties in constructing an evolutionary model for the interior of a rapid rotator are among the themes of

Section 1 in 2011ApJ...732...68C. This same paper discusses difficulties involved in deducing the mass and age of a rapid rotator, and the problem of deviations from the von Zeipel 1925 gravity-darkening law for oblate-spheroid stars. The law would give the correct result for gravity darkening if the flattened star had a purely radiative envelope. With rotation, however, gravity darkening can lower the photosphere effective temperature at the equator, causing convection to set in there even when the envelope is radiative at the poles. In our 325-star set, this pathology is present in at least α Aql A (Altair) and α Cep A (Alderamin).

Even where the convective regime is uniform, the assigning of a single photospheric effective temperature to a rapid rotator is in a way misleading, at any rate as not corresponding in a straightforward way to a single MK temperature type. The assigning of an effective photospheric temperature *T* is conceptually straightforward: *T* is straightforwardly the (theoretically calculable) temperature of a thermodynamically perfect radiator (a body that is perfectly black at all wavelengths, in the sense of absorbing all electromagnetic radiation impinging on it) whose ratio of all-wavelengths-radiated-power to total surface area equals the ratio of the given star's all-wavelengths-radiated-power to total photospheric area. Conceptually straightforward though this is, it has to be accompanied, when MK spectroscopy is discussed, with the caveat that the rapid rotator's single observed MK temperature type is a mongrel, the result of light entering the spectrograph from the differing temperature regimes of (hot) poles and (cool) equator.

5.5: MK classification and stellar evolution: structure, energy flows

As a further preface to details of evolution, it is now necessary to introduce discussion-guiding concepts of stellar structure and stellar energy flows.

A star still stably fusing hydrogen in its innermost portion (whether predominantly via the CNO cycle or predominantly via the proton-proton chain) is said to have a hydrogen-fusing "core." The layers outside the energy-producing "core" of such a star are said to comprise its "envelope." Under this definition of "envelope," the envelope is not a place of energy generation, but merely a place of energy transport. This transport involves a cascade, in which a single core-produced photon is absorbed by some envelope atom, causing the envelope atom to re-radiate multiple photons, each individually less energetic, and with the same aggregate energy as the now-vanished input photon. Each of these less energetic photons is in turn absorbed by some envelope atom in a still higher layer, which in its turn re-radiates a plurality of correspondingly less energetic photons. Eventually, as that outer-skin part of the envelope that is the photosphere is reached, photons begin travelling freely, without processes of absorption and re-radiation.

Those young stars with cores hot enough to have the CNO cycle as their principal mode of hydrogen fusion have convective cores. In the case of the very hottest O stars (perhaps hotter than any of the 35 or 40 or so O stars in our set of 325 MK-classified bright stars), not only the core but even the envelope is convective. The more usual case, however, for a CNO-dominated star, and perhaps the only case appearing for the CNO-dominated subset of our 325-star set, involves a convective core overlain by a radiative envelope.

Where the temperatures at the core are low enough for the proton-proton chain to predominate, the core of a young star is radiative. High envelope opacities in this low-temperature case make radiation an inefficient mode of energy transport, causing envelopes to be convective. As one advances along the temperature sequence in the sense OBAFGKM, stars at first present just a thin convective layer (settling in at a photosphere effective temperature of ~8300 K), with convection then running deeper and deeper (and in particular, in the case of our own Sun, as a G2V star, pervading the entire envelope).

Here (once again) a caveat is necessary regarding rotation. A rapid rotator can straddle the ~8300 K boundary, with convection absent at its (hot) poles, and at least a thin convective layer present at its (cooler) equator.

As an irony of nature, an extreme case exists at the cool end of the OBAFGKM progression, just as for its already-discussed hot end. In the coolest young M stars, convection extends all the way down to the core. As for the extreme O stars, so also, however, the extreme-M case is irrelevant for us: our set of 325 MK-classified bright stars contains no young M stars at all.

5.6: MK phenomenology of early evolution within the theoretically defined MS

Having so far mentioned just the "observational MS," we may now proceed to the theoretical definition of the MS, or more strictly of departure-from-MS (and soon we shall also be relating this bit of theory to the already-presented observational MS concept). The theoretical MS will turn out (subsection 5.8, below) to be defined in such a way that departure perhaps can occur already within class V, but can also be delayed until an aging star has brightened enough to take it into class IV.

It is a sufficient, although not a necessary, condition for a star lying within the theoretical MS that it be still fusing hydrogen within its core.

Even within this early, seemingly placid, stage of a star's life, large changes can occur. While our own Sun has another four or five gigayears of life before its core-hydrogen fusion is over, the placid process of early MS evolution will, after just a single gigayear, already drive its luminosity high enough to destroy Earth's biosphere.

At the heart of this early MS process is a gradual change in core composition, as helium ash accumulates. With the core becoming progressively helium richer, even while core hydrogen nuclei continue to fuse, the number of particles constituting the aggregate of gas that is the core progressively falls. Given this rise in the mean mass of the core-gas particles (the free electrons, and a diminishing number of hydrogen nuclei, and a rising number of helium nuclei: but the increased helium comes at the expense of the hydrogen, with two hydrogens yielding one helium) the core, while maintaining the pressure needed to support the overlying envelope, is under the Ideal Gas Law forced to contract. Under a physical principle known as the Virial Theorem, half of the gravitational potential energy liberated by the contraction is translated into thermal energy, i.e. into a rise in the temperature of the core. With this rise in temperature, core hydrogen fusion (a process already decidedly dependent on temperature in the case of the proton-proton chain, and very strongly dependent on temperature in the case of the CNO cycle) becomes more vigorous. As a result, the star overall becomes more luminous, and also experiences a modest increase in radius.

It is now convenient to distinguish in our set of 325 MK-classified bright stars between *(A)* the very massive ones (possessing at birth a mass greater than around 8 $M_\odot$ or 10 $M_\odot$) and *(B)* all the others. The very massive stars are destined to die as supernovae (leaving behind perhaps a black hole, perhaps a neutron "star"). The others are destined to die as white dwarfs.

5.7: MK phenomenology of evolving high-mass stars (eventual supernovae)

In observational terms, the very massive MS stars are of MK temperature class O, or else of the hot B subdivisions B0, B1, or B2. In our set of 325 MK-classified bright stars, at least the following ten (in order of increasing RA) can be said with confidence to meet this condition: η Ori Aa (B0.5 V), θ Car (B0.5 V), α Cru B (B1 V), β Mus Aa (B2 V), π Sco A (Fang; B1 V), β Sco Aa (Acreb; B0.5 V), τ Sco (Paikauhale; B0 V), ζ Oph (O9.5 V), and α Ara A (B2 V). Additionally, 31 are observed to be on the borderline for meeting this condition (being in IV, or being classified "IV–V," or being of MK temperature class B2.5).

In the process leading up to the supernova climax, these massive stars will eventually rise in observational terms into the MK "supergiant" luminosity class I. In the set of 325, 35 are clearly now at that late stage in their development.

We will not discuss at any length the details of massive-star evolution once core hydrogen is exhausted, instead contenting ourselves with just five brief points:

(i) The very concept of MS is a little misleading for the most extreme of the massive stars, since in the most extreme cases scarcely has starbirth (the commencing of core hydrogen fusion) been achieved before gross observable evolutionary changes have set in. We will not here attempt to chart this territory (and in particular will not attempt to define for this group of stars the tricky theoretical concept of "departure from MS"). We remark only that a safe early life theoretical concept for the most massive stars is the concept of a mere instant, as opposed to an interval—namely arrival on the "Zero Age [Theoretical] MS," as the instant at which core hydrogen fusion starts.

(ii) In their so-short lives, these very massive stars fuse progressively heavier elements, in a central aggregation and in shells overlying the aggregation. The fusion after helium is finished is fuelled first by carbon, then by oxygen, and neon, and magnesium, and finally by sulphur, and silicon, yielding the eventual dumping of iron ash, from sulphur-silicon burning in a shell, onto a growing inert central aggregate of iron.

(iii) A "core-collapse" supernova eventuates after the iron aggregate exceeds the "Chandrasekhar limit" of ~1.4 $M_\odot$

(iv) The complexities of core and shell burning, with burning at various levels switching itself on and off in the process leading up to the supernova, translates in observational terms into movements across the MK luminosity-class-vs-temperature-type surface, with luminosity not changing much, but with temperature type changing dramatically (and with changes possible both in the redward, or OBAFGKM, sense and in the blueward,

or MKGFABO, sense). Each of the MK types OBAFGKM is represented in our group of 35 supergiants, with at the hot (blue) extreme ζ Pup (Naos; O5 Ia) and ζ Ori Aa (Alnitak; O9.5 Ib), and at the cool (red) extreme at least by α Ori Aa (Betelgeuse; M2 Iab), α Sco A (Antares; M1.5 Iab), and μ Cep ("Herschel's Garnet Star," M2 Ia).

(v) In its redward or blueward progressions, an evolving supergiant can pass, possibly more than once, through the "Instability Strip" (IS) in the luminosity class-vs-temperature type MK plane, thereby temporarily becoming a Cepheid variable. This possibility is presently actualized in our set of 35 class-I stars by (in order of increasing RA) α Umi Aa (Polaris), β Dor, l (ell) Car, η Aql A, and δ Cep A.

5.8: MK phenomenology of evolving lower-mass stars (eventual white dwarfs)

(B) We may now proceed to explain the sense in which, extreme cases of lower-mass cases of rotation aside (where rotation yields gas flows so violent as to leave no gas unmixed), all stars in the 325-star set with masses below ~8 $M_\odot$ or ~10 $M_\odot$, and not disturbed by mass transfer from some companion star, proceed from a readily definable theoretical-MS interval of life to the theoretical Sub-Giant Branch (SGB), then to the theoretical Red Giant Branch (RGB), then to either the theoretical Horizontal Branch (HB) or the theoretical Red Clump, then to the theoretical Asymptotic Giant Branch (AGB), and finally (as almost-corpses or corpses) to a post-theoretical-AGB phase, which, in the fullness of time, yields a white dwarf.

It might seem natural to set up a definition of "theoretical MS" for our eventual-white-dwarf stars on which such a star is deemed to leave the theoretical MS upon finishing core hydrogen fusion. The definition actually employed is, however, different (Carroll-and-Ostlie 2006ima..book.....C, pp. 452, 453). That definition has (surely?) been motivated, over the past few decades of theory construction, by a desire to make the theoretical-astrophysics demarcations correspond as closely as possible to the actual spectrograph-observable changes of direction (i.e. to the actual observed bends) as a star traces its path, over a span of megayears or tens or hundreds or thousands of megayears, on the phenomenological I-through-V vs O-through-M surface. Under the standardly employed definition, a star is said to remain on the theoretical MS not only through the process of luminosity increase attributed in Subsection 4.6 to the Ideal Gas Law, but somewhat later, even a little after the depletion of core hydrogen has brought core fusion to a halt.

The matchup of theory and phenomenology is, despite efforts at fine-tuning the theoretical definitions, imperfect. Awkwardly enough, not only can a star be on the theoretical MS even after finishing core-hydrogen fusion: conversely, a star can even have left the observational MS, in other words can have left the MK luminosity class V, while residing so far within the theoretical MS as to be still burning its core hydrogen. In terms of our table, this awkward converse possibility is illustrated by at least the following (in order of increasing RA): χ Car (B3 IV (p?), λ UMa (Tania Borealis; A1 IV), β Cru A (Mimosa; B0.5 III), ν Cen (B2 IV), ζ Cen (B2.5 IV), ι Lup (B2.5 IVn), α Tel (B3 IV), and the celebrated variable β Cep Aa (Alfirk; B1 III). Additionally, α Lyr A (Vega) is still far within the theoretical MS, and yet might erroneously be thought to have evolved to the edge of the observational MS, since its MK class is A0 Va. Here the cause of the "Va," as distinct from "V," is rotation (with Vega presenting itself to the spectrograph pole-on while rotationally flattened, in other words presenting a misleadingly increased radius).

At the moment when the depletion of core hydrogen has brought core fusion to a halt, the luminosity of the star derives from fusion in a core-surrounding hydrogen shell, now raised to a fusion-capable temperature by the increased temperature of the inactive helium-ash core. For some modest time after core-hydrogen fusion has ceased, nothing dramatic happens from an observational MK standpoint. Departure from the MS is defined as occurring when the central deposit of non-fusing helium ash becomes so massive as to trigger a rapid internal reorganization of the star, with one or the other of two possible types of rapid contraction, to be distinguished below as "*(B.a)*" and "*(B.b)*." This is the point at which something MK-noteworthy, i.e. something that registers strongly in the spectrograph, finally happens.

(B.a) For stars in the 325-star set of mass below ~1.25 $M_\odot$, the growing central deposit of still-inert helium ash becomes so massive as to trigger a further, this time rapid, contraction of the core. Some of the gravitational potential energy present before the abrupt contraction, and now liberated by infall, is under the Virial Theorem translated into an increase in the thermal energy of the shell (in which fusion of hydrogen is therefore in turn speeded up). Paradoxically, although the core has decreased in radius, the rise in shell temperature causes the shell to expand, increasing the radius of the star overall.

Two contending factors are now at work. On the one hand, the star has become more luminous. On the other hand, it is now larger. The latter factor outweighs the former, entailing a fall in the photosphere effective temperature. (Total luminous output from the photosphere is determined both by the attained photosphere effective temperature and by the attained photosphere radius, i.e. by the extent of stellar bloat. If the overall radius increase is large, then a reasonable modest increase in total luminous output has to be accompanied by a temperature decrease.)

In MK observational terms, the star, now defined to have departed the theoretical MS and simultaneously arrived on the theoretical SGB, has on the one hand moved some modest distance upward out of luminosity class V, and has on the other hand advanced redward, i.e. has evolved in the sense OBAFGKM.

(B.b) For stars of mass above ~1.25 M☉ (and nevertheless not, we repeat, attaining the ~8 M☉ or ~10 M☉ threshold that makes an eventual supernova possible), the star is found under computer modelling to undergo a more radical internal reorganization. On this more radical scenario, not just the inactive helium-rich core, but the entire star, suffers a rapid contraction. It is this spectrograph-detectable event that is in the "*(B.b)*" case taken to define the end of the theoretical MS phase.

As in the less radical "*(B.a)*" scenario, the star increases in luminosity, with some of the liberated pre-contraction gravitational potential energy once again translated into an increase in temperature (with, once again, a consequent speeding up of hydrogen fusion in the shell). In contrast with the "*(B.a)*" scenario, however, the star is of a reduced radius overall. Under the unavoidable correlation of overall luminous output with both attained photosphere effective temperature and attained photosphere radius, the now shrunken, and yet now brightened, photosphere must now be of a higher temperature. In MK observational terms, the star therefore now quite abruptly not only advances upward in the V–IV–III–II–I sense, but also advances blueward, i.e. evolves in the sense MKGFABO.

Whereas in scenario "*(B.a)*," the star is said to arrive on the theoretical SGB simultaneously with its departing the theoretical MS, in the "*(B.b)*" scenario now under consideration arrival on the theoretical SGB is defined as occurring just a little later than departure from the theoretical MS, with a further episode of core contraction following the overall contraction that under "*(B.b)*" defines departure from the theoretical MS. This further episode of core contraction yields a cooling of the photosphere, and consequently a spectrograph-observable change in the sense OBAFGKM.

In scenario "*(B.a)*," i.e. for stars exceeding ~1.25 M☉, movement through the SGB is rapid, making the detection of such stars statistically improbable, and generating the so-called "Hertzsprung Gap" in HR-diagram plots of same-age stars when the subject population is so selected as to be duly rich in masses exceeding ~1.25 M☉, and duly rich both in observational-MS stars and in observational-RGB stars. (Many open clusters meet this sampling requirement.) The statistical improbability notwithstanding, our 325-star set does succeed in capturing several fleeting residents of the Hertzsprung Gap, at any rate (in order of increasing RA)
α Aur Ab (the close Capella companion), ε Leo, ζ Leo A (Adhafera), ο UMa A (Muscida), and ζ Her A.

From this point onward, it is no longer necessary to distinguish scenarios "*(B.a)*" and "*(B.b)*." Under both scenarios, residency on the SGB (admittedly started, as we have just said, in one way in the "*(B.a)*" scenario, in a different way in "*(B.b)*," with residency in the former case brief) in due course yields a cooling of the photosphere. With this cooling, the photosphere opacity rises, causing not only the photosphere-proximate layers but even much of the deeper interior to convect. Since, however, convection is a markedly efficient mode of energy transport, the star becomes progressively more luminous and larger, while keeping its photosphere effective temperature roughly constant. As this observationally dramatic increase in luminosity starts, the star is defined as leaving the theoretical SGB and (simultaneously) arriving on the theoretical RGB.

As in the late phases of theoretical MS life, and as in the theoretical SGB, so also here on the theoretical RGB, the star is fusing hydrogen in a shell overlying an increasingly massive, although still inactive, central ball of helium. Now, however, luminosity is much higher than in the MS and SGB phases. As the still-inactive central helium ball increases in mass, it gradually contracts under its own weight. Some of the gravitational potential energy thus liberated once again becomes thermal energy in the ball, as dictated by the Virial Theorem. With the helium ball now getting gradually hotter, the overlying hydrogen-fusing shell becomes gradually hotter also, producing in turn a gradual speeding-up of its hydrogen fusion, and therefore a gradual increase in the star's (already high) luminosity.

RGB life comes to an end with one of two possible kinds of transition to core helium fusion, both entailing a decrease in overall luminosity and yet without much change in photosphere temperature. The transition is violent in the case of the less-massive stars in our set, less violent in the case of the more-massive stars in our set: we again omit details. The core-helium-fusion phase is analogous to, and yet is briefer than, the core-hydrogen fusion that characterizes the earlier part of the theoretical MS. The exact destination of this transition depends on whether the star was at the time of its birth (its arrival on the theoretical MS) metal-poor or metal-rich.

For a star born as metal-poor, exit from the RGB takes it rapidly to the "theoretical HB." This region of the theoretical luminosity-vs-photosphere-effective-temperature plot corresponds to a long, roughly horizontal, roughly straight locus of points, which we might term the "observational HB," on the MK surface. Since globular clusters are metal poor, the observational HB becomes prominent when a globular is (at least partly) resolved into its constituent stars, for which spectroscopy then yields individual MK types. Different metal-poor stars switching on their core-helium fusion are found to arrive at different points on the observational HB, i.e. to attain different photosphere effective temperatures. The particular attained photosphere effective temperature is found in computer modelling to depend chiefly not on the mass of the newly ignited helium core (this proves on modelling to be rather constant across the metal-poor population), but on the mass of the outer, non-helium, layers.

However, with just two or three or so known exceptions—the most celebrated of these being α Boo (Arcturus)—our 325 MK-classified bright stars are metal-rich. Moreover, the exceptions in our set of 325 are perhaps all at phases of evolution either preceding or following residency on the theoretical HB and observational HB. We will therefore not discuss the HB further.

For a star born as metal rich, exit from the RGB, i.e. the switching on of core-helium fusion, involves a rapid transition to the theoretical and observational "Red Clump" (in effect the red-most rump of the grander theoretical and observational HB), as further discussed at, e.g. en.wikipedia.org/wiki/Red_clump. Since the Red Clump is the helium-fusion analogue of theoretical-MS core-hydrogen fusion, it is unsurprising that it is followed by an evolutionary phase analogous to the observational RGB and theoretical RGB, namely the observational AGB and theoretical AGB.

On the AGB, helium-core fusion has come to an end, with the star at this late stage in its life harbouring an inert core rich in carbon and oxygen. Fusion now proceeds, simultaneously or alternately, in an inner shell of helium and an overlying (and in terms of overall luminous output, for most of the AGB lifetime dominant) shell of hydrogen. With more than one shell in play, evolution becomes rather elaborate. In particular, it is possible for the helium shell to be temporarily inactive, simply accreting mass from the helium ash being dumped on it by the overlying hydrogen shell. Once the helium shell becomes sufficiently massive, it turns on helium fusion, causing the overlying hydrogen shell to expand and briefly switch off. The net result of this is a temporary drop in the luminosity of the star, until the helium burning in turn subsides and the hydrogen burning resumes. In its overall evolution along the AGB, and in its post-AGB transition to the quiet, dead state of a white dwarf, a star can undergo even many tens of such "helium shell flash" episodes. Additionally characteristic of evolution on the AGB are pulsation and mass loss. The possibility is dramatically illustrated in our 325-star set by α Her Aa (Rasalgethi), and with a still higher mass loss by o (omicron) Cet Aa (Mira).

We will skip over the further details of stellar evolution toward the white-dwarf corpse phase, remarking here only that in the case of a star nearly, but not quite, massive enough to die as a supernova, even carbon may be fused before all thermonuclear activity finally ceases.

Two concluding remarks are now in order.

(1) Mention has already been made of "Dredge-Up" as a process affecting the elemental composition of the spectroscopically observed photosphere. In terms of the concepts now laid out, it can be added that "Dredge-Up" may occur in the violent and deep convection of the RGB, as "First Dredge-Up" (FDU), or after the RGB, as "Second Dredge-Up" (SDU) and "Third Dredge-Up" (TDU). A highly evolved star may experience more than one episode of TDU, and it is also possible for FDU and TDU to occur without SDU. Our table cites α Tau A (Aldebaran) as a star that has undergone FDU. On the other hand, our table in its present state of development does not cite instances of SDU or TDU.

(2) The deducing of a star's evolutionary stage from its observed MK type, as it makes its way off the MS toward, eventually, the AGB, is not always straightforward. In the case of the most massive stars (with masses greater than ~8 $M_\odot$ or ~10 $M_\odot$, and with death-by-supernova therefore impending, and with temperature evolution late in life at one or more stages proceeding in the sense OBAFGKM and at one or more stages proceeding in the contrary sense MKGFABO), temporary observed residence, as a Cepheid variable, on the Instability Strip (IS) raises the question (not always easy to answer) "Is this star making a first, a second, or a third crossing of the IS?" As pointed out in the table "Remarks," this problem complicates, in particular, the analysis of that rather untidy Cepheid variable that is α UMi Aa (Polaris). For those stars massive enough to achieve core-helium fusion at some point in their lives, and not so massive as to die a supernova death (a condition met in our 325-star set by all

the stars below ~8 M☉ or ~10 M☉), it sometimes proves difficult to distinguish residency on the theoretical RGB, residency in the theoretical Red Clump, and residency in the theoretical AGB from the available spectroscopy. Indeed the theoretical "Asymptotic Giant Branch" is so named because it corresponds in observational terms to a locus of MK-surface points running perilously close to, so-to-speak, asymptotically approaching, that just slightly redder locus of points that is the observational RGB.

5.9: Supplementary remarks on rotation with "Be phenomenon" and "shell" (in MK types O, B, A)

Some of our 325 bright MK-classified B stars have an "e" flag, for emission lines in spectroscopy. Some, and yet not all, such cases involve the important, and not yet well understood, "Be phenomenon." Strictly speaking, the presently known "Be-phenomenon" stars in our set of 325 are at least the following 19 (in order of increasing RA): γ Cas A, α Eri (Achernar), ε Cas, η Tau Aa (Alcyone), η Ori Aa, ζ Tau (Tianguan), α Col A (Phact), κ CMa, β CMi A (Gomeisa), ω Car, p Car (HR4140), γ UMa A (Phecda), δ Cen Aa, μ Cen Aa, η Cen, δ Sco A (Dschubba), α Ara A, ζ Oph, and β Cep Aa (Alfirk). As we discuss again below, β Lyr Aa1 (Sheliak) may or may not constitute a 20th case, and some doubt hangs additionally over γ Ara A (in our treatment, not a "Be phenomenon" star, because too evolved; but we are not confident in this dismissal of "Be"). Further, closely related to the Be phenomenon is the spectroscopic (predominantly B-star) "shell" phenomenon. The amateur-spectroscopy essay in the Handbook current printed editions notes that the spectroscopic-shell phenomenon, and by implication the Be phenomenon, is a potentially fertile field for amateur spectroscopy. We accordingly supply here a general briefing on the Be phenomenon and its "shell" associate, highlighting the connection of both Be and shell with the often-troubling topic of rotation.

Although many of the most tempting amateur targets in the Be-phenomenon and "shell" fields are members of our 325-star set, we nevertheless discuss the Be and shell phenomena for the most part in general terms, without restriction to the set of 325. We hope thereby to maximize the value of our discussion, and in particular to stimulate an interest in Pleione, as a Be and sometimes "shell spectrum" star not much fainter than our mag. ~3.55 cutoff.

Of all the non-cluster B stars in the galaxy, about 17% at some point in their lives present the "Be phenomenon," with the phenomenon more prevalent at the hotter (near-O) than at the cooler (near-A) end of the B range. Within the overall set of galactic stars, the exceeding rare O stars are known to sometimes present the same phenomenon (with the term "Oe" star therefore used occasionally in the literature). In our set of 325, ζ Oph, as an O star with a photosphere almost, and yet not quite, cool enough to entail classification as a hot B, is an instance. Also within the overall set of galaxy stars, some A stars are known to present the Be phenomenon. Again, our 325-star set furnishes an instance, namely γ UMa A (Phecda): this star is of MK temperature type A0, and so is just barely cool enough not to fall into the B classification bin. Nevertheless, since the phenomenon (which we will soon describe in proper detail) occurs predominantly in the B stars, the term "Be phenomenon" is standardly applied to stars in all three of the O, B, and A observational MK temperature types.

Several qualifying comments are now necessary.

The Be-phenomenon stars are not to be confused with the "Herbig Ae/Be 'stars'." The latter are not stars in the strict sense, but instead are contracting starlike bodies that have not yet achieved starbirth, i.e. have not yet started core hydrogen fusion. In their present stage of development, they are continuing to heat up under gravitational contraction, and are (unsurprisingly for objects condensing out of ISM clouds) embedded in circumstellar dust.

A true "Be phenomenon star" need not currently have emission lines in its spectrum. It must, on the other hand, be known to have at some point in its past presented emission. In observational practice, the emission is always found to occur in at least one or more lines of the hydrogen Balmer series.

The condition of past-or-present emission, while necessary, is not in its turn sufficient. A supergiant in MK type B, with Balmer emission, is not a Be-phenomenon star. For a star to be Be-phenomenon, it must either lie on the theoretical MS or (as in the case of Be-phenomenon ζ Tau (Tianguan) in our table, observationally in MK luminosity class III) be evolved only modestly beyond the theoretical MS.

Also not harbouring a Be-phenomenon star is a theoretical-MS or near-theoretical-MS member of a binary system with mass transfer, in which the observed hydrogen Balmer emission comes from an incandescent mass-transfer stream. In the table, this is perhaps the case for β Lyr Aa1 (Sheliak), which certainly has such a mass-transfer stream. Confusingly, however, a "shell" spectrum is observed for Sheliak, and "shell" in the case of a young B star (as we explain below) is generally, or even inevitably, associated with the Be phenomenon. Perhaps all that can be said here is that Sheliak is a confusing case. (It has certainly been notorious over the decades, in one way or another, as a challenge to modelling.) The conceptual point remains that if, hypothetically speaking, emission in a young B star were to come from no source other than a mass-transfer stream, thanks to that star's membership in a tight binary system, then that star, while being obliged to show the observation-driven "e" flag in its MK type, would not count as an instance of the Be phenomenon.

This, then, concludes the qualifying comments. To recapitulate: the true Be-phenomenon stars are theoretical-MS or near-theoretical-MS stars with presently observed or historically observed emission lines, where the emission is not due to a mere mass-transfer process attributable to membership in a tight binary system.

The astrophysical task is now to determine what produces the emission. Emission must mean that the star has somehow managed to shed significant quantities of incandescent gas. Copious shedding cannot be attributed to stellar winds, since winds play only a minor role in mass-shedding for stars within or near the MS (except, perhaps, for the case of stars at the hottest end of the O range, where even the concept of time-spent-on-theoretical-MS is, as noted above, problematic). Our own Sun, for instance, as an MS star, sheds a mere tenth-of-a-trillionth of its mass per year.

The cause of the copious shedding has not yet been determined with confidence. It is possible that all Be stars are rapid rotators (although, as we remarked in Subsection 5.4, spectroscopy, with its incorporation of "n" or "nn," as occasionally appropriate, in an MK type, cannot by itself detect rotation when the star is oriented pole-on to Earth). On the other hand, there are many rapidly rotating theoretical-MS or near-theoretical-MS O, B, and A stars that do not present the Be phenomenon.

The following picture therefore suggests itself: if the star is a rapid rotator, and in addition possesses some mechanism "X" for launching photosphere gas from near its equator into its equatorial plane, then an incandescent disk forms, girdling the star, and registering as emission at the spectrograph. With the star a rapid rotator, it will not be a sphere but a rotationally somewhat flattened object, with local gravity in the photosphere somewhat lower at the equator than at the poles, and with launching into an equator-plane orbit consequently favoured. The observed hydrogen Balmer emission is in this picture a signature of hydrogen ionization in the disk, under a violent barrage of UV from the (hot, as O-or-B-or-A) photosphere: Balmer-lines hydrogen light is emitted as part of the process in which free electrons and hydrogen nuclei recombine, where a captured electron falls to the penultimate energy level from some higher level.

The equatorial-disk picture was first proposed in 1931. Now quite widely accepted is a "Viscous Decretion Disk" elaboration of this idea, introduced in 1991MNRAS.250..432L. "Decretion" proves a useful contrived astronomical term, created as an antonym for "accretion." Accretion disks figure in various astrophysics contexts, for instance in such black-hole binaries as Cyg X-1 (material shed by the readily amateur-visible member of this binary falls first onto an accretion disk around the black-hole event horizon), and again in the case of starbirth, where material from the gestating ISM cloud forms an accretion disk around the protostar, in a process that might see the disk eventually transform itself into a bevy of exoplanets, with perhaps also a belt of small rocky asteroid-like bodies, and with some analogue of our Solar System's zodiacal dust, all orbiting an infant star. Correspondingly, a "decretion disk" forms when an astronomical object (in our case the Be-phenomenon star) for one reason or another releases matter into orbit in its neighbourhood.

Although the dimensions of the hypothesized disk are not easily investigated, emission in the Balmer hydrogen-α line in the cases so far studied has been found to come from a disk on the order of 0.3 au to 0.6 au in radius. We seem to have here, in other words, one of the grandest of all theoretical-MS or near-theoretical-MS stellar spectacles.

Unfortunately, it is a spectacle that at best can be imaged only fuzzily, even with the most capable current optical interferometers. Let the Jupiter disk, of diameter ~50″, familiar from the small telescope, become a circular tea-tray 50 cm in diameter. The binaries resolvable in good seeing by the small telescope, at a separation of ~1″, thereby become a pair of points on that tray lying 1 cm apart. The most celebrated of the Be-phenomenon stars, γ Cas A, already noted as spectroscopically peculiar by the first stellar spectroscopist, Fr Angelo Secchi, in or shortly before 1866, lies at a distance of 600 ly from Earth. A disk of incandescent gas on the order of 0.5 au in radius, or 1 au in diameter, is seen at this distance as an object a mere 5 mas across. In terms of the tea-tray, this corresponds to an object around 50 microns wide, in other words to an object having the approximate width of a human hair. Consistent with the picture of gases launched by "Mechanism X" into circumstellar orbit is the 2007A&A...464...59M discovery that the gas in Be-phenomenon star α Ara A is in a normal central-gravitational-field (i.e. Keplerian) orbit, moving unconstrained by any such nongravitational forces as magnetism, and not possessing the kinetics of a mere stellar wind.

What, then, can "Mechanism X" be? It is possible that different Be-phenomenon stars have different gas-launching mechanisms. Outflows from the poles are not currently considered relevant. Nonradial pulsation, on the other hand, may play a role in at least some cases, as may also local magnetic phenomena at the low latitudes. (There is perhaps no known case of a Be-phenomenon star with a strong global magnetic field.) Helpfully, all hitherto scrutinized Be-phenomenon stars have been found to be pulsating variables, although in some cases the pulsation-produced luminosity variation is at the millimagnitude level or below, eluding detection by ground-based photometry. (In addition to facing possible very-low-amplitude variations, photometric monitoring of the stellar pulsation is confronted by the complication that the disk itself may vary photometrically (possibly with high amplitude).)

Nonradial pulsation aside, it is possible that in some cases, where the Be star is a member of a binary with tight orbit, or at any rate with an orbit possessing a tight periastron, the "X" role is played by the perturbing gravitational field of the companion.

Some Be-phenomenon stars have emission (from, on the currently accepted modelling, equatorial disks) which is, so far as the existing multidecade observational record goes, stable. Other Be-phenomenon stars, however, present emission lines only intermittently, in their years or decades of "outburst." Two prominent instances of outburst-and-quiescence in our 325-star set are the already-cited γ Cas A and the recently active δ Sco A (Dschubba). Another well-known instance, although a little too dim for inclusion in the 325-star set, and sharing the notoriety of bright γ Cas A, is Pleione. This star, easy in binoculars as the northern neighbour of Atlas at the eastern extremity of the Pleiades, presented an emission-line outburst of uncertain commencement extending to 1903, and presented additional emission-line outbursts in the periods 1955–1972 and 1989–2005.

Where the disk is permanent, the "X" mechanism works steadily to launch fresh consignments of photospheric gas into orbit, i.e. to perpetuate the decretion. The ongoing launch compensates for the ongoing accretion of matter from at least the inner part of the disk back onto the photosphere. If the mechanism should for some reason cease to operate, decretion ceases, and yet accretion continues. This has the consequence that the disk vanishes (with, however, some of the outlying parts of the disk lost not to accretion onto the photosphere but to outflow, into the embedding ISM).

On some current modelling, a typical Be disk increases in thickness rather gently as one progresses outward (with radially directed tangents to the disk, as taken at the points where disk meets photosphere, yielding a tight "full-opening angle" of ~10˚). A further geometrical detail from some current modelling may also be noted: if, as is often the case, the Be-phenomenon star is a member of a binary not tight enough to produce mass transfer, and yet tight enough to produce a gravitational perturbation from the companion star, and if the Be-phenomenon star equatorial plane diverges somewhat from the orbital plane of the binary system, then the disk is warped.

We may now turn from Be to the related "shell spectrum" phenomenon. The term is somewhat unfortunate, being perhaps a relic from discussions in the early 20th century, when it was perhaps thought that an O or B or A star in or near luminosity class V could, under the right circumstances, surround itself not with an equatorial disk of gaseous ejecta (as on the currently accepted modelling) but with a literal "shell" of gaseous ejecta, in other words with an enclosing blanket. For better or worse, the term has stuck, surviving the acceptance of the disk morphology (and has nothing to do with thermonuclear-fusion shells in stellar interiors, as discussed in subsections 5.6, 5.7, and 5.8 of this essay). A "shell" spectrum in a rapid rotator, oriented equator-on to Earth, occurs when some lines are seen not in the expected broadened absorption typical of an equator-on rapid photosphere, but in, or also in, narrow absorption. Typically, though not inevitably, the unexpected narrow absorption lines occur as narrow absorption cores within Balmer emission.

On the current understanding, "shell" in this sense typically results when a Be star not only generates its (perhaps temporary) disk of equatorial ejecta but happens to be oriented more or less equator-on in relation to the spectrograph. Under these circumstances, part of the disk lies between photosphere and spectrograph, yielding the absorption. Since this part of the disk is moving more or less orthogonally to the line of sight, i.e. is neither approaching the spectrograph nor receding, its absorption lines escape the rotational broadening characteristic of absorption lines from the photosphere.

Although a Be-phenomenon star with equator-on orientation can, as just noted, be simultaneously in emission-line outburst and in "shell," it sometimes happens that shell absorption is present in a Be-phenomenon star even after its emission has for the time being subsided. The Be-phenomenon star Pleione, in particular, had a shell spectrum without emission in the period 1938–1954, and then again for some years after 1973.

Rapid rotators fitting the definition of “shell spectrum” occur even somewhat outside our present domain of interest, the Be-phenomenon stars, with instances known even in type F, right down to the F5 “rotation break.” It remains the case, however, that “shell” is most prominently connected with the Be, as a phenomenon contemporaneous with a Be outburst or present in a star that at some earlier or later time is observed to be in Be outburst.

What, in this general Be-cum-“shell” field, are the possible lines of activity for the amateur spectroscopist?

On the humblest level (even with a visual spectroscope and no camera, as in the case of 1860’s Fr Angelo Secchi), it is possible to monitor theoretical-MS or near-theoretical-MS rapid rotators, to see whether emission is currently present or currently absent. The sudden onset of emission would be newsworthy of communication to AAVSO, to the LESIA laboratory at Paris-Meudon (as mentioned again below), or to other appropriate pro-am authorities.

On a less humble level, where spectrograms are taken, and are converted into intensity-against-wavelength plots, or “extracted one-dimensional spectra,” with such professional astrophysical tools as IRAF, the evolution of emission-line and shell-absorption-line profiles could be tracked. In particular, where shell absorption is present simultaneously with emission, as in the (conveniently strong) hydrogen Balmer lines, duly equipped amateurs could examine from month to month whether emission is currently stronger on the violet, or on the contrary red side of the partitioning absorption.

Finally, we suggest in a speculative spirit that it might prove possible to keep a month-upon-month polarimetry log (although we do not ourselves know whether any amateurs in any country have attempted polarimetry, whether in a Be-phenomenon context or in other contexts): if the Be-phenomenon star is not seen pole-on, then some light from its photosphere will be scattered toward the polarimeter by free electrons in the disk and will therefore be linearly polarized.

The recent literature includes a long review article, 2013A&ARv..21...69R, on the Be phenomenon. The IAU Working Group on Active B Stars (a group whose domain of interest includes, and yet is not confined to, the Be and shell phenomena) has a homepage at activebestars.iag.usp.br/bstars, with a link to its newsletter materials, including a newsletter archive. The LESIA laboratory at the Observatoire de Paris-Meudon maintains the “BeSS Database” comprising Be-phenomenon stars, the Herbig Ae/Be “stars” briefly mentioned near the beginning of this subsection, and a “B[e]” category of supergiants, at basebe.obspm.fr/basebe.

SECTION 6: Supplementary user guide, concerning the treatment of photometric variability and photometric non-variability in our “Remarks” column

6.1: Preliminary remarks concerning photometric variability and photometric non-variability

6.1.1: Temporal and amplitudinal thresholds for photometric (V-band) variability:

We confine the entirety of this Section 6 photometry discussion to measurements *(i)* in the Johnson-Morgan (and Cousins) V passband (the central portion of the UBV, or “ultraviolet-blue-visual,” system introduced in 1953ApJ...117..313J, and *(ii)* in two reasonable approximations for V.

The 1953 three-band UBV system (extended in later years in several ways, notably with Cousins to a five-passband UBVRI system) is in two respects a large concession to pragmatism.

First, the “U,” or near-ultraviolet, passband has in practice a short-wavelength cutoff determined by local atmospheric conditions. The air over different ground-based observatories absorbs ultraviolet to different degrees, and even the constancy of ultraviolet absorption at any one site is not guaranteed, at any rate not over spans of years and decades.

Second, the generous width of the passbands makes this photometric system a notably coarse approximation to the (admittedly unattainable) photometric ideal of spectrophotometry, in which the incoming flux from a star would be plotted, not even in mere magnitudes, but in laboratory units of joules-per-square-metre or ergs-per-square-centimetre. On this ideal, flux would be taken in exceedingly narrow wavelength bins, say of width 1 pm (0.01 Å), as a full “Spectral Energy Distribution” (SED) histogram all the way from the vanishingly faint gamma-ray tail to the vanishingly faint radio-wave tail. (If the ideal were by some miracle to be attained, astrophysical benefits would accrue: in particular, by comparing the flux, as the area under the full SED curve, with the flux that is the definite integral, from negligible-gamma to negligible-radio, of the black-body curve, one could directly measure the black-body-perturbing effect of spectral absorption lines and spectral emission lines.)

Narrow-band photometric systems, the best known of which is Strömgren, provide a somewhat better approximation to the SED ideal. This pair of pragmatic concessions notwithstanding, Johnson-Morgan-Cousins UBV possesses several features that have earned it a wide following from the 1950s up to the present.

Firstly, the readily measurable difference of U and B (the "U-minus-B colour") allows one to predict the extent of the Balmer-discontinuity jump that would be found in the more laborious procedure of taking a spectrogram centred on the Balmer-limit wavelength (in the near ultraviolet) of 364.6 nm. The extent of the jump is in turn a useful indicator, at any rate for stars redder than (cooler than) MK temperature types O and B, of photosphere density, and so supplies for stars cooler than MK types O and B a usable estimate or indication of their MK V, IV, III, II, or I luminosity class.

Again, the readily measurable B-minus-V colour allows photometry to predict the MK temperature type that would be found if the star were to undergo the more laborious procedures of spectroscopy. UBV photometry can at the present time be performed with a basic thermocouple-cooled astronomical CCD (as a sufficiently exact substitute for the RCA 1P21 photomultiplier tube presupposed by the UBV definition in 1953ApJ...117..313J) even on a budget of a few thousands of CAD (or USD, or EUR), with even such a modest telescope aperture as 0.3 m or 0.2 m.

Finally, the generous width of the passbands helps ensure that UBV photometry at any given aperture, with a CCD camera of any given sensitivity and noise level at an observatory site of any given constant quality, can push its way to fainter stars than would be feasible for a spectrograph under the same conditions. The following points from within the present writer's experience, although merely anecdotal, are nevertheless suggestive of the practical advantages of photometry, at any rate in a situation where only a coarse indication of MK temperature type and MK luminosity class is needed:

- When Canada's David Dunlap Observatory (DDO) was in the final (2007-era) phases of its research-grade spectroscopy, a professional-grade liquid-nitrogen-cooled camera was operated under light-polluted suburban skies at the principal (1.88 m) DDO telescope. It was at this point considered feasible to obtain usable spectrograms from stars of mag. 13 or so. On the other hand, the present writer does not recall, from a couple of years of DDO warm-room operations, taking usable spectrograms from stars as faint as mag. 15.
- Of the three principal telescopes operated at the Tartu Observatory dark-sky (Tõravere) campus (in northeastern Europe, under rural or near-suburban skies with two horizon-hugging urban light-pollution incursions), the smaller two are used principally for photometry. One has 0.6 m of aperture and is equipped with traditional wide-passband Johnson-Cousins BVRI-system filters. The other, remotely operable, has just 0.3 m of aperture but compensates for its restricted light-grab by using interference filters in place of traditional glass (Johnson-Morgan-Cousins for BVRI, but additionally Sloane u and Sloane g: the Sloane u passband is preferred at Tõravere to Johnson-Cousins U, as lying entirely on the shortward side of the Balmer-series limit instead of straddling it as Johnson-Morgan-Cousins U does). Cooling is in both cases with thermocouple, rather than with liquid nitrogen. It is not quite certain how faint these installations can go, while achieving a good signal-to-noise ratio: it has been suggested that S/N=100 is achievable in V at magnitude 13, or fainter, and perhaps some helpful data can be had even at magnitude 18. Here, then, is a photometric capability, supporting among other things the estimation of MK two-dimensional spectral luminosity-versus-temperature types, in the more extreme of the two cases from an aperture so small as to procure just one stellar photon for every ~40 procured at DDO. —It should for completeness be added that the roboticized 0.3 m has a piggyback rider, a 60-mm refractor, known locally as the "VLT," for "Very Little Telescope." Tõravere's VLT is suited to the photometry of very bright stars, which would saturate the CCD on a telescope of conventional aperture. Its wheel has not only filters for photometry, but additionally a 200 lines/mm transmission grating, for taking quick-and-coarse spectrograms for an entire stellar field. This itself might be a conceivable tool for quick-and-rough MK classification checks (although its principal use at Tõravere is, rather, to evaluate atmospheric extinction, for cases in which the target star in photometry is far from the zenith).

From the wide realm of UBV, we are here—we repeat—confining ourselves to V and to two of its reasonable approximations. The pair of approximations is of importance, given the frequent need to examine the photometric behaviour of stars over several decades, including from decades prior to the 1950s-onward implementation of UBV. In examining, for example, the historical record for Mira, one might first input “Mira” at the “Pick a Star” interface of www.aavso.org, selecting “Plot a light curve.” This yields a light curve covering just the last couple of years. Upon clicking, however, within the displayed plot, on “Plot Another Curve,” and now requesting a plot of Mira from 1850 January 1 to the present, one gets a vast historical record, the bulk of which antedates the 1950s. For the interpretation of what is displayed, it is useful to have some knowledge of the pair of V-passband approximations to which we now proceed.

(a) Visual-estimate approximations to the V passband, in the best case good to ± 0.1 mag. as measured within their own (roughly-V) passband, have been made with the unaided eye at the telescope eyepiece since the days of Friedrich Wilhelm August Argelander. His first *Bonner Durchmusterung* volume appeared in 1859. Perhaps at a similar accuracy was also the pioneering 1850’s work of von Seidel. Additionally, as an improvement on the mere eye-at-eyepiece, various types of comparative photometer, notably the Zöllner, contributed to 19th-century photometry between the advent of the *Bonner Durchmusterung* and the introduction of the first (“pg-magnitude”) photographic plates.

(b) The V passband was approximated before the 1953 Johnson-Morgan definition with the “photovisual” photographic emulsions, as 20th-century “pv” magnitudes. (More primitive emulsions, with useful sensitivity only at the blue end of the spectrum and brought into significant observatory use from the 1880s onward, instead yielded the “pg,” or “photographic,” magnitudes. These early measurements do not approximate today’s V passband as well as their photographic-plate successors, the pv magnitudes.)

With the V passband and its approximations duly highlighted, a conceptual question arises: how short an interval of V-passband or V-approximation passband photometric constancy suffices for a star to be considered “not a variable star”? Or equivalently: how rapid is a photometric change required to be for a star to count as (at least sluggishly) variable?

All stars evolve over the scale of at any rate gigayears, with evolution in some cases producing marked photometric changes already over the scale of megayears or kiloyears. Nobody, however, would want to take this as a reason for calling all stars “variables.”

One might here be tempted to draw a conceptual distinction, within the special realm of the “intrinsic” variables (the special realm is examined in sub-subsection 6.2.1 below), as follows: (A) On the one hand within this realm are the intrinsic-variable stars whose photometric variations correspond directly to an advance along an evolutionary track. Such a star would count as “intrinsically varying, and yet not momentarily a variable.” An instance of this would be a star that, even while remaining within the theoretical and MK-phenomenological MS, while stably burning core hydrogen, steadily brightens over a period of megayears, as its core becomes progressively more helium-rich, progressively denser, and progressively hotter. In this gradual evolutionary advance, the steady temperature rise favours a steadily increasing energy output, as the highly productive hydrogen-to-helium CNO process becomes progressively more favoured over the less-productive hydrogen-to-helium “pp chain” process.

(B) On the other hand, within this realm are the intrinsic variable stars whose photometric variations are rapid enough to be discernible even within one single stage of stellar evolution. Instances of “(B)” would be furnished by the Cepheids, whose photometric fluctuations occur rapidly, at well-demarcated particular stages in their career, specifically when helium-shell burning repeatedly takes them to “blueward excursions” that happen to cross the Instability Strip (the IS) in two-dimensional MK classification space. Over a period of just a few cycles, the evolutionary stage of a Cepheid is, for practical purposes, fixed (even though evolutionary effects can make themselves felt, through tiny changes in pulsation period, over tens or hundreds of cycles—as is again remarked in sub-subsections 6.1.4 and 6.2.4, below).

Again, instances of “(B)” would be furnished by intermittently flaring MS stars, such as α Cen C, destined to remain on the MS for many gigayears, and so almost at an evolutionary standstill across even the whole probable span of human history.

Appealing though this distinction might seem, the temptation to draw it is best resisted. A solar-mass star late in life, suffering a helium-shell flash episode, as nested shells of helium and hydrogen have their thermonuclear fusion turn on and off (this situation is discussed in subsection 5.8 above), would have to be placed under heading “(A).” Awkwardly, such a star would have to go under heading “(A)” even if one of its evolutionary-process photometric transitions were to prove dramatically swift, consuming a mere kiloyear, or a mere year. Moreover, it would be unclear what to make of Wolf-Rayets (among the massive stars) and Miras (among the solar-mass stars). Although these two stellar types are universally considered variables, it might be argued that their episodes of mass shedding, with their consequences for V-passband light curves, are processes of (rapid) advance along the evolutionary track. This would, awkwardly and counterintuitively, force Wolf-Rayets and Miras to go under heading "(A)."

Having drawn attention to the conceptual problem, we resist, as we say, the temptation to offer it this particular solution. We suggest instead that "variability" is a mere pragmatic matter, not to be defined formally, and to be governed merely by the exigencies of given concrete photometry programs. A team studying δ Sct-type variability (a type of rapid pulsation, discussed in detail in sub-subsection 6.2.4 below) might well conduct differential photometry of some δ Sct star at a single observatory over a continuous period of 10 hours, or in the more ambitious case of the "Whole Earth Telescope" over a continuous period of 500 hours, with a more westerly observatory in that globe-spanning consortium coming onto the duty roster as daybreak forces a less westerly observatory to await its next nightfall. In differential photometry, a field is imaged of the target star, and additionally of a "comparison star" and (for monitoring both the stability of the "comparison" and the stability of the observatory equipment) a "check star." If, in this research program, the "comparison" and "check" are found not to vary against each other, beyond the level of mere stable-instrument noise, over the duration of the observing run, it would be reasonable to call the comparison and the check "non-variable." This situation contrasts with the situation of a team applying the same target star/ comparison star/ check star method to a slow Cepheid, pulsating with a roughly 10-day period. In the case of a Cepheid, observations might be taken not continuously, but merely a few times each night, over a run of six months. It would now in a pragmatic way be convenient to call the comparison star and the check "non-variable" if they are found not to vary against each other, above the mere stable-instrument noise level, over the duration of the six-month campaign.

We end this timeframes discussion by raising three AAVSO-specific questions that we may possibly hope to answer in later years, as this Handbook supplement goes through revisions:

- Over what timeframe is photometric constancy asserted at the (for many purposes authoritative) AAVSO(VSX) database when a star is flagged as not variable? (This is the flagging performed with the grey "N" symbol, in the AAVSO(VSX) Web interface—with the grey "N," as distinct from the red "S," which marks a suspected variable, and as distinct from the green "V," which marks a confirmed variable.)
- Over what timeframe is photometric constancy asserted at AAVSO(VSX) when a star not only receives the grey "N" status flag but additionally is given the "CST" variability classification symbol (as distinct, for instance, from a star receiving the green "V" status flag and the classical-Cepheid "DCEP" variability classification symbol, or again as distinct from a star receiving the green "V" status flag and the eruptive-variable (UV Cet-type) "UV" variability classification symbol?
- Over what timeframe is photometric constancy asserted at AAVSO (outside the specific ambit of the AAVSO database that is AAVSO(VSX), when a star is placed into one of the non-variable "standard fields," from the work of Landolt and Henden, announced at app.aavso.org/vsd/stdfields? (An initial glance at a foundational Landolt paper, 1992AJ....104..340L, suggests to this writer that a reasonable answer might be "constant over ~10 nights," as distinct from "constant over ~100 nights": is this correct?)

A second, more obvious, conceptual question arises also. How small can the overall (V passband or approximate-V passband) photometric change be, over whatever temporal span has for whatever (perhaps rather pragmatic) reason been adopted, before the specimen under study is deemed to be "not a variable"? Here the question is not, so to speak, "How sluggish is the swing in a variable permitted to be?" but, rather, "How low is the permitted swing amplitude?" Some perhaps as yet unknown, but large, percentage of stars would prove variable in the V passband over any reasonable chosen fixed temporal span if measurements could be made at the micromagnitude level. Spectroscopy of the Sun, with the slit directed at various different portions of the 31- or 32-arcminute apparent disk, reveals multiple localized oscillations with periods of a few minutes. It would therefore be unsurprising to find some corresponding V-passband fluctuation, with a similar short period, in the micromagnitude range, if someone were at each instant in the interval to integrate the total V-passband flux from the entire apparent disk. Further, a major development in 21st-century photometry has been the introduction of stellar photometry from space, at the micromagnitude level (pioneered by the Canadian 2003–2019 MOST nanosatellite mission; more recent work includes BRITE, and micromagnitude stellar photometry is a useful by-product also of exoplanet missions, such as *CoRot* at ESA (2006–2013), and *Kepler* (2009–2018) at NASA and *TESS* (2018–present) at NASA). This Handbook supplement, however, will confine itself to variability as in practice handled in most of the AAVSO(VSX) database, in other words to variability at a level on the order of 10 millimagnitudes.

Such variability is within the range of even modest amateur electronic equipment, notably of an off-the-shelf astronomical CCD camera set up to image a star field wide enough to contain the target star, a comparison star, and a check star.

With V-passband variability thus characterized, in particular possible to answer, in the affirmative, a question liable to arise at public-outreach events, for instance at events offered by RASC: "Is the Sun variable?" The Sun varies in AAVSO-relevant terms over its 22-year magnetic, or 11-year sunspot, cycle, quite apart from the possible (sub-AAVSO) micromagnitude variability previously mentioned. An observatory equipped with an off-the-shelf astronomical CCD and working some tens or hundreds of light-years outside the Solar System would detect tiny V-passband changes in the Sun from week to week, or at the very worst from quinquennium to quinquennium, at any rate outside such quiet-sun (low-sunspot-number) decades as the roughly 1645-through-1715 Maunder Minimum. This hypothetical observatory would note a clear regularity, although less strict than can be noted over ten days (even with the naked eye) in the case of pulsating η Aql or eclipsing β Lyr. The hypothetical observatory would detect V-passband maxima of approximately equal height, and V-passband minima of rather more varying depth, with an overall swing on the order of 10 millimag from maximum to minimum. So yes (one can say from the podium on RASC public-lecture occasions): V-passband variability, in the familiar AAVSO sense, is present within a not-too-protracted timeframe in even a star as placid as the Sun.

6.1.2: Stars versus multiple-star systems in the AAVSO(VSX) taxonomy of photometric variabilities:

This Handbook supplement follows the usual [notably, the AAVSO(VSX)] practice of working in most cases with entire binary, or indeed with entire nested-binaries-hierarchy, systems, rather than with individual stars. Rare exceptions can arise where a binary features an angular separation so wide as to make it natural and easy, even at the level of binoculars, to work with individual components. It is also conceivable that some such exceptions, in other words some cases in which the literature has become accustomed to discussing individual components in a binary or a nested-binaries hierarchy, arise in this supplement for merely historical reasons. (Is it perhaps for merely historical reasons that photometry references discuss separately α Cen A (Rigil Kentaurus) and α Cen B (Toliman)?) This supplement consequently discusses such things as "β Per," in place of such things as "Algol" (treating "β Per" as the entire hierarchically organized system within which the now rigorously IAU-named Algol, in other words the star that in rigorous WDS nomenclature becomes β Per Aa1, is a component: the gross, naked-eye, photometric β Per dips are due to eclipses of hot, small β Per Aa1 by large, cool β Per Aa2, and conversely the small CCD-detectable photometric dips are due to the transits of hot, small β Per Aa1 across the face of large, cool β Per Aa2).

The focus on systems, as opposed to individual stars, makes it easy not only to discuss cases in which the photometric variations are due to eclipses, but to discuss other binarity-involving cases also: for instance, where some difficult, perhaps only interferometrically resolved, binary, seen face-on and therefore not eclipsing (the two-star system "ω Foo Baris AB," or "ω FBr AB") is found to harbour variability, and it is not clear whether the seat of the variability is ω FBr A or ω FBr B.

With all this said, we nevertheless allow ourselves the usual liberty of writing "variable star" in this Handbook supplement even where pedantry would require the phrasing "variability-harbouring binary" or "variability-harbouring hierarchical nested-binaries system."

We also occasionally allow ourselves to write of variability in a "system" where what is likely the case really is variability on the part of what condensed from the gestating molecular cloud as a lone star, not as a binary.

Finally, we do not attempt to separate out any of the conceivable cases in which *(i)* what is traditionally entered into atlases merely as "ω FBr" is found at high visual resolution to be the double "ω FBr A" and "ω FBr B," and in which the AB pairing harbours variability (perhaps ω FBr A is a flare star, and ω FBr B is non-varying; perhaps, again, ω FBr A is a flare star, and ω FBr B is an unresolved eclipsing spectroscopic binary, destined some day to be resolved into "ω FBr Ba" and "ω FBr Bb"), and in which further *(ii)* as bad luck would have it, the pairing of ω FBr A and ω FBr B is a mere line-of-sight coincidence (meaning that there is in astrophysical reality no such thing as "the ω FBr system," even though there is such a thing as the (binary, rather than three-star) “ω FBr B system.”

6.1.3: Taxonomy of photometric variables as less useful than taxonomy of photometric variabilities:
It is possible for one and the same star, let alone for one and the same binary or nested-binaries system, to harbour more than one type of variability. A particularly striking instance of this possibility (although, admittedly, an instance falling outside Sample S) is some lone star, gravitationally unpaired with any companion, which simultaneously harbours BY Dra- and UV Cet-type variability. As noted in sub-subsection 6.1.7 below, a BY Dra variable has a severely inhomogeneous photosphere, and is a rotator, and is detected as variable when successive portions of the photosphere rotate into the view of the observatory, from one night to the next or from one week to the next. As noted in sub-subsection 6.1.9 below, on the other hand, a UV Cet-type variable has a violently active photosphere, with large flares. Since flares are driven by magnetism, and since magnetism in stars is a rotation-driven dynamo effect, it is not surprising to find the two types of variability co-occurring, at any rate in some (rather faint) stars outside Sample S.

A similar possibility, discussed again in sub-subsection 6.2.4 below, is the case of a star that at one and the same time presents both δ Sct-type variability (in which pulsations are excited by the “kappa mechanism,” involving stellar-interior opacity changes) and γ Dor-type variability (in which pulsations are excited by convection).

We therefore have a situation reminiscent less of classic Linnean botanic taxonomy than of medicine. In botany, no plant that happens to be, say, a specimen of *Crocus vernus* is simultaneously considered a specimen of *Scilla sibirica*. Medicine, on the other hand, is obliged to accommodate “comorbidities”: one and the same patient may, e.g. simultaneously suffer both lung cancer and heart disease.

With all this said, we nevertheless do in this Handbook supplement allow ourselves the usual shorthand, in which one speaks of classifying “variables” (referring loosely, as already remarked in sub-subsection 6.1.2, to “variable stars” and “variable systems,” foregoing pedantry) when what is strictly meant is the classifying of “variabilities.”

6.1.4: Purely phenomenological taxonomy as less useful in photometry than in spectroscopy:
In Section 5.1, MK spectral classification was discussed as a classification scheme at one and the same time based purely on observables and useful in astrophysics. In MK classification, the mere inspection of spectrograms, in the absence of astrophysical theorizing, is used to allocate a “temperature type” (typically some phenomenologically defined subtype of O, B, A, F, G, K, or M) and a “luminosity class” (typically one of the phenomenologically defined classifications V, IV, III, II, I). It is then found that stars occupying the same spot in the two-dimensional MK classification scheme are astrophysically similar, and that the more disparate two stars are in the scheme, the more astrophysically diverse they tend to be. In Section 5.1, a parallel was drawn with cardiac medicine, in which the diverse phenomenologies evident through the stethoscope are found to correspond well to diverse underlying physical conditions (the leaky valve, or alternatively the poor neuro-electrical signalling, or alternatively the aortic aneurysm).

With photometry, unfortunately, the situation is less favourable, calling to mind pre-modern efforts in fever medicine. One can, and physicians before the 19th century did, impose a classification based on observables, as when the three-day “tertian fevers” are distinguished from the four-day “quartan fevers.” However, it was noted in Section 5.1 that such a pure-phenomenology classification does not correspond in a useful way to the underlying physical realities of bacteria and viruses. In particular, cases that are in photometric terms rather similar can differ radically in their astrophysics. One might, for example, naively think that a regular alternation of deep and shallow minima, in V-passband photometry, always has the same general underlying cause. Alternating deep and shallow minima are observed with many eclipsing systems (at the CCD-photometry level with β Per, as noted above, and at even the naked-eye level with that hierarchical system β Lyr—where the observed variation stems from the mutual motion of WDS-canonical β Lyr Aa1 (in IAU-canonical naming, Sheliak) and β Lyr Aa2, along with the motion of their connecting light-emitting mass stream). And yet this is not the exclusive preserve of eclipsing binaries: the light curves of RV Tau variables (outside Sample S), which are pulsators, and can occur outside a binary pairing, likewise feature alternating deep and shallow minima.

As a second example showing the inappropriateness of an MK-like phenomenological taxonomy in photometry, we note that two different underlying astrophysical causes can produce light curves with a clock-like regularity, each cycle lasting just a few days, and with the period changing by a few seconds over the span of many tens or a few hundreds of cycles. This light-curve phenomenology is generated on the one hand by some eclipsing binaries (with mass transfer driving a slight, and inexorably one-way, drift in period), and on the other hand by typical Cepheids (pulsators, in a subset of which a similarly inexorable tiny one-way year-upon-year change in period occurs: here the one-way drift is instead a consequence of changes in the stellar interior, as thermonuclear fuel reserves are progressively depleted). It is necessary, then, to forego the phenomenological approach successful with MK in spectroscopy, and to work instead on underlying causes. What is found to be important is not, so to speak, the number of days the fever lasts, but the nature of the underlying microbe.

6.1.5: Logical challenges in photometric taxonomy: (1) sets versus supersets; (2) essential (defining) features versus empirically salient features:

We shall later, in our detailed examination of AAVSO(VSX) variable-star sub-subclasses, run up against two taxonomic problems arising repeatedly in natural science, even outside astronomy.

First, there is the danger of confusing sets with supersets (as would be comically the case if the curator of a taxidermy museum were to compile a catalogue with the entries “rodents, mammals, primates”). In variable-star work, it can be quite obvious where the intention is to demarcate sets and where the intention is to demarcate some superset. Clearly, for instance, for AAVSO(VSX) (and also for its leading input authority, Moscow-based GCVS) “E” denotes a superset, the general ensemble of eclipsing binaries, of several more narrowly defined groupings, such as the β Per-like (“Algol-like”) “EA” eclipsing binaries and the β Lyr-like “EB” eclipsing binaries. On occasion, however, the intention may not be obvious—as it will be necessary to remark in sub-subsection 6.2.4 below, in connection with the GCVS-and-AAVSO(VSX) Cepheid symbols “DCEP” and “DECEPS.”

Second, there is the danger of confusing features that are taken, at least provisionally, as pertaining with conceptual necessity to a group with features that are merely in empirical practice found salient (even invariably present) in the group. An instance, from outside astronomy, of this problem is furnished by zoology. How is one to define the domestic dog, in Linnean terminology *Canis familiaris*? In general, specimens of *Canis familiaris* are of a lighter bodily build than their interbreeding-capable genetic relatives the wolves, or *Canis lupus*, and are more amenable to life with humans than are wolves. These are not, however, conceptually essential features of the species. Feral dogs, perhaps even radically resistant to domestication, are observed in the field. Furthermore, *Canis familiaris* breeders can elicit massive, wolf-sized, body builds, as with what the American Kennel Club officially terms the “Irish Wolfhound.” Whether a given specimen belongs to *Canis familiaris* is ultimately a matter of underlying DNA-level causes, not necessarily well understood at this time. All that can be done is to start by picking out some paradigm specimens, decreed as clearly belonging to *Canis familiaris* (or as “clearly UV Cet-type flare stars,” or as “clearly β Cep pulsators”; or as “clearly basalts”; or again as “clearly cholera”; or whatever). One then has to seek for causes, as the “real essences” of the things being defined. In zoology, the “real essences” somehow involve genes. In geology, they involve chemistry, and additionally (an important consideration in the case of allomorphs) crystalline lattices. In the study of stars, they chiefly involve celestial mechanics and thermal physics.

It may well be that, as underlying causes become better studied, classification boundaries have to be shifted, with some provisional defining features even set aside, in a progressive distancing from mere “quartan versus tertian fever” taxonomy. What were once “fish,” formally “Pisces” (to the exclusion of whales) are now, with a better understanding of speciation (with Darwinian selection, over megayear and gigayear timespans), placed into a large so-called “clade” that does include the whales. This currently accepted clade contains no single Linnean grouping of “Pisces.” It does, on the other hand, contain multiple Linnean groupings for such things as the cartilaginous fish, the armoured fish, and the bony fish, as well as various Linnean groupings of four-limbed land animals.

Although it is not necessary for Handbook supplement purposes to venture far into the conceptual analysis of taxonomy, a contextual remark at this stage may help illuminate the various references later in this photometry section (in sub-subsections 6.2.2 and 6.2.4) to “real essence” problems. “Natural kinds,” or in more dramatic language “real essences,” repudiated in the 1930s by those parts of the philosophical community most closely engaged with natural science (notably by the “Logical Positivists”), are in favour once again, due to the 1970 “naming-and-necessity” analysis of philosophical logician Saul Kripke. His studies highlight the fact that taxonomic propositions emerge not as verbal deductions from clauses in a definition, but instead emerge in the course of empirical investigation, as truths that—surprisingly—succeed in being both a posteriori and conceptually necessary. Kripke remarks that while people have for millennia referred successfully (meaningfully) to gold, it is only in recent times that the real essence of gold has been identified, in other words that the "natural kind" that is gold has been adequately elucidated. A mere 18th-century definition, or quasi-definition, of gold might have specified that that substance is lustrous, yellow, malleable, and of high mass-per-unit-volume. Only in the 19th and 20th centuries did it become clear that gold is in its essence the 79th element in the periodic-table numbering, or still more adequately that gold is in its essence the element with 79 nuclear protons. The proposition that gold has 79 nuclear protons has, then, emerged as a truth that is a posteriori, and nevertheless is—surprisingly—necessary rather than contingent. If chemists or metallurgists were someday to find a way to prepare a brittle and charcoal-grey and low-density allotrope of the atomic-number-79 element, the product of their manipulations would still, as a matter of an only recently discovered definitional necessity, be gold.

6.1.6: The "Silent Watchdog Problem" regarding photometric non-variability:

The majority of stars in Sample S are either confirmed or suspected variables. It will, however, be seen toward the end of sub-subsection 6.2.7 that Sample S does contain a significant number of stars known to be in some reasonable sense not variable (as well as, frustratingly, a significant number of stars both not known to be in any reasonable sense variable and also not known to be in any reasonable sense not variable). Admittedly—but we will not examine this difficulty further—the problem of temporal thresholds for variability, inconclusively discussed in sub-subsection 6.1.1 above, becomes in a special way acute when a star or a binary system is classified as "known to be not variable." (Has such a system been found V-passband constant over 1 year, or over 10 years, or over 50?) It is worth, then, keeping in view not only the logic-of-taxonomy challenges discussed in sub-subsection 6.1.5, but additionally what might be termed the "Silent Watchdog Problem."

As with the pair of challenges from sub-subsection 6.1.5, here is in a sense a problem with a philosophical or logical aspect. The fact that a star fails to vary is significant, and consequently is a fact itself calling for a study of underlying causes. This is particularly the case with stars close in two-dimensional MK phenomenological space, and consequently also close in the two-dimensional total-energy-output-versus-effective-photosphere-temperature space of astrophysical theory, to known pulsators. Why, for instance, are there stars on or near that part of the IS that intersects with the phenomenological or theoretical MS, and that therefore ought to be δ Sct-type pulsators (discussed in sub-subsection 6.2.4, below), which nevertheless have been found to be non-variable?

This problem is a special case of a more general problem, perhaps not yet solved: what determines the pulsation amplitude (large, small, or, as in the sub-subsection 6.2.4 concern just mentioned, zero) of a star residing on the IS?

This could be called, with reference to the Sherlock Holmes race-track tampering case, the "Silent Watchdog Problem." In that Conan Doyle mystery story, a watchdog has failed to bark because the person approaching the stables in the night, intent on wounding a racehorse, was a trusted member of the dog's own household:

- *'Is there any point to which you would wish to draw my attention?'*

- *'To the curious incident of the dog in the night-time.'*

- *'The dog did nothing in the night-time.'*

- *'That was the curious incident,' remarked Sherlock Holmes.*

6.2: Overview of the AAVSO(VSX) photometric taxonomy

6.2.1: Top-level classes, and their subclasses, in the AAVSO(VSX) taxonomy of V-band variabilities:

In the AAVSO(VSX) taxonomy, variables are first divided into two broad classes. To these, and to their numerous subclasses, we within this particular Handbook supplement apply our own sequential letters, for enhanced readability. We reiterate now a point from sub-subsection 6.1.1 above, that we are confining ourselves to the V passband and its two good historical approximations (thereby skipping over some details at AAVSO(VSX), involving X-ray astronomy).

At the top of the AAVSO(VSX) taxonomic tree are the two broad classes of (A) extrinsic variables and (B) intrinsic variables, with the extrinsic class divided at AAVSO(VSX) into (A.a) variability-through-eclipsing and

(A.b) variability-through-rotation. AAVSO(VSX) has also (A.c) variability through gravitational microlensing, even within the V passband. As might be expected, however, gravitational microlensing is absent from Sample S, since Sample S is drawn from the Sun's own immediate galactic neighbourhood.

The guiding idea in extrinsic variability is that photometric fluctuations are due not to changes in a star, but to changes in the observatory's view. Perhaps, for example, a binary system is seen nearly edge-on, with its stars consequently found to undergo mutual partial eclipses, or again total eclipses alternating with transits. Perhaps, again, a star that is for one or another reason photospherically inhomogeneous both *(a)* rotates and *(b)* is not seen strictly pole-on, and as a consequence of this pair of circumstances is found to present different longitude ranges to the observatory at different times. Such a star might resemble the Sun in being a spotted oblate spheroid. On the other hand, such a star might suffer an egg-like distortion, through being *(i)* in a binary system far enough from an edge-on orientation to Earth to present no eclipses or transits to the observatory, and on the other hand *(ii)* close enough to an edge-on orientation to ensure that different areas of its (far-from-spherical, even far-from-oblate-spheroid) photosphere present themselves to the observatory at different times. There is admittedly an element of arbitrariness here, with the possibility arising of an egg-shaped distortion that is not only presented to the observatory from different perspectives at different times (as could be the case even in a perfectly circular, adequately tight, orbit), but also (in a case of high orbital eccentricity) is intrinsically varying—negligible, perhaps, at apastron, and severe at periastron. Strict pedantry would in such a case require one to speak of something like "externally occasioned intrinsic variation."

The intrinsic class of variables divides at AAVSO(VSX) into the subclasses of (B.a) pulsating, (B.b) eruptive, and (B.c) cataclysmic variables. In all these subclasses, it is the star, not the observatory perspective on some orbiting or spinning star, that undergoes the changes.

The pulsators do not require further examination at this stage. They are, however, examined at length, through a multitude of AAVSO(VSX) sub-subclasses of pulsational variability, in sub-subsection 6.2.4 below.

Eruptive variability involves gross photometric changes that stem not from pulsation (even though pulsation might also be present, as in medical terms a separately classifiable comorbidity), but instead stem from some single-star non-pulsational process. One possible such process is the formation of a bright equatorial "decretion disk," from a hot star that is on or near the theoretical MS. (This is the "Be-phenomenon" case, discussed in subsection 5.9 above.) Another possible such process is a copious bright-matter outflow, from a star evolved far beyond the theoretical MS, with the formation of an outright sphere-like shroud (as with η Car, outside Sample S, and in a different way with the Wolf-Rayet (WR) stars, represented in Sample S by the WR component in the unresolved spectral binary that is γ Vel Aa). A third possible such process is flaring. A fourth is veiling by a dark carbon-rich outflow (as with a star much discussed in both amateur and professional astronomy, although too faint for inclusion in Sample S, R CrB).

The conceptual line between mere "eruptive" variability and outright "cataclysmic" variability, in other words between what are for readability in this Handbook supplement labelled "B.b" and "B.c," perhaps defies rigorous characterization. In actual taxonomic practice, however, there would seem to be no ambiguous cases. Cataclysmic variability involves the recurrent novae (represented in Sample S by one system, T CrB), and additionally in AAVSO(VSX) work outside Sample S by various possibilities, of which the following four are particularly noteworthy: *(i)* the novae not yet observed to be recurrent; *(ii)* the "dwarf novae," or U Gem-type variables; *(iii)* those exotic phenomena of recent professional study that are the contact-binary mergers; and *(iv)* the supernovae. In all these instances of cataclysmic variability, some star is found to undergo a fundamental intrinsic change, more radical than the mere formation of a bright equatorial decretion disk or the formation of a bright or dark ejected-mass shroud.

We note, as a final comment on the subclasses, that the printed-edition RASC Handbook treatment of variability (constrained to be brief) diverges in two respects from the AAVSO(VSX) taxonomy that this Handbook supplement (unconstrained by page count) is following. First, the printed-edition treatment classifies rotational variability as intrinsic. This is to be defended as appropriate in a brief overview, in that a rotating star with photosphere patches, such as spots or large (Betelgeuse-type?) convection cells, is indeed in a simplified sense "doing something," is indeed "in a process": as time passes, there is at any rate a change in the flux reaching the observatory. Second, the printed treatment makes the cataclysmic variabilities a subclass of the extrinsic variabilities. This is to be defended as appropriate in a brief overview, in that the most common cases of cataclysmic variability are extrinsically occasioned instances of intrinsic variation: they occur in binaries, specifically in a scenario in which some white dwarf first accretes matter from outside—from its companion, through Roche-lobe overflow—and then reacts explosively to the intrusion.

6.2.2: The AAVSO(VSX) sub-subclasses of the eclipsing-variability subclass of the extrinsic variability class:

It is now possible to proceed to the details of the AAVSO(VSX) taxonomy, examining its fine-grained levels of subdivision. Except where noted to the contrary, the AAVSO(VSX) symbols are used also as an authority that AAVSO(VSX) follows closely, although in a spirit of occasional correction, namely the venerable (1948 onward) "General Catalogue of Variable Stars," or GCVS (administratively associated with the section of Lomonosov Moscow State University entitled the Sternberg Astronomical Institute, formally the Государственный астрономический институт имени Штернберга: particulars are at www.sai.msu.su/groups/cluster/gcvs/).

It goes almost without saying that most of the individual detailed levels of subdivision are discussed not only in individual short paragraphs within the VSX introductory page (www.aavso.org/vsx/index.php?view=about.vartypes) and (except in the few cases where VSX and GCVS diverge) its GCVS equivalent www.sai.msu.su/gcvs/gcvs/vartype.htm, but additionally, and in greater detail, with appropriate bibliographies, in readily locatable individual *Wikipedia* articles. In a few exceptional cases, however, *Wikipedia* details are not readily locatable. In these cases, we add some bibliographic discussion, with the necessary *Wikipedia* pointers. We also allow ourselves remarks on *Wikipedia* materials that, while readily locatable, make especially useful points, over and above what is available from the just-cited AAVSO(VSX) and GCVS introductory pages.

Represented in Sample S are the provisional or placeholder divisions "E" (for the entire eclipsing-variabilities subclass), "E/GS," "EA," and "EB" (for portions of the eclipsing-variabilities subclass not yet specified at the duly canonical sub-subclass level), along with the duly canonical sub-sub-classes denoted by the symbols "EA/DM," "EA/GS," "EA/SD," "EB/GS," and "EB/SD."

- The **E** binaries are simply the eclipsing binaries (whether totally or merely partially eclipsing). The bare "E" symbol is a placeholder, in the sense of being appropriate for cases in which little is presently known about the system, making it not yet possible to assign a variability sub-subclass.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* θ Tau (a system that is considered by AAVSO(VSX) to exhibit not only confirmed δ Sct-type intrinsic (pulsational) variability, but also possible eclipsing-variability-not-further-specified, yielding the compound VSX symbol, with a colon flagging a mere possibility, "DSCTC+E:")
-* ε Car (a system considered at AAVSO(VSX) to harbour possible, not confirmed, variability, and accordingly (a) flagged as a mere suspected variable in the VSX interface (with the red "S" status flag, not the green "V"), and (b) in terms of classification symbols given the uncertainty-marked "E:" for "possible eclipsing variability that, if present at all, cannot at the present time be further specified.")

- The **E/GS** group consists of the eclipsing binaries in which at least one component is in MK phenomenology either a giant or a supergiant. Under this definition, a binary initially and provisionally labelled merely "E" is to be classified as E/GS even if one component is either a giant or a subgiant, while the other is less luminous, for instance because still residing on the MK-phenomenological MS. While more specific than the bare "E," this symbol, too, is a placeholder, in the sense of being appropriate for cases in which the available data do not yet make it possible to specify a duly canonical sub-subclass (Sample S features both "EA/GS" and "EB/GS") of the eclipsing-variability subclass.

Within Sample S, this placeholder category is represented at AAVSO(VSX) (as consulted in 2022) by ζ Tau (a system that is considered by AAVSO(VSX) to harbour not only E/GS variability, but additionally γ Cas-type variability, yielding the compound VSX symbol "E/GS+GCAS").

- In the traditional GCVS notation, followed by AAVSO(VSX) but not universally adopted in the literature, an **EA** is an eclipsing system with a light curve making it possible to specify beginning time and ending time of the eclipses. The traditional definition is thus given in terms of photometric phenomenology, without an attempt to specify an underlying physical mechanism. In particular, *(a)* in an EA system a Roche lobe might possibly be filled, with a mass-transfer stream therefore possible. However, if there is a filled Roche lobe, with mass transfer, the transfer is on the definition of EA so slight as to make the light curve nearly constant between eclipses. Similarly, *(b)* "EA" on this definition allows very slight distortions of the mutually gravitating stars from oblate spheroids to ellipsoids or similar shapes, but with the departure from oblate-spheroid symmetry, if present at all, so slight as to keep the light curve nearly constant between eclipses. The bare use of "EA" as a GCVS-and-AAVSO(VSX) classification symbol, without a qualifier in the style "EA/x," is appropriate in case of an inability to further characterize the evolutionary status (MS? or, rather, evolved beyond MS?) of the binary-system components. While we in this Handbook supplement follow the GCVS-and-AAVSO(VSX) tradition, the authoritative textbook 2007uvs..book.....P (in its Section 5.3, on p. 108) favours a not purely photometric-phenomenological definition, in other words favours a more astrophysical definition, on which an "EA" eclipsing binary is required to be detached. It must be admitted that if, as advocated in sub-subsection 6.1.5 above, photometric taxonomy is a search for "real essences," then the phenomenological use of "EA" is a departure from photometric-taxonomy best practice—justifiable, however, on the basis that "EA" is applied in a mere placeholder spirit, before deeper astrophysical studies become available.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* δ Cas (a system considered at AAVSO(VSX) to be a confirmed variable, but to feature possible-and-yet-not-confirmed EA-type variability: VSX accordingly assigns not the symbol "EA," but the symbol "EA:")
-* η Ori (a system considered at AAVSO(VSX) to harbour not only confirmed EA-type variability (with the placeholder EA type not more closely specified) but also possible-and-yet-not-confirmed β Cep-type pulsational variability: VSX accordingly assigns the compound symbol "EA+BCEP:")
-* δ Ori
-* δ Vel
-* λ Sco (a system considered at AAVSO(VSX) to harbour not only EA-type variability (with the placeholder EA type not more closely specified) but also β Cep-type pulsational variability: VSX accordingly assigns the compound symbol "BCEP+EA")
-* δ Cap (a system considered at AAVSO(VSX) to harbour not only EA-type variability (with the placeholder EA type not more closely specified) but also the γ Dor-type and the δ Sct-type pulsational variabilities; VSX accordingly assigns the compound symbol "EA+GDOR+DSCT"; cf further the discussion, with reference to 2010ApJ...713L.192G, of GDOR-and-DSCT sub-subclass overlap (comorbidity) in sub-subsection 6.2.4 below)

- An **EB** is in the traditional GCVS notation, followed by AAVSO(VSX) but perhaps (the present writer's knowledge in composing the current version of this Handbook supplement is not in the relevant way sufficient) not universally adopted in the literature, an eclipsing binary with a light curve (1) making it impossible to specify beginning time and ending time of the eclipses, and (2) satisfying the additional requirement that the period be longer than in the case of the exceedingly rapid contact binaries, where periods of 1 d or less are typical. (The short periods are partly definitive of the EW UMa stars, in GCVS-and-AAVSO(VSX) notation the "GW" stars, absent from Sample S. The prototype, EW UMa itself, is far fainter than the Sample-S magnitude cutoff, varying in the V band between mag. 9.83 and mag. 11.08.) The present writer believes it is correct to characterize the traditional GCVS-and-AAVSO(VSX) "EB" definition in the same way as the traditional GCVS-and-AAVSO(VSX) "EA" definition is characterized above, namely as a definition in terms not of underlying astrophysics but in terms of photometric phenomenology. The present writer believes, subject to eventual correction by authorities such as AAVSO, that the GCVS and AAVSO(VSX) phrasing, which includes the clause "eclipsing systems having ellipsoidal components," is offered as an explanation for the definitive phenomenology without being made part of the definition. The "B" in the notation "EB" was evidently intended historically as a mnemonic for β Lyr, notorious for the impossibility of assigning beginning times and ending times to its so-gradual eclipses. However, one should, even if adhering—as we here in this Handbook supplement do—to the GCVS-and-AASVO(VSX) notational scheme with its phenomenological formal definition for

“EB,” keep in view an admonition from the already-cited textbook (on p. 107 of its Section 5.3): “[β Lyr] is so bizarre that it should not be a prototype for any class.” The puzzling β Lyr, in other words, should be regarded as a star that, after the EB class is defined in general phenomenological terms without specific reference to β Lyr, is simply found to lie within the class, and is on close inspection found to present peculiarities not necessarily presented by other stars satisfying the EB definition. In any case, the EB systems, like the EA systems, are so classified merely in a placeholder spirit, given the unavailability of deeper physical studies: the canonical sub-subclasses of the eclipsing-variability subclass of the extrinsic-variability class are, rather, EB/GS and EB/SD, as explained below.

Within Sample S, this placeholder category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* μ UMa (a system considered by AAVSO(VSX) to present possible-yet-not-confirmed EB variability, and additionally to present slow irregular cool-star pulsational variability, yielding the compound VSX symbol “EB:+LB”)
-* β Lyr (a system also considered by AAVSO(VSX), at any rate on the present writer’s interpretation of a somewhat intricate situation, to present possible-yet-not-confirmed intrinsic, eruptive, variability of the DPV type: VSX assigns the symbol “DPV:/EB” [as is discussed in a little more detail in sub-subsection 6.2.5 below, in an examination of the “DPV” sub-subclass of the eruptive-variability sub class of the intrinsic-variability class])

- EA/DM: The **EA/DM** sub-subclass of the eclipsing-variability subclass of the extrinsic-variability class consists of the EA binaries that are fully detached, and in which both components are so unevolved as to be in MK phenomenology MS stars.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* λ Tau
-* β Aur
-* α CrB

- The **EA/GS** sub-subclass of the eclipsing-variability subclass of the extrinsic-variability class consists of the EA binaries in which at least one component is so evolved as to be in MK phenomenology either a giant or a supergiant. (Under this definition, an EA binary is to be classified as EA/GS even if one component is in MK phenomenology either a giant or a supergiant, while the other is much less evolved, and so much less luminous, for instance through still residing on the MK-phenomenology MS.)

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* γ Per
-* ε Aur
-* η Gem (a system considered by AAVSO(VSX) to harbour both EA/GS and semiregular cool-star variability, yielding the compound VSX symbol “EA/GS+SRA”)

- The **EA/SD** sub-subclass of the binary-variability subclass of the extrinsic-variability class consists of the semi-detached EA binaries, i.e. the EA binaries in which one (and only one) star is overflowing its Roche lobe. (It now becomes a little tricky to sort out what were characterized in subsection 6.1.5 above as the “real essences.” So far as can be seen from the present writer’s perspective—this is written very much subject to eventual correction by photometry authorities, such as AAVSO authorities—*(a)* an EA/SD system would typically, although not as a matter of unavoidable astrophysical necessity, be an EA/GS system (overflow, from a filled Roche lobe, would be a typical scenario only in the case of a bloated, evolved-beyond-MS, star), while *(b)* an EA/GS system might well fail to be an EA/SD system (for a binary, even with both components supergiants, might well have an orbit wide enough to prevent Roche lobe overflow). “EA/GS” and “EA/SD” are on this provisional reading not intended to be disjoint (as in, for instance, zoology the sets of rodents and primates are intended to be disjoint, or as in geomorphology the classes of mountains and plateaux are intended to be disjoint).

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by β Per.

- The **EB/GS** sub-subclass of the eclipsing-variability subclass of the extrinsic-variability class consists of the EB binaries in which at least one component is so evolved as to be in MK phenomenology either a giant or a supergiant. This sub-subclass is thus the EB parallel to the EA/GS sub-subclass, discussed above.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by γ Phe (a system considered by AAVSO(VSX) to also harbour slow irregular pulsation in a cool star, yielding the compound VSX symbol "EB/GS+LB").

- The **EB/SD** sub-subclass of the binary-variability subclass of the extrinsic-variability class consists of the semi-detached EB binaries, i.e. the EB binaries in which one (and only one) star is overflowing its Roche lobe. This sub-subclass is thus the EB parallel to the EA/SD sub-subclass, discussed above (and is subject to the same real-essence questions as were raised above for the EA/SD sub-subclass).

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by μ^1 Sco.

6.2.3: The AAVSO(VSX) sub-subclasses of the rotating-variability subclass of the extrinsic variability class:
Represented in Sample S are the provisional or placeholder division "ROT" (for the entire rotating-variabilities subclass),and additionally the duly canonical sub-subclasses denoted by the classification symbols "ACV," "BY," "ELL," "LERI," "R," and "SXARI," and finally a special situation (perhaps a sub-sub-subclass of the canonical ELL sub-subclass, formally a subset of "ELL"?) denoted by the symbol "HB." Of these eight symbols, all but three have been taken over from GCVS—the placeholder "ROT," and the canonical "LERI," and the specialized "HB." (AAVSO(VSX) has additionally found it necessary to go beyond GCVS in noting a peculiarity within SXARI, in other words within the SX Ari-type variabilities—namely, variability due not merely to rapid stellar rotation in the presence of a strong stellar magnetic field, but additionally featuring "eclipse-like dimmings probably caused by magnetospherically confined circumstellar disk material that occults the central star." For this situation, AAVSO(VSX) introduces the symbol "SXARI/E." Since, however, the refinement is not represented within Sample S, it will not be examined here.)

- The **ROT** cases of variabilities are simply the photospherically inhomogeneous (for instance, spotted) variable-because-rotating stars not otherwise classified. This AAVSO(VSX)-although-not-GCVS symbol would be appropriate for inhomogeneous-photosphere rotating stars awaiting more thorough study, in the same sense in which the GCVS-and-AAVSO(VSX) classification E would be appropriate for eclipsing binaries awaiting more thorough study.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* α Cas (a system considered at AAVSO(VSX) to be a confirmed variable, but to feature possible-and-yet-not-confirmed rotational variability: VSX accordingly assigns not the symbol "ROT," but the symbol "ROT:")
-* η Tau (a system considered at AAVSO(VSX) to harbour not only rotational variability, but additionally MS, hot-star, slow-pulsator variability, yielding the compound VSX symbol "ROT+SPB")
-* ζ Pup (a lone star considered at AAVSO(VSX) to be a confirmed variable, but to feature possible-and-yet-not-confirmed rotational variability: VSX accordingly assigns not the symbol "ROT," but the symbol "ROT:")

- The **ACV** sub-subclass of the rotational-variability subclass of the extrinsic-variability class consists of the variabilities in which a star's strong magnetic fields produce chemical inhomogeneities in the photosphere (with abnormally strong lines of Cr, Si, Sr, and the rare earths), and in which movement of the star in turn causes the brightness to vary as first one set, then another set, of localized anomalous-composition photosphere patches is presented to the observatory. Spectral types are required to fall within the range B8p through A7p ("p" for "chemically peculiar"). In evolutionary terms, the star is required to still lie on the MK-phenomenological MS. The prototype, a member of the unresolved α CVn A (also known as the "α^2 CVn") spectral binary, surely has its rotation affected by its close companion (perhaps with tidal locking?). Nevertheless, membership in a binary (tight and tidally locked, or otherwise) is not made part of the definition.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* α And (a system considered at AAVSO(VSX) to be a confirmed variable, but to feature possible-and-yet-not-confirmed variability of the type whose paradigm is α CVn A ("α^2 CVn"): VSX accordingly assigns not the symbol "ACV," but the symbol "ACV:")
-* α Dor
-* μ Lep
-* θ Aur
-* γ Cen (a system considered at AAVSO(VSX) to be a confirmed variable, but to feature possible-and-yet-not-confirmed variability of the type whose paradigm is α CVn A ("α^2 CVn"): VSX accordingly assigns not the symbol "ACV," but the symbol "ACV:")
-* ε UMa
-* α CVn (the system that serves as the ACV paradigm, thanks to the variability of its component α CVn A, also known as α^2 CVn)
-* α Cir (a system that is also considered at AAVSO(VSX) to harbour variability of the character associated with rapidly oscillating chemically peculiar MK-type A stars, yielding the compound VSX symbol "roAp+ACV")

- The **BY** sub-subclass of the rotational-variability subclass of the extrinsic-variability class consists of variability of the "BY Dra" type. The prototype BY Dra is, admittedly, fainter than the Sample S magnitude cutoff, varying in the V band between magnitude 8.04 and magnitude 8.48. In this grouping, as with the ACV-variability instances discussed above and the SXARI-variability instances discussed at the end of the present sub-subsection, the photometric variation is due to the rotation of an inhomogeneous photosphere, and the star is required not to be evolved beyond the MK-phenomenology MS. In this case, however, the effective temperature is required to be low, corresponding to the two coolest types in the MK-spectroscopy OBAFGKM sequence. The inhomogeneities typically or always involve localized chromosphere-perturbing activity, in some cases with flaring (causing some specimens of BY variability to be instances of comorbidity, classified not only as BY but additionally as instances of UV Ceti-type (GCVS-and-AAVSO(VSX) symbol "UV") eruptive variability).

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* ε Hya (a system considered at AAVSO(VSX) to be a confirmed variable, but to feature possible-and-yet-not-confirmed BY Dra-type variability: VSX accordingly assigns not the symbol "BY," but the symbol "BY:")
-* α Cen A (considered at AAVSO to be a suspected variable, rather than a confirmed variable, and accordingly assigned not the symbol "BY" but the symbol "BY:"; here, in one of its infrequent departures from classifying entire binaries or entire nested-binaries systems, AASVO(VSX) treats the brighter component of the α Cen binary as a specimen in its own right [retrievable in a VSX lookup under such things as its BSC designation "HR5459"]).

- The **ELL** sub-class of the rotational-variability subclass of the extrinsic-variability class (with "E" for "ellipsoid") consists in variability due to egg-shape-distorted stars that, through the geometry of their motion, present different photosphere areas to the observatory at different times. Such a situation would be impossible for a solitary star, whether slowly rotating (and so almost a perfect sphere) or rapidly rotating (and so an oblate spheroid with its polar radii less than its equatorial radii). Egg-shape distortion can, however, arise for one or both components of a sufficiently tight binary. AAVSO(VSX), following its senior authority GCVS, additionally requires that ELL variability not arise from an eclipsing binary. Without this additional requirement, EB binaries (subsection 6.2.2 above) in which the light variation is in part due to the varying orientations of ellipsoidal photospheres would become cross-classified as instances of ELL variability. But the present writer wonders whether the GCVS and AAVSO(VSX) decision to avoid cross-classification is appropriate. Might there be some point in distinguishing among *(a)* partially-or-totally eclipsing binaries in which the photometric fluctuation is due to eclipsing, with egg-shape-distortion, if present at all, making only a negligible contribution to the fluctuation, *(b)* partially eclipsing binaries in which the photometric fluctuation is due about as much to eclipsing as to the egg-shape distortion, and *(c)* non-eclipsing binaries in which the photometric fluctuation is solely due to the egg-shape distortion? The first of these three cases might be marked with the appropriate one of the eclipsing-pathology symbols, in the style "EA/x" or "EB/x," the second with "EA/x+ELL" or "EB/x+ELL" (actually, one would not expect "EA/x+ELL," but might well encounter "EB/x+ELL"), and the third with "ELL." The second case, with its "+," would then become duly highlighted as an instance of comorbidity. On the current practice at GCVS and AAVSO(VSX), provision for the possibility of this comorbidity is (unfortunately, on the present writer's assessment) lacking.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* α Tri
-* η Aur (a system considered at AAVSO(VSX) to be a confirmed variable, but to feature possible-and-yet-not-confirmed ELL variability: VSX accordingly assigns not the symbol "ELL," but the symbol "ELL:")
-* σ Pup (a system considered at AAVSO(VSX) to harbour not only ellipsoid-type variability, but additionally variability due to slow and irregular stellar pulsation of a cool star: VSX accordingly assigns the compound symbol "ELL+LB")
-* α Vir (a system considered at AAVSO(VSX) to harbour not only ellipsoid-type variability, but additionally pulsational variability of the β Cep type; VSX accordingly assigns the compound symbol "ELL+BCEP")
-* π Sco
-* T CrB (a system considered at AAVSO(VSX) to harbour ellipsoid-type variability, over and above the recurrent-nova feature for which this system is perhaps most celebrated; VSX accordingly assigns the compound symbol "NR+ELL")

- For AAVSO(VSX), although not, as already noted, for GCVS, **LERI**, or λ Eri-type, variability, is in effect due to a subset of what we in this Handbook supplement call the Be-phenomenon stars (as explained in subsection 5.9 above, the MS or near-MS stars at some point in their known history exhibiting emission lines in spectroscopy); stars in this subset are additionally required by AAVSO(VSX) to exhibit periodic photometric variations, due to one or both of (1) non-radial pulsation and (2) rotation (whether of an inhomogeneous photosphere, or of an inhomogeneous overlying decretion disk, or both). In its introductory, "Conventions Used," paragraphs at www.aavso.org/vsx/index.php?view=about.vartypes,VSX takes care to warn users that in the current state of research, the correct choice among "(1) only," "(2) only," and "both (1) and (2)" is not known. The present Handbook-supplement writer concurs with the en.wikipedia.org/wiki/Lambda_Eridani_variable suggestion that GCVS errs in assigning to the BCEP class the AAVSO(VSX) LERI prototype, λ Eri (with a V-band range of mag. 4.17 to mag. 4.34, almost, but not quite, bright enough for inclusion in Sample S).

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* γ Cas (a system considered at AAVSO(VSX) to harbour not only λ Eri-type variability, but additionally X-ray variability (an AAVSO(VSX) theme left unexamined in this Handbook supplement) and γ Cas-type variability, with the LERI variability considered possible-and-yet-not-confirmed; VSX accordingly assigns the compound symbol "GCAS+X+LERI:"; the authoritative Be-phenomenon database at obspm.fr catalogues γ Cas as an instance of the Be phenomenon)
-* ν Pup (a little disconcertingly, the authoritative Be-phenomenon database at obspm.fr does not catalogue ν Pup as an instance of the Be phenomenon; it is, on the other hand, the case that a shell spectrum, consistent

with the Be phenomenon, has been asserted in the literature, with a reference to a “central quasi-emission peak”: the present writer does not know if this differs in any meaningful way from an actual “central emission peak”)
-* η Cen (a system considered at AAVSO(VSX) to harbour not only λ Eri-type variability, but additionally γ Cas-type variability; VSX accordingly assigns the compound symbol “GCAS+LERI” [and, reassuringly, η Cen is catalogued as an instance of the Be phenomenon by obspm.fr])
-* α Ara (a system considered at AAVSO(VSX) to harbour not only λ Eri-type variability, but additionally γ Cas-type variability; VSX accordingly assigns the compound symbol “LERI+GCAS”[and, reassuringly, α Ara is catalogued as an instance of the Be phenomenon by obspm.fr])

- The **R** sub-subclass of the rotational-variability subclass of the extrinsic-variability class consists of the instances of variability in which a component of a binary shows “reflection” in its light curve. The term refers here not to reflection as from a mirror, but rather to absorption at one wavelength and re-radiation at some possibly different, longer, wavelength. “Reflection” in this sense may be expected in a sufficiently tight binary, with the wavelength change notable if the two stars are of notably differing photospheric temperatures. (The present writer conjectures that one and the same component in one and the same binary might present both “ELL” and “R” variability, as an instance of comorbidity.) Admittedly, the notion of “extrinsic” variability contains here a potential element of arbitrariness, paralleling the potential element of arbitariness already noted in sub-subsection 6.2.1 in connection with the classification of shape-distortion, i.e. “ELL,” variation as “extrinsic.” The star that is in the sub-subclass R sense “reflecting” not only is placed into a special temperature regime through irradiation by its companion, if notably different in MK spectral type from its companion, but would actually be in a temporally varying (fluctuating) regime (and so might be accused of actual “externally occasioned intrinsic variation”) if its orbit were to be so eccentric as to make the apastron distance markedly smaller than the periastron distance.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* ν Cen
-* γ Lup

- The **SXARI** sub-subclass of the rotational-variability subclass of the extrinsic-variability class consists of the instances of SX Ari-type variability. Both GCVS and VSX remark that the SX Ari stars are “high-temperature analogues” of the α CVn A (“α^2 CVn,” symbol “ACV”) class: strong magnetic fields produce chemical inhomogeneities in the photosphere (with abnormally strong lines of neutral helium and doubly ionized silicon), and rotation of the star in turn causes the brightness to vary as first one set, then another set, of localized anomalous-composition photosphere patches comes into view. Spectral types are required to fall into the range B0p through B9p (“p” for “chemically peculiar”). In evolutionary terms, the star is required to still lie on the phenomenological MS. The prototype, the solitary and rapidly rotating star SX Ari, is rather too faint for inclusion in Sample S (varying between mag. 5.75 and mag. 5.81), but is nevertheless bright enough to possess a Flamsteed number, as 56 Ari. *Wikipedia* consequently discusses this prototype at the mildly unexpected URL en.wikipedia.org/wiki/56_Arietis (while discussing the variability type at the expected URL en.wikipedia.org/wiki/SX_Arietis_variable).

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by ε Cas (a system considered at AAVSO(VSX) to be a confirmed variable, but to feature possible-and-yet-not-confirmed SXARI variability: VSX accordingly assigns not the symbol “SXARI,” but the symbol “SXARI:”; the obspm.fr database considers ε Cas to be an instance of what we in the Handbook call the “Be phenomenon,” and yet, perhaps surprisingly, this system is not classified either as GCAS or as LERI by AAVSO(VSX)).

- The **HB** sub-subclass of the rotational-variability subclass of the extrinsic-variability class is characterized by AAVSO(VSX) (not by GCVS), in the following terms: “Heartbeat stars. A type of eccentric binary stars ($e > 0.2$) whose light curves resemble a cardiogram. They are ellipsoidal variables that undergo extreme dynamic tidal forces. As the two stars pass through periastron, brightness variations occur as a consequence of tidal deformation and mutual irradiation. There may also be tidally induced pulsations present. The morphology of the photometric periastron variation (heartbeat) depends strongly on the eccentricity, inclination and argument of periastron. The amplitude of variations is very small, usually below 0.01 mag. but it may exceed 0.3 mag. in extreme cases." It is stated at en.wikipedia.org/wiki/Heartbeat_star that this variability type was demarcated in 2012, on the basis of OGLE, and more significantly of NASA *Kepler*-mission, photometry. The present writer thinks, subject to correction, that an HB binary, if non-eclipsing, would at AAVSO(VSX) be considered a special case of ELL variability, in the same set-and-subset sense as an EA system is considered both at AAVSO(VSX) and at GCVS to be a special case of an E system. It appears reasonable for AAVSO(VSX) to place its special HB situation somehow within the "rotating" subclass of extrinsic variabilities, rather than somehow within the "pulsating" subclass of intrinsic variabilities: under the just-quoted AAVSO(VSX) HB characterization, while a star in a highly eccentric HB binary may at periastron be driven into pulsation by the gradient in the gravitational field of its companion, it need not be driven into pulsation. (As stated or implied in the characterization, there may be, and yet not be, "tidally induced pulsations present.") A background point of special interest is supplied by en.wikipedia.org/wiki/Heartbeat_star with its remark that if pulsations are present, then they can take on a one-sided geometry, due to the tidally induced shape distortion of the pulsator.)

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* ι Ori
-* θ Car
-* ε Lup (a system considered at AAVSO(VSX) to harbour not only HB-type variability, but additionally—if the present writer understands AAVSO correctly—many-interior-nodal-surfaces, few-photospheric-nodal-lines g-mode pulsation on the part of a hot MS star: VSX accordingly assigns the compound symbol "HB+SPB")

6.2.4: The AAVSO(VSX) sub-subclasses of the pulsating-variability subclass of the intrinsic-variability class:

(0) The following sequence of general points regarding stellar pulsation serves as a background briefing, before our (unavoidably complex and protracted) examination of the (unavoidably numerous) individual AAVSO(VSX) categories of pulsating variables:

- Stellar pulsation can involve pressure waves ("p-waves") or gravity waves ("g-waves"; not to be confused with the more exotic, more elusive propagating disturbances, or "gravitational waves," in local spacetime curvature detected from 2016 onward by LIGO, and from 2017 onward also by the Virgo team). A kind of p-and-g-mongrel stellar wave is additionally said to occur in some stellar cases. Pressure waves—whether in stars, or in planetary atmospheres and oceans, or for that matter in solids, as when sounds conduct through rock—are acoustic. In the known stellar cases, p-waves are from the realm of infrasound rather than of human hearing. In particular, pressure waves in the solar photosphere have been detected, through Doppler-shift measurements in stellar-disk spectroscopy, with periods on the order of 5 minutes. Sounds in the Sun are thus on the order of 16 octaves below the concert-hall Middle C. Gravity waves could also be called "buoyancy waves," since buoyancy, rather than pressure, is in their case the local restoring force. In terrestrial experience, gravity waves are encountered not only at water-air interfaces, but also (in meteorology) where a higher and a lower layer of the atmosphere differ widely in temperature, and there is something—in notable cases a mountain ridge, disturbing the free movement of air masses—to excite oscillations in the thermal boundary. In the standing waves that form on a violin string or drumhead, there is something rather similar to a gravity wave, but with the restoring force supplied by the tension in the filament or membrane, rather than by buoyancy. (Admittedly, the standing wave for its part creates pressure waves, in other words acoustic waves, in the surrounding air, and it is these that actually get heard in the concert hall.)
- An oscillating mass, whether a violin string or an organ-pipe air column, or a bell, or a drumhead, or a

musical acoustics-lab Chladni plate, or a star, typically oscillates simultaneously in many different "modes," also termed "eigenmodes." Single-mode oscillation, on the other hand, is encountered in the pure tone generated in the acoustics-lab headphones by an audio-frequency tank circuit (capacitor and inductor in series), yielding what an oscilloscope reveals to be a purely sinusoidal alternating current. To a good approximation, single-mode oscillation is encountered in the concert hall when a tuning fork is struck.

- In a violin string's "fundamental mode," the movement of each point on the sounding string, with the exception of the anchored endpoints at the peg-box and bridge, obeys a sinusoidal displacement-versus-time curve. The individual sinusoids, although of different amplitudes (larger toward the middle of the string, smaller toward its anchored ends), are identical in period and identical in phase. This period, adjustable by adjusting the string's restoring force, in other words by tightening or loosening its peg, is the "natural" or "resonant" fundamental-mode frequency.
- In each of its various other modes of vibration, the violin string has a nonzero number of interior motionless points, or "nodal points": one such point, dividing the string into equal vibrating halves, in the "first overtone"; two such points, dividing the string into equal vibrating thirds, in the "second overtone"; and so on. Each of these overtone modes has its own "natural" period (in the case of the first, second, ... overtone, half, one-third, ... as great as the natural fundamental-mode period). As with the fundamental mode, the individual displacement-versus-time graph of each moving point is a sinusoid, with all these sinusoids possessing the same period (a period that is to be thought of as "natural," or as "resonant," for the given overtone). In contrast with the fundamental mode, however, points separated by an interior motionless point now do not vibrate in phase, but with some fixed phase difference (180° in the case of the first overtone, 120° in the case of the second overtone, 90° in the case of the third overtone, and so on).
- Analogous points hold for a sounding plate or sounding membrane, such as a Chladni plate or a drumskin. Now, however, there are not motionless points, but motionless lines (in the case of a drum stretched over a circular hoop, circles interior to the hoop, and concentric with it, and additionally radial straight lines). These systems of motionless lines may be inspected by sprinkling the Chladni plate or drumhead with a fine powder, shaken aside where a given mode puts the metal or skin surface into motion, and left undisturbed where the mode leaves the surface motionless.
- Analogous points hold also for a three-dimensional vibrator, and in particular for a spherical rotating star devoid of significant global magnetism (in other words having at most localized magnetic poles, as in sunspots). In place of the drumhead's nodal lines, however, there are now nodal surfaces—zero, one, two, ... spherical surfaces in the stellar interior, each concentric with the star's photosphere, and additionally zero, one, two, ... planar surfaces in the stellar interior. The various curves formed where the planar surfaces meet the photosphere are circles of latitude and longitude, with the longitude circles intersecting at the rotational poles. (A curious refinement arises, however, in the case of the rapidly oscillating peculiar MK-type A stars, or AAVSO(VSX) "roAp" stars, as is noted again later in this sub-subsection: a global dipole magnetic field is present, similar to the Earth's dipole magnetic field; with such stars, as with Earth, the magnetic poles are in general offset from the rotational poles; and although the same system of nodal latitude and nodal longitude circles is present as in the non-magnetic case, this system is now anchored not on the rotational but on the magnetic poles.)
- The simplest of the possible spherical-vibrator cases is the sphere that oscillates purely radially, remaining at all times a sphere while changing in size. Such a purely radial oscillation (in stellar astronomy, notably present in the Cepheid variables; for which, however, non-radial modes can also be found) might be in the fundamental mode (the literature counts interior nodal spheres with "n," writing this as the case "$n = 0$"), but could also be in, *e.g.* the first, second, ... overtone (written as "$n = 1$," "$n = 2$," ...). A gaseous first-overtone, i.e. "$n = 1$," spherical oscillator might have a non-travelling p-wave oscillation, with a spherical nodal surface deep in the interior. The surface is a place where the local pressure is constant. When the local pressure at points inside the nodal surface is rising (falling), pressure at points outside the nodal surface is falling (rising).). A similar situation of purely radial oscillation is possible also with higher n-values. In more intricate spherical cases, on the other hand, the sphere is deformed, like a wobbling jelly ball, and one accordingly speaks of "non-radial pulsation." In such cases, there are zero, one, or more interior nodal surfaces (so that one continues to speak of the fundamental, the first overtone, and the higher

overtones, in other words of cases $n = 0$, $n = 1$, $n = 2$, ...) but additionally one, two, or more nodal lines at the surface, analogous to the lines seen on the powdered drumskin. With a rotating star, the analogy with the drumskin is in a notable respect imperfect: where in a drumskin the nodal lines do not migrate as the sound persists, in a star the entire ensemble of longitude circles does migrate, either in the same sense as the sphere's rotation (in "prograde movement") or in the contrary sense (in "retrograde movement"). Pulsating stars with 0, 1, 2, 3, ... interior nodal planes, i.e. exhibiting 0, 1, 2, 3, ... nodal lines at the photosphere, are said to be of "degree" $l = 0, 1, 2, 3, \ldots$. In addition, the symbol "*m*" is used to document separately the photospheric nodal lines-of-longitude and photospheric lines-of-latitude, in what is called an accounting of "aziumuthal order": for each given l, m ranges over the set $\{-l, -l+1, \ldots , 0, \ldots, l-1, l\}$, with $|m|$ the number of photospheric nodal lines that are lines of longitude, in other words the number of lines that correspond to azimuthal-rather-than-declinational variation. The integer m is negative (positive) if the lines of longitude are migrating with respect to the stellar rotation in the retrograde (prograde) sense. So, for example, if a star were to have among its various pulsational modes the mode corresponding to $n = 4$, $l = 17$, and $m = -6$, then it would be vibrating in the fourth overtone (in other words with four spherical nodal surfaces in its interior), and with a grand total of 17 photospheric nodal lines. Of these 17, 11 would be lines of latitude, and 6 lines of longitude, and the ensemble of lines of longitude would be migrating opposite to the direction of stellar rotation. This classification scheme now makes it possible to ask, in the spirit of Sherlock Holmes in "Silver Blaze" (subsection 6.1.6 above), "Which of the various arithmetically possible (n, l, m) combinations (arithmetically possible in the sense that $|m| \leq l$) is absent from the given star's actually realized pulsation modes—or more generally, is of some unexpected, perhaps dramatically low, amplitude—and why?"

- Violin strings are celebrated for their musical quality, in that of all the arithmetically possible modes, only a small number are excited to more than a negligible amplitude, and the natural periods of these few stand to each other in aesthetically pleasing simple integer ratios. In drumheads, on the other hand (with the exception of the pleasingly musical tympani), many modes are excited, simple integer ratios of periods are no longer prominent to the ear, and the effect is in musical terms a dissonance. A ringing Chladni plate is perhaps less pleasant than a violin string, while more musical in quality than a bass drum or snare drum. How musical or dissonant, then, are the stars—or, at any rate, how musical or dissonant is the star most extensively studied, the Sun? The disappointing answer is that in musical terms the Sun is merely in the category of drums-other-than-tympani. Nevertheless, at www.konkoly.hu/staff/kollath/stellarmusic Hungary's Konkoly Observatory documents various explorations of aesthetic possibilities, offering various tonal suggestions for avant-garde composers.
- Oscillations in stars can be excited in at least two different ways: through the "kappa mechanism," and alternatively (as in the case of the Sun's observed p-waves) through short-lived episodic perturbations driven by the vagaries of convection. The present version of this Handbook supplement examines only the first of the two in detail.
- In the "kappa mechanism," some significant percentage of the atoms of some relevant atomic species, at some appropriately deep level in the stellar interior, undergo a further degree of ionization as the pressure and density at that level temporarily increase. This process of ionization enhancement temporarily absorbs energy coming up from below, causing that layer to temporarily be a less efficient upward conduit of energy. The temperature below this increasingly ionized, temporarily transport-blocking, layer accordingly rises. When a sufficiently high temperature is reached, the star at last expands, with the blocking-layer opacity now falling in a release of its dammed-up energy, and with its ionization reduced. As the star expands, momentum carries the upward movement temporarily above the normal point of equilibrium between upward pressure and downward weight, in overshoot. As gravity finally wins out over upward pressure, the star starts to contract again, eventually with overshoot below the normal pressure-versus-weight equilibrium point. With the downward overshoot comes an increase of pressure and density in the partial-ionization layer, once again producing enhanced ionization in the relevant atomic species, causing the cycle to repeat. In the case of the Sample S IS stars, the relevant blocking-layer atomic species is singly ionized helium (doubly ionized when pressure and density increase, and the layer opacity rises). In the case of the β Cep-type pulsators, on the other hand, the relevant atomic species is (as is again soon noted in this sub-subsection) some ionization level of iron.

- Stellar pulsation is of astrophysical interest, in helioseismology (and in the twenty-first century, also in the emerging discipline of asteroseismology). A principal achievement of helioseismology has been the identification, in the solar interior, of the solar tachocline, or boundary surface between the Sun's radiative deep interior and its overlying convective zone. Perhaps the most contested question in helioseismology is this: Are g-waves (believed by both sides in the recent debate to be present at deep levels, right down to the centre of Sun) detectable by subtle traces present at the photosphere, and therefore amenable to Doppler-shift spectroscopy? We will not attempt to pronounce on the current state of the debate here. We do, on the other hand, briefly note the practical implications of the debate: a duly developed helioseismology might hope to enhance current capabilities for predicting solar-dynamo phenomena, including sunspots and coronal mass ejections (CMEs); success in predicting CMEs might in turn someday help engineers mitigate the global power-grid destruction entailed by a CME on the scale of the 1859 "Carrington Event."

(1) We begin this examination of the AAVSO(VSX) pulsational sub-classes with the hot pulsating "BCEP," "SPB," and "SPBe" cases.

- The **BCEP** sub-subclass of the pulsating-variability subclass of the intrinsic-variability class consists of the "variables of the β Cep type" (also known in parts of the literature as "β CMa stars"). These are pulsating stars, lying within the hot (blue) MK spectral types O8 through B6, and not so evolved as to be (invariably unstable) supergiants. Although such stars are too hot to lie on the IS, where pulsation is driven by the ionization of singly ionized helium to doubly ionized helium, their pulsation mechanism has since the 1980s been known to be analogous to the IS mechanism, with iron ionization (deep in the stellar interiors) playing the role of IS helium ionization in the less deep layers of somewhat cooler (yellow, MK A,F,G) stars. The 1980s BCEP theoretical advance is discussed further by 2007uvs..book.....P, in Section 6.5, on p. 142.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* γ Peg (a system that is considered at AAVSO(VSX) to harbour not only BCEP-type variability, but also another of the pulsational sub-subclasses of variability, yielding the compound symbol "BCEP+SPB")
-* ε Per
-* η Ori (a system in which the BCEP variability is considered at AAVSO(VSX) to be possible-and-yet-not-confirmed, and in which AAVSO(VSX) also finds confirmed eclipsing variability, not yet fully studied, of the placeholder EA type: this yields the compound symbol "EA+BCEP:")
-* ζ CMa (a system considered at AAVSO(VSX) to harbour possible, not confirmed, variability, and accordingly *(a)* flagged as a mere suspected variable in the VSX interface (with the red "S," not the green "V"), and *(b)* in terms of classification symbols given the uncertainty-marked "BCEP:," for "possible BCEP variability")
-* β CMa
-* χ Car
-* δ Cru
-* α Mus
-* β Cru
-* α Vir (a system considered at AAVSO(VSX) to harbour also ellipsoid-type variability, yielding the compound VSX symbol "ELL+BCEP")
-* ε Cen
-* β Cen
-* ι Lup (a case considered at AAVSO(VSX) to harbour confirmed variability, but to be a possible-and-yet-not-confirmed instance of BCEP variability, yielding the symbol "BCEP:")
-* α Lup
-* κ Cen
-* δ Lup
-* σ Sco

-* θ Oph (a system considered at AAVSO(VSX) to harbour not only BCEP-type variability, but also another of the pulsational sub-subclasses of variability, yielding the compound symbol “BCEP+SPB”)
-* λ Sco (a system considered at AAVSO(VSX) to also be an eclipser of the placeholder EA type, yielding the compound VSX symbol “BCEP+EA”)
-* κ Sco
-* β Cep (the paradigm for the sub-subclass)

- The **SPB** symbol, used at AAVSO(VSX) although not at GCVS, denotes a sub-subclass of the pulsating-variability subclass of the intrinsic-variability class characterized as “Main Sequence B2–B9 stars (3–9 solar masses) that pulsate in the high radial order low degree g-modes.” We take it here in this Handbook supplement (subject to possible eventual correction by AAVSO, or by others) that here “radial order” refers not to the symbol “*l*” as discussed earlier in this sub-subsection, but simply to “*n*” (since why otherwise could the phenomenon be “radial”?). On this reading of AAVSO(VSX), as the various pulsation modes of an SPB star are inventoried, modes are found in which there are many interior spherical nodal surfaces, and yet no modes are found having a large number of photospheric nodal lines: the pulsation of an SPB star, while non-radial, is just mildly non-radial.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* γ Peg (a system considered at AAVSO(VSX) to also harbour β Cep-type variability, yielding the compound symbol “BCEP+SPB”)
-* η Tau (a system considered at AAVSO(VSX) to also harbour some type of rotational variability, yielding the compound VSX symbol “ROT+SPB”; although AAVSO(VSX) asserts neither γ Cas-type nor λ Eri-type variability, the system is classified by the obspm.fr database as an instance of what is in Subsection 5.9 above called the “Be phenomenon”)
-* η UMa (a system that might, in view of its rapid rotation and its line variability, be thought to exhibit the “Be phenomenon”; however, this system is absent from the authoritative Be-phenomenon database at obspm.fr)
-* ε Lup (a system considered at AAVSO(VSX) to also harbour the “Heartbeat Star” type of rotational extrinsic variability, yielding the compound VSX symbol “HB+SPB”)
-* θ Oph (a system considered at AAVSO(VSX) to also harbour β Cep-type variability, yielding the compound VSX symbol “BCEP+SPB”)
-* ζ Peg (a system that might, in view of its fast rotation, possibly be an instance of the “Be phenomenon,” especially if the MK luminosity class, namely III, assigned in this Handbook supplement (Table, “MK Type” column) should happen to be in error, with the correct class instead being V; however, ζ Peg is absent from the authoritative Be-phenomenon database at obspm.fr)

- The **SPBe** symbol, used in VSX although not at GCVS, is explained by AAVSO(VSX) as signifying “rapidly rotating Be stars showing g-mode non-radial pulsations.” The present writer wonders if this sub-subclass of the pulsating-variability subclass of the intrinsic-variability class should be subdivided, or alternatively if its characterization should be tightened up, to exclude stars that have evolved far beyond the MS: a rapidly rotating Be star not evolved far beyond the MS, and with a history of at least temporary Be emission, is an instance of the Be phenomenon (with its emission due, on the current understanding of that phenomenon, to the formation of an equatorial decretion disk, as discussed in Subsection 5.9 above); and on the other hand, a highly evolved B star in emission (here, admittedly, rapid rotation is unlikely) will be liable to have its emission instead due to copious winds, and so will be liable to sit within an ejected bright gaseous aggregate not confined to the geometry of a disk. It is stressed in Subsection 5.9 above that a highly evolved star of MK type B, with emission, does not qualify as an instance of the Be phenomenon.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by β CMi (classified as an instance of the Be phenomenon by the obspm.fr database).

(2) We continue this examination of the AAVSO(VSX) pulsational sub-classes by taking a group of pulsators

having no very striking affinity with any other pulsator group represented in Sample S (although arguably having some affinities with the GCVS-and-AAVSO(VSX) S Dor-type variables, or "SDOR stars": a celebrated SDOR specimen, P Cyg, temporarily surmounted the Sample S brightness threshold around the year 1600, and perhaps again on one or two occasions later in the 1600s; another celebrated SDOR specimen, η Car, temporarily surmounted the Sample S brightness threshold in 1843, having, however, fallen far below the threshold by 1856; as explained in Section 1 above, the Handbook brightest-stars supplement chooses to omit these specimens from Sample S, since there is no concrete, timeframe-assignable, expectation of their at some point once again surmounting the threshold).

- The **ACYG** sub-subclass of the of the pulsating-variability subclass of the intrinsic-variability class consists of the "variables of the α Cyg type": rapidly, non-radially, pulsating MK-class supergiants in the hot MK types B and A. The group was first considered a distinctive class of pulsators in 1985, in a predecessor edition of the present-day GCVS. Both the present-day GCVS and AAVSO(VSX) mention Bep and Aep ("p" as the MK-qualifier flag for "chemically peculiar," "e" as the MK-qualifier flag for "emission"). However, this is surely not definitive, since the unavoidable prototype, α Cyg, MK-classified as A2 Ia, is in MK terms neither "p" nor "e." (Here, then, is an instance of the situation discussed in sub-subsection 6.1.5 above, where defining features in a taxonomic group need to be distinguished from empirically noted features, widely present across the group.) Since multiple modes of rapid pulsation are on the GCVS-and-AAVSO(VSX) definition possible, beat effects, capable even of giving the impression of irregular pulsation, may be expected. The ACYG pulsators are notably hotter (bluer) than the IS and near-IS variables (a broad family represented in Sample S by the DCEP, DCEPS, DSCT, DSCTC, GDOR, and roAP pulsators; the IS and near-IS pulsators are in turn notably hotter (yellowish, less red) than the LB pulsators, the LC pulsators, the M pulsators, and the various SR-grouped pulsators).

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* β Ori
-* ε Ori
-* κ Ori
-* o^2 CMa
-* η CMa
-* α Cyg

(3) As a next step in this examination of the AAVSO(VSX) pulsational sub-subclasses, we take the fairly hot pulsators groups that are "DCEP"(these must be discussed at length, in view of their special role in establishing the intergalactic distance scale),"DCEPS," "DSCT," "DSCTC," "GDOR," and "roAp" (the "roAp" stars, too, must be discussed at length, in view of their special utility in modelling).

- The **DCEP** sub-subclass of the pulsating-variability subclass of the intrinsic-variability class consists of the "classical Cepheids," a sub-subclass with prototype δ Cep. These are yellow Population I (young, comparatively metals-rich) stars, in MK phenomenology bright giants and supergiants, in other words evolved Population I (evolved metals-rich) stars that have made a blueward excursion, temporarily residing on the IS. Multiple excursions toward the blue and returns toward the red are possible, with the consequence that a Cepheid may be making its first, but may also be (as temporarily yellowish) making even its fifth, crossing of the IS. The most common observed case is the case of a second crossing, where evolution is relatively slow. The pulsational character of the δ Cep prototype has been known since 1894 (Belopolsky), and the fact that δ Cep is a radial pulsator since 1914 (Shapley). The post-1912 efforts to establish the distance of nearby galaxies through a period-luminosity law (Leavitt, communicated by Pickering) were compromised by a failure to distinguish classical Cepheids from a less luminous Population II class of pulsators, with prototype W Vir. (The members of the latter class are not only intrinsically less luminous than the classical Cepheids, but also all happen to lie far from Earth: W Vir itself has an apparent V-magnitude range of 9.46 through 10.75, making it far fainter than the Sample S cutoff.) The failure caused distances of galaxies, very notably M31, to be underestimated by a factor of two. Baade rectified the situation, thereby helping to establish the correct distance scale for extragalactic astronomy, from his 1944 publishing onward. With the classical Cepheids duly segregated from the misleading W Vir stars, the determination of galactic distances, from observations of extragalactic Cepheids, still requires that some (nearby) classical Cepheids have their distances accurately determined. Until the launch of HST, with its fine-guidance sensor, Cepheids lay beyond the reach of the most reliable (because the most theory-neutral) method of distance determination, the purely astrometric measurement of parallax. From the 1950s until HST, Cepheid distances were determined in several rather indirect ways. In particular, some distances were determined from those Cepheids that could safely be assumed to be (not just coincident on the celestial sphere with, but actually resident in) those Population I assemblages that are the open clusters: open-cluster distances can be obtained from the intrinsic luminosities of cluster members, as deduced through spectroscopic "Main-Sequence fitting." Again, some distances were determined from those Cepheids that could be established to have not merely optical, but actual binary companions, of spectroscopically ascertainable luminosities and readily known apparent magnitudes. The prospects for more direct classical-Cepheid distance determination have improved in recent years with HST, and additionally with the parallax-dedicated *HIPPARCOS* and *Gaia* missions. We touch on recent distance determinations again in our table, in our "Remarks" for δ Cep. Distances aside, a topic of interest in Cepheids, and amenable to CCD investigation under a low financial budget, is the monitoring of period changes. Precise though the classical Cepheids are in their pulsation, tiny changes (perhaps on the order of a mere second in a hundred cycles) do occur. In the case of changes with a consistently increasing or consistently decreasing trend, the process becomes progressively more evident in the "O–C" ("observed minus calculated") diagram, as the number of cycles plotted becomes progressively greater. Impossible though it may seem for the low-budget observer, working over just a few months or years, actually to observe stellar evolution, it is actually evolution that is postulated as a cause of those special-case Cepheid period changes that are found to have a single progressive trend.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* β Dor
-* l (letter ell) Car
-* η Aql
-* δ Cep

Another Cepheid, at maximum light shining just below the Sample S visibility threshold, is ζ Gem (V-band range 3.62–4.18; the formally announced discovery of variability was made rather early, in 1844; further, www.aavso.org/vsots_zetagem suggests that since the historical Arabic name "Mekbuda" means "pulled-in paw," pre-modern Arab astronomers may have already noticed the variability).

- In GCVS-and-AAVSO(VSX) notation, the **DCEPS** symbol ("S" for "symmetrical"?) is used for cases like the DCEP prototype δ Cep except in presenting low-amplitude brightness variations and symmetric light curves. For variability to count as DCEP-type, it is required to resemble the prototype δ Cep: on this writer's interpretation of that classification rule, resemblance to the δ Cep DCEP prototype makes both a large amplitude and an asymmetric (rapid brightening, slow dimming) light curve mandatory. The present writer believes, subject to possible eventual correction, that the intention of both GCVS and AAVSO(VSX) is not to make the DCEPS a subclass of the DCEP class, but rather to make the two classes disjoint: if the light curve is of low amplitude and symmetrical, then the star is on this interpretation of the rules to be classified as DCEPS-and-not-DCEP. If the interpretation is correct, then the DECPS variables are a sub-subclass of the pulsating-variability subclass of the intrinsic-variability class, logically coordinate with, and disjoint from, that sub-subclass that is the DCEP variables (in the same sense in which, e.g. in geomorphology the mountains and the plateaux are logically coordinate, disjoint, groupings).

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by α UMi.

- The “DSCT” sub-subclass of the pulsating-variability subclass of the intrinsic-variability class consists of the “δ Sct variables,” i.e. stars that reside on the IS, and additionally are in MK phenomenology residing on the MS. As members of the IS, part of their “real essence” is that they share in the helium-ionization pulsation-driving mechanism (that particular form of the “kappa mechanism” that is governed by the transition from singly ionized helium to doubly ionized helium) of the DCEP and DCEPS stars. Pulsation periods are found to be short, from 0.01 to 0.2 days.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* ρ Pup
-* ζ Vir
-* α Oph (a system considered at AAVSO(VSX) to also harbour γ Dor-type pulsational variability, yielding the composite VSX symbol “DSCT+GDOR”)
-* ξ Ser (a system considered at AAVSO(VSX) to harbour possible, not confirmed, variability, and accordingly *(a)* flagged as a mere suspected variable in the VSX interface (with the red “S,” not the green “V”), and *(b)* in terms of classification symbols given the uncertainty-marked “DSCT:” for “possible DSCT variability”)
-* α Aql
-* α Cep
-* δ Cap (a system considered at AAVSO(VSX) to also harbour EA-type (eclipsing) variability and γ Dor-type pulsational variability, yielding the composite VSX symbol “EA+GDOR+DSCT”; for the “GDOR+DSCT” part of this composite, cf. the taxonomic-overlap discussion in 2010ApJ...713L.192G, examined in detail later in this sub-subsection, in the treatment of the “GDOR” sub-subclass)

- AAVSO(VSX) departs from GCVS in holding the **DSCTC** class (defined by GCVS as having low amplitude, in contrast with the δ Sct DSCT prototype) to lack physical relevance. The reasoning at AAVSO is that MK-phenomenology MS pulsators on the IS are very typically of low amplitude, and that the only statistically helpful distinction is between *(a)* the moderate- and low-amplitude MS IS pulsators and *(b)* the MS IS pulsators presenting exceptionally high amplitudes, greater than 0.15 in V, labelled in AAVSO(VSX)-and-not-GCVS terms as “HADS.” Sample S lacks HADS stars. The usefulness of segregating even the high-amplitude δ Sct pulsators is questioned in 2007uvs..book.....P (in Section 6.12, on p. 184), which suggests that the underlying determinant (we would here say, the relevant “real essence” feature) of pulsation amplitude is rotation, with the more rapid rotators pulsating more gently.

Its dissent from GCVS notwithstanding, AAVSO(VSX) does apply the deprecated symbol “DSCTC” to the following cases from Sample S, presumably for historical reasons:
-* β Cas
-* θ Tau (a system that is considered at AAVSO(VSX) to also harbour possible-and-yet-not-certain eclipsing variability of some as yet undetermined eclipsing type, yielding the composite VSX symbol “DSCTC+E:”)
-* β Leo
-* γ Boo (a system considered at AAVSO(VSX) to be a confirmed variable, but only a suspected δ Sct variable, classifiable as DSCTC; this yields the VSX symbol, with a colon flagging a mere possibility, “DSCTC:”)
-* γ UMi
-* α Lyr (unfortunately used as a photometric standard from the pioneering 1850s visual work of von Seidel onward, and assessed at AAVSO(VSX) as variable in the V passband over the range –0.02 through –0.07; 2007ASPC..364..305G discusses the unfortunate character of this historical error)

- The **GDOR** (“γ Dor”) sub-subclass of the pulsating-variability subclass of the intrinsic-variability class consists (in the characterization at AAVSO(VSX), which is a little tighter than the characterization at GCVS), of “high order g-mode non-radial pulsators, dwarfs (luminosity classes IV and V) from spectral types A7 to F7 showing one or multiple frequencies of variability.” In gross observational terms, periods are longer than for the δ Sct variables, extending from 0.25 days to 4 days. Fig. 6.20 (p. 185) of

2007uvs..book.....P shows the GDOR group as adjacent to, and slightly cooler than, the IS. The characterizations of AAVSO(VSX), GCVS, and 2007uvs..book.....P notwithstanding, however, the key point regarding GDOR variability is that it is due not to the kappa mechanism as in the case of DCEPS variability, but to envelope convection-driven excitations. This leaves open the possibility that one and the same star should, in a display of co-morbidity, be both a δ Sct variable (in its various short-period modes of pulsation) and a GDDOR variable (in its various longer-period modes of pulsation). 2007uvs..book.....P remarks (in sub-subsection 6.12.2, on p. 187) that at least one star realizes this possibility. 2010ApJ...713L.192G takes this theme of category overlap further, drawing on recent NASA *Kepler Mission* photometry, and making a fresh taxonomic proposal: "analysis of /.../data for hundreds of variable stars shows that the frequency spectra are so rich that there are practically no pure δ Sct or γ Dor pulsators, in *Wikipedia* essentially all the stars show frequencies in both the δ Sct and the γ Dor frequency range. A new observational classification scheme is proposed that takes into account the amplitude as well as the frequency and is applied to categorize 234 stars as δ Sct, γ Dor, δ Sct/γ Dor or γ Dor/δ Sct hybrids."

Within Sample S, the GDOR category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* α Oph (a system that is considered at AAVSO(VSX) to harbour also δ Sct-type pulsational variability (cf. the remark on δ Cap, immediately above), yielding the compound VSX symbol "DSCT+GDOR")
-* δ Aql (a system considered at AAVSO(VSX) to be a confirmed variable, but to feature possible-and-yet-not-confirmed GDOR variability; VSX accordingly assigns not the symbol "GDOR," but the symbol "GDOR:")
-* δ Cap (a system that is also considered at AAVSO(VSX) to harbour EA-type eclipsing variability and δ Sct-type pulsational variability (is the latter fact perhaps a consequence of the taxonomic overlap (the co-morbidity) discussed in the just-cited 2010ApJ...713L.192G?), yielding the compound VSX symbol "EA+GDOR+DSCT")

- The **roAp**, or rapidly oscillating stars that are in MK temperature-sequence OBAFGKM terms peculiar A, were noted in the 1970s as a distinctive species of pulsator by Donald Kurtz. The symbol "roAp," used by AAVSO(VSX) for a sub-subclass of the pulsating-variability subclass of the intrinsic-variability class, is, however, absent from GCVS,
- instead has a symbol "ACVO." This is further explained at cdsarc.u-strasbg.fr/ftp/cats/B/gcvs/vartype.txt: GCVS chooses to emphasize not the pulsational, but instead the rotational, aspect of the grouping, in its choice stressing the similarities between the peculiar-A rapid pulsators and the α CVn A ("α^2 CVn") inhomogeneous-photosphere rotators. As pulsators, the roAp stars reside within the δ Sct portion of the IS, as an enclave of stars that are not δ Sct-like, even while lying entirely in δ Sct territory (in the same topological sense as infants born in the sovereign micro-nation of San Marino constitute an enclave, lying entirely within Italian territory, of persons-who-are-not-Italian-citizens). The AAVSO(VSX) definition is as follows: "Rapidly oscillating Ap variables. These are pulsating variables oscillating in high-overtone [i.e. with many interior nodal surfaces-of-constant-radius], low-degree [i.e. with only a low number of photospheric longitude-circle and latitude-circle nodal lines] non-radial pressure modes. Pulsation periods are in the range of 0.003–0.015 days (4–21 min.), while amplitudes of light variation caused by the pulsation are about 0.01 mag. in V. The pulsational variations are superposed on those caused by rotation." To this definition it might be added, in the spirit of an "underlying real-essence" clarification, that the roAp stars are magnetic, in a sense that differs from the Sun and instead resembles Earth: the magnetism is dominated by a dipole field, whose poles do not in general coincide with the poles of rotation. It is the magnetic poles, not the rotational poles, that define the latitudinal and longitudinal nodal lines of the roAp stars. This unusual geometry presents a unique observational opportunity, in that as the star rotates, different portions of the overall latitude-longitude pulsational grid swing into the view of the observatory. (In the more usual case of a rotating not-globally-magnetic star, not significantly perturbed by any system companion, the poles in the latitude-longitude pulsational grid never change their orientation with respect to the observatory.) The position of the roAp stars within the IS notwithstanding, attempts to explain the pulsations in terms of the singly-ionized-helium kappa mechanism fail. Pulsation is believed to be

governed by the dipole magnetic field, which at the magnetic poles inhibits convection. A further observationally convenient circumstance is that spectroscopy reveals the pulsation to involve some atomic species, yet not all. In particular, radial-velocity variations, as the spectroscopic signature of pulsation, are absent in the case of iron. This is explained by the hypothesis that pulsation occurs only at higher levels around the star, involving only those atomic species that are subject to radiational lofting: in a duly quiet stellar atmosphere, iron suffers not lofting, but gravitational settling. Spectroscopy thus conveniently supports inferences regarding the altitude dependence of the photometrically studied pulsation. A table in en.wikipedia.org/wiki/Rapidly_oscillating_Ap_star lists roAp stars down to V-band mag. ~10.3, serving as a useful reminder that this category contains β CrB A, at V magnitude ~3.6 or ~3.7 almost bright enough to qualify for inclusion in Sample S, and additionally what is perhaps the most chemically bizarre star known, HD 101065 ("Przybylski's star," at V-mag ~8.0; even the possibility, from some process of dredge-up, of photospheric plutonium, americium, curium, berkelium, californium, and einsteinium has been asserted).

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by α Cir (a system that is also considered at AAVSO(VSX) to harbour (extrinsic) variability of the rotational type associated with α CVn A ("α^2 CVn"), yielding the compound VSX symbol "roAp+ACV").

(4) As the final step in this examination of the AAVSO(VSX) pulsational sub-subclasses, we take the cool (red) pulsators—the Miras (with symbol "M"), then the semiregular "SR" (a placeholder grouping, appropriate where detailed studies are lacking), "SRA," "SRB," "SRC," and "SRD" stars, and finally the irregular "LB" and "LC" pulsators.

- The **M** sub-subclass of the pulsating-variability subclass of the intrinsic-variability class consists of variables of the Mira (o Cet) type. It is a definitional requirement that the V-band brightness variation be at least 2.5 magnitudes. In actual photometric practice, however, much greater V-band variations can be found, even to the extent of 11 magnitudes. The infrared variation is smaller: as a Mira dims in visible light, it not only cools, but more importantly forms atmospheric titanium oxide, which absorbs visible radiation and re-radiates in infrared. It is additionally a definitional requirement that the MK luminosity class be "giant" (i.e. III), rather than "subgiant," "bright giant," or "supergiant" (or indeed, as is sometimes stated, "hypergiant"). In "real essence" terms, this evidently means that Miras are stars of a mass moderate enough to yield an eventual white dwarf, rather than a supernova. Again in "real essence" terms, the Miras are found to lie not on the RGB or in the Red Clump or the HB, but on the AGB, and indeed to be in the final million or so years of their existence as stars. A Mira is, other words, found to be only a million or so years away from evolving into a white-dwarf stellar corpse embedded in a planetary nebula. If a star is a human being, then a Mira is thus not a human in the last year or even the last month of life, but rather a human due to die in a day or two. Interferometry has established that a Mira can be far from spherically symmetric (as one might already conjecture from the observable variety in shapes of planetary nebulae, with the neat smoke-ring symmetry of planetary nebula M57 often absent). In contrast with the "irregular" LB and LC stars, periodicity is by definition discernible, even while not in practice found to be as strict as for the IS pulsators. It is in fact possible that pulsation deep within a Mira is more regular than at the observable level of the convection-perturbed photosphere. Mira pulsation has now been found to involve the fundamental mode, rather than an overtone. But on the other hand, in contrast with IS pulsators, there cannot be an expectation of constant energy generation from the stellar interior, or even of a nearly constant stellar structure from one cycle to the next: since a Mira is on the AGB, it has an inert core, with thermonuclear fusion confined to a hydrogen or helium shell, and these shells can turn on and off rapidly, in "flash" episodes. Emission is present (here the sub-subsection 6.1.5 concern arises once again: in typical observational practice? or, rather, as a matter of formal definition, ultimately stemming from underlying "real essence"?)—making the expected MK temperature types Me, Ce, and Se, rather than M, C, and S. Accompanying the emission is copious mass loss, as a precursor of planetary-nebula formation. Mass loss occurs when a shock wave (visible in spectroscopy as emission) propagating through the atmosphere causes local density to rise and dust grains to consequently condense. These grains, flung out into the ISM, carry some of the stellar gas with them. The topic of Miras is handled in a perhaps unexpectedly thorough way by *Wikipedia*, which offers not only the expected survey article en.wikipedia.org/wiki/Mira_variable, but additionally a multiple-article portal, with links to individual articles for over 60 individual Miras, en.wikipedia.org/wiki/Category:Mira_variables.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022 or 2023) by the following:
-* ο Cet
-* χ Cyg

- The **SR** symbol is to be thought of as a placeholder, appropriate where a cool pulsator is not yet well studied, being known simply to fit one of the five canonical pulsational sub-subclasses denoted by "SRA," "SRB', "SRC," "SRD," and "SRS." ("SRS," the group of red-giant semiregular rapid pulsators, however, happens not to be represented in Sample S.) The bare "SR" thus plays the same role in pulsational-variability taxonomy as the bare "EA" (and still more austerely, the bare "E") does in eclipsing-variability taxonomy: the SR grouping is a so-to-speak genus embracing various (in Sample S, four, and yet in full generality five) so-to-speak species. It is not the genus, but the species, that are the canonical sub-subclasses of the pulsational subclass of the intrinsic-variabilities class. The genus consists of all the semiregular significantly evolved moderately cool or very cool pulsators, whether giants or supergiants. Although many of the SR class variables have a rather modest V-band variation, strong variation is possible also, as instanced by VX Sgr (in the SR "genus," in the SRC "species," with exceedingly strong variation in V between mag. 6.52 and mag. 12.4; the mag. 6.52 peak makes VX Sgr a bit too faint for inclusion in Sample S) and strongly-but-not-exceedingly-strongly variable μ Cep (again, in the SR "genus," in the SRC "species," with variation in V between mag. 3.43 and mag. 5.1: this means that μ Cep qualifies, although just barely, for inclusion in Sample S). *Wikipedia* has a convenient tabulation of what is here being called the "genus," with its five "species," and with some useful history, at en.wikipedia.org/wiki/Semiregular_variable_star. The article notably remarks that SRA, SRB, SRC, and SRD were formalized long ago, in 1958, at the tenth IAU General Assembly, with the fifth so-to-speak species (in AAVSO(VSX) terms, duly canonical pulsational sub-subclass) SRS, by contrast, a recent addition.

Within Sample S, this placeholder category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* μ Gem
-* N Vel
-* γ Cru
-* δ Vir
-* α Ser (a system considered at AAVSO(VSX) to harbour possible, not confirmed, variability, and accordingly *(a)* flagged as a mere suspected variable in the VSX interface (with the red "S," not the green "V"), and *(b)* in terms of classification symbols given the uncertainty-marked "SR:" for "possible SR variability")
-* β Peg

- The **SRA** sub-subclass of the pulsating-variability subclass of the intrinsic-variability class consists of the slow pulsators that are very cool giants (in the sense of falling into MK types M, C, S, Me, Ce, or Se) displaying "persistent periodicity." Both GCVS and VSX remark that "many of these stars differ from Miras only by showing smaller light amplitudes." However, to the present writer the remark is puzzling: all the various SR species are by definition semi-regular, and yet Mira for its part is better than merely semi-regular (even while not presenting the clock-like regularity of the IS stars). Perhaps in future editions of this Handbook supplement it will be possible to revisit the problem, resolving the puzzlement. Additionally, it is advisable to keep in view the admonition of 2007uvs..book.....P (in section 6.16.1, on page 205) that "the distinction between Miras and semi-regulars (an amplitude of 2.5 magnitudes) is rather arbitrary; there is a smooth gradation of properties between them, and there are stars whose amplitudes [since maxima are not the same from cycle to cycle] may vary from more than 2.5 magnitudes to less."

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by η Gem (a system considered at AAVSO(VSX) to harbour not only SRA-type pulsational variability, but also EA/GS-type eclipsing variability: VSX accordingly assigns a symbol compounded from the pair of symbols "EA/GS" and "SRA," namely "EA/GS+SRA").

- The **SRB** sub-subclass of the pulsating-variability subclass of the intrinsic-variability class consists of the slow SR pulsators that are very cool MK-phenomenology giants (in the sense of falling into MK red types M, C, S, Me, Ce, or Se) displaying "poorly defined periodicity," in other words pulsators like the SRA stars, except still less regular.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* ρ Per
-* γ Hyi
-* L_2 Pup
-* σ Lib
-* α Her
-* β Gru

- The **SRC** sub-subclass of the pulsating-variability subclass of the intrinsic-variability class consists of the slow SR pulsators (whether—the present writer presumes—displaying "persistent periodicity" or "poorly defined periodicity") that are very cool stars (in the sense of falling into red MK types M, C, S, Me, Ce, or Se), and also are in MK-phenomenology terms more tenuous (more sharp-lined, more "tending to hypergiant") than mere giants.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* α Ori
-* α Sco
-* μ Cep

- The **SRD** sub-subclass of the pulsating-variability subclass of the intrinsic-variability class consists of the slow SR pulsators (whether—the present writer presumes—displaying "persistent periodicity" or "poorly defined periodicity," and whether in MK-phenomenology terms giants or still-more-sharp-lined-than-giants), that are moderately cool (yellowish) stars, in the sense of falling into the MK yellow-temperatures range FGK.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* π Pup
-* ξ Pup

In both cases, the system is considered at AAVSO(VSX) to be a confirmed variable, but to feature possible-and-yet-not-confirmed SRD variability. VSX accordingly assigns in both cases not the symbol "SRD," but the symbol "SRD:".

- The **LB** group (for AAVSO(VSX), a sub-subclass of the pulsating-variability subclass of the intrinsic-variability class) is explained by GCVS and AAVSO(VSX) in the same words, with the same caveat regarding some special usage at GCVS, absent from AAVSO(VSX): "low irregular variables of late spectral types (K, M, C, S [C and S are chemically anomalous very-cool MK types, parallel to the cool (red) end of the classic-MK OBAFGKM sequence]);as a rule, they are giants. This type is also ascribed, in the GCVS, to slow red irregular variables in the case of unknown spectral types and luminosities."

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* β And
-* γ Phe (a system considered at AAVSO(VSX) to harbour not only LB-type pulsational variability, but also EB/GS-type eclipsing variability: VSX accordingly assigns a symbol compounded from the pair of symbols "EB/GS" and "LB," namely "EB/GS+LB")
-* γ And (a system considered at AAVSO(VSX) to harbour possible, not confirmed, variability, and accordingly *(a)* flagged as a mere suspected variable in the VSX interface (with the red "S," not the green "V"), and *(b)* in terms of classification symbols given the uncertainty-marked "LB:" for "possible LB variability")
-* α Ari
-* α Cet (a lone star (i.e. not in a binary) considered at AAVSO(VSX) to be a confirmed variable, but to exhibit possible-and-yet-not-confirmed LB-type pulsational variability; VSX accordingly assigns not the symbol "LB," but the symbol "LB:")
-* γ Eri (a system considered at AAVSO(VSX) to be a confirmed variable, but to harbour possible-and-yet-not-confirmed LB-type pulsational variability: VSX accordingly assigns not the symbol "LB," but the symbol "LB:")
-* α Tau (a system considered at AAVSO(VSX) to be a confirmed variable, but to harbour possible-and-yet-not-confirmed LB-type pulsational variability: VSX accordingly assigns not the symbol "LB," but the symbol "LB:")
-* σ Pup (a system considered at AAVSO(VSX) to harbour not only LB-type pulsational variability, but also extrinsic variability in the ellipsoid-star class: VSX accordingly assigns the compound symbol "ELL+LB")
-* μ UMa (a system considered at AAVSO(VSX) to harbour not only confirmed LB-type pulsational variability, but additionally possible-and-yet-not-confirmed eclipsing variability in the placeholder EB group; VSX accordingly assigns the compound symbol "EB:+LB")
-* α Boo
-* γ Dra (a system considered at AAVSO(VSX) to be a confirmed variable, but to harbour possible-and-yet-not-confirmed LB-type pulsational variability: VSX accordingly assigns not the symbol "LB," but the symbol "LB:")
-* η Sgr (a system considered at AAVSO(VSX) to be a confirmed variable, but to harbour possible-and-yet-not-confirmed LB-type pulsational variability: VSX accordingly assigns not the symbol "LB," but the symbol "LB:")

- The **LC** sub-subclass of the pulsational-variability subclass of the intrinsic-variability class is similar to the "LB" sub-subclass, except that the pulsating stars are stipulated to be in MK-phenomenology terms higher-than-mere-giant. The present writer presumes, the "as a rule" clause in the above-quoted LB characterization notwithstanding, that LB and LC are intended to be disjoint classes. Regarding both LB and LC, it is necessary to keep in view the 2007uvs..book.....P admonition (in sub-subsection 6.16.1, on page 205) that it is "rather arbitrary" to make a division between *(a)* outright irregularity and *(b)* the semi-regularity that at GCVS-and-AAVSO(VSX) demarcates the SR so-to-speak genus and its five so-to-speak species.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* ε Gem
-* σ CMa
-* λ Vel
-* q Car
-* ε Peg
-* ζ Cep

(5) We note as a postscript that AAVSO(VSX) (although not GCVS) has a placeholder, **PULS**, applied to

stars or systems that have been found in some large-scale survey to harbour pulsation, but whose pulsational character is not at present more precisely known. "PULS" thus serves the same purpose among the pulsators, at AAVSO(VSX), as is served by "E," both at GCVS and at AAVSO(VSX), among the eclipsing binaries. Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by ε Oph.

6.2.5: The AAVSO(VSX) sub-subclasses of the eruptive-variability subclass of the intrinsic-variability class:

- The **BE** symbol is used at GCVS to mark those stars that show what this Handbook supplement (subsection 5.9, above) calls the "Be phenomenon," and in that additionally there is some photometric variability, but perhaps, in practice, photometric variability is never altogether absent from the overall history of a star when a "Be phenomenon" star is found at the spectrograph to have at some point in its history gone into emission), and in which (a third GCVS definitional requirement) there is no history of an outburst with the photometric extreme of the γ Cas variables. (The "Be phenomenon," when identified in the spectroscopy of a hot MS star by one or more episodes of emission lines, is commonly found to involve also, in the decades-long photometry record, one or more episodes of photometric outburst. Common though this photometric accompaniment is, it is not invariable. It is where it is missing—where the photometric variability, so far as historical records go, is always modest, never rising to the level of an outburst—that the "BE" symbol is used at GCVS.) AAVSO(VSX) for its part marks some systems with this same symbol, while noting that the symbol is formally and officially GCVS-not-VSX, and while remarking that "most [GCVS-classified BE stars] may be LERI variables." It was remarked above that the LERI symbol is used at VSX without being used at GCVS. Perhaps AAVSO(VSX) applies the symbol "BE" for merely historical reasons, provisionally and in advance of eventual deeper study?

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* α Eri (classified as an instance of the Be phenomenon in the obspm.fr database)
-* a Car (a system considered at AAVSO(VSX) to be a confirmed variable, but to harbour possible-and-yet-not-confirmed BE-type eruptive variability; VSX accordingly assigns not the symbol "BE," but the symbol "BE:")
-* ω Car (classified as an instance of the Be phenomenon in the obspm.fr database)
-* γ UMa (a system considered at AAVSO(VSX) to harbour not only BE-type eruptive variability, but also eruptive variability of the UV Cet type; VSX accordingly assigns the compound symbol "BE+UV"; the system is classified as an instance of the Be phenomenon in the obspm.fr database)
-* ζ Oph (classified as an instance of the Be phenomenon in the obspm.fr database)

- The symbol **DPV** is used at AAVSO(VSX), but not at GCVS, for a rather specialized sub-subclass of the eruptive-variability subclass of the intrinsic-variability class, the "Double Periodic Variables," further divided in the case of some systems outside Sample S into "DPV/ELL" and "DPV/E," where "E" simply means "eclipsing." The eruptive episodes are required to have a rather specialized cause, involving binarity: DPV systems are characterized as "semi-detached interacting binaries (with a B-type component) with optically thick disks around the gainer, that experience regular cycles of mass loss into the interstellar medium and are characterized by orbital photometric variability (ellipsoidal, DPV/ELL or eclipsing, DPV/E) in time scales of few days and a long photometric cycle lasting roughly 33 times the orbital period."

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by just one system, the notoriously hard-to-model β Lyr, with its DPV status considered by AAVSO(VSX) as possible-and-yet-not-certain. In a slight variation on its usual syntax (in the usual syntax, the uncertainty-marking colon follows a classification symbol, occurring either as the final character in a (compound or simple) symbol or as the character immediately preceding the compound-symbol marker "+"), AAVSO(VSX)assigns the symbol "DPV:/EB." We in this Handbook supplement take this somewhat variant symbol to be shorthand for "definitely in the EB eclipsing-variability placeholder grouping within the eclipsing-variabilities subclass of the extrinsic-variabilities class, but also possibly-yet-not-certainly a system in the DPV sub-subclass of the eruptive-variability subclass of the intrinsic-variability class."

- The **GCAS** group (for AAVSO(VSX), a sub-subclass of the eruptive-variability subclass of the intrinsic-variability class) denotes the "γ Cas variables," in other words the stars that not only present what is in Subsection 5.9 above called the "Be phenomenon," but in addition present that prevalent-and-yet-not-universal feature of the Be phenomenon that is the strong photometric outburst. A complication arises for the prototype (as we note again in the "Remarks" column of our table below, in the γ Cas entry): the prevalence of violent outbursts notwithstanding, γ Cas unfortunately cannot itself (in view of its atypical X-ray behaviour) be considered a fully typical Be-phenomenon star.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by the following:
-* γ Cas (considered at AAVSO(VSX) to harbour not only GCAS-type eruptive variability, but also X-ray variability, and possible-yet-not-confirmed LERI (extrinsic) λ Eri rotational-type variability; VSX accordingly assigns the compound symbol "GCAS+X+LERI:"; classified as an instance of the Be phenomenon in the obspm.fr database)
-* δ Per (considered at AAVSO(VSX) to be a confirmed variable, but to harbour possible-and-yet-not-confirmed GCAS-type variability; VSX accordingly assigns not the symbol "GCAS," but the symbol "GCAS:")
-* ζ Tau (considered at AAVSO(VSX) to harbour not only GCAS-type eruptive variability, but also E/GS-type eclipsing variability: VSX accordingly assigns a symbol compounded from the pair of symbols "E/GS" and "GCAS," namely "E/GS+GCAS"; classified as an instance of the Be phenomenon in the obspm.fr database)
-* α Col (a system considered at AAVSO(VSX) to harbour possible, not confirmed, variability, and accordingly *(a)* flagged as a mere suspected variable in the VSX interface (with the red "S," not the green "V"), and *(b)* in terms of classification symbols given the uncertainty-marked "GCAS:," for "possible GCAS variability"; classified as an instance of the Be phenomenon in the obspm.fr database)
-* κ CMa (classified as an instance of the Be phenomenon in the obspm.fr database)
-* p Car (classified as an instance of the Be phenomenon in the obspm.fr database)
-* δ Cen (classified as an instance of the Be phenomenon in the obspm.fr database)
-* μ Cen (classified as an instance of the Be phenomenon in the obspm.fr database)
-* η Cen (considered at AAVSO(VSX) to harbour not only GCAS-type eruptive variability, but also (extrinsic) λ Eri rotational-type variability; VSX accordingly assigns the compound symbol "GCAS+LERI"; classified as an instance of the Be phenomenon in the obspm.fr database)
-* δ Sco (classified as an instance of the Be phenomenon in the obspm.fr database)
-* α Ara (considered at AAVSO(VSX) to harbour not only GCAS-type eruptive variability, but also (extrinsic) λ Eri rotational-type variability; VSX accordingly assigns the compound symbol "LERI+GCAS"; classified as an instance of the Be phenomenon in the obspm.fr database)

- The **UV** sub-subclass (at AAVSO(VSX)) of the eruptive-variability subclass of the intrinsic-variability class consists of the eruptive variables of the UV Cet type, characterized as "K Ve–M Ve stars sometimes displaying flare activity with amplitudes from several tenths of a magnitude up to 6 mag. in V." Both GCVS and AAVSO(VSX) remark that stars presenting BY Dra variability (symbol "BY," discussed above), as MS rotators with photospheric inhomogeneities, can also present UV variability (since such rotation can be accompanied by flaring). UV Cet is itself far too faint, even in eruption, to pass the V-band mag. ~3.55 threshold for Sample S: AAVSO(VSX), as consulted on 2022 Dec. 27, gives the V-band range 6.8–12.95. The *Wikipedia* writeup dedicated to the prototype UV Cet is, a little unexpectedly, en.wikipedia.org/wiki/Luyten_726-8. This is a consequence of the fact that UV Cet is the variable-star name given to a star originally catalogued as the "B" component in a tight binary, Luyten 726, and only subsequently discovered to be variable: "Although UV Ceti was not the first flare star discovered, it is the most prominent example of such a star, so similar flare stars are now classified as UV Ceti type variable stars. This star goes through fairly extreme changes of brightness: for instance, in 1952, its brightness increased by 75 times in only 20 seconds." Also useful for background and context is en.wikipedia.org/wiki/Flare_star (as the closest approach in *Wikipedia* to an article explicitly dedicated to UV Cet-type variability).

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by γ UMa (considered at AAVSO(VSX) to harbour not only UV-type eruptive variability, but also BE-type eruptive variability; VSX accordingly assigns the compound symbol "BE+UV"; the system is classified as an instance of the Be phenomenon in the obspm.fr database).

- The **WR** sub-subclass of the eruptive-variability subclass of the intrinsic-variability class involves photometric variability presented by a star that in spectroscopic terms is a Wolf-Rayet, and more particularly is a spectroscopic Wolf-Rayet not yet appearing as the nucleus of a planetary nebula. The photometric variability is in practice not found to be extreme: AAVSO(VSX) comments that what is encountered when photometry is directed to a star known from spectroscopy to be a Wolf-Rayet is "irregular light changes with amplitudes up to 0.1 mag. in V." AAVSO(VSX) adds that such fluctuations "are probably caused by /.../ non-stable mass outflow." While the photometric WR variability is modest, the spectroscopic Wolf-Rayet phenomenon is so dramatic as to be observable by the eye, with a mere spectroscope, in other words with a spectrally dispersive eyepiece-attachment viewing instrument lacking the capability of creating a photographic record. A Wolf-Rayet star is seen at the spectroscope to be in emission, like a Mira (or indeed like a "Be phenomenon" star in an emission episode), and to have emission bands, rather than (as with the Miras and the "Be phenomenon" stars) mere emission peaks. The underlying astrophysical status of Wolf-Rayet stars not yet in planetary nebulae is the following: masses are high, in contrast both with the Miras and with some of the planetary-nebula nuclei; thermonuclear fusion is nearing its end (as with Miras; in the case of actual planetary-nebula nuclei, on the other hand, fusion has already ended); mass loss is still more copious than in the case of Miras; the mass outflow, driven by radiation pressure, causes emission peaks to be Doppler-broadened into the observed bands.

Within Sample S, this category is represented at AAVSO(VSX) (as consulted in 2022) by γ Vel.

6.2.6: The sole Sample S AAVSO(VSX) sub-subclass of the cataclysmic-variability subclass of the intrinsic-variability class:

The recurrent novae are designated **NR**. While the overall AAVSO(VSX) scheme recognizes various sub-subclasses of the cataclysmic-variability subclass of the intrinsic-variability class, the recurrent novae are the sole such sub-subclass represented in Sample S. It may well be that all observed novae would prove recurrent if observatory records were to extend over some tens of millennia. AAVSO(VSX), however, following GCVS, applies the symbol "NR" only to those novae that the available historical record shows to be recurrent. That record is brief. Spectacular historical novae, like historical supernovae, might in principle some day turn up as archaeo-astronomers continue their inspections of pre-modern chronicles. On the other hand, a duly careful photometric record, at an accuracy of ±0.1 mag. in roughly the V band, down to around mag. 9.5, and surveying more than just 200 or 300 stars, perhaps goes no further back than the *Bonner Durchmusterung* (the observations for which began in 1852; 1999JRASC..93...17C supplies some details.)

Within Sample S, this NR category is represented at AAVSO(VSX) (as consulted in 2022) by the T CrB system (actually assigned the compound symbol "NR+ELL," since one component in this binary presents ellipsoidal-type extrinsic variability).

6.2.7: Other Sample-S-relevant aspects of the AAVSO(VSX) taxonomy:

(a) AAVSO(VSX) uses **VAR** as a placeholder for variables of unspecified type, explained as "used for suspected variables lacking deeper studies." Despite the "suspected," however, all the instances present in Sample S are flagged by VSX as confirmed variables (with the green "V" flag, not with the red suspected-variable "S"

flag; in the case of the elaborate β Cap system, with its two most prominent members separated by fully 3.5 arcminutes, lookup in VSX must be made not from "β Cap" but from some such input as "β Cap 1"). The green "V" flag for confirmed variability is assigned by AAVSO(VSX) despite the presence, for all of these systems except possibly ζ Cen and β Dra, of an entry in the suspected-variables catalogue NSV (a companion to GCVS, maintained by the same Lomonosov Moscow State University authorities as maintain GCVS).

Within Sample S, the "VAR" category is represented at AAVSO(VSX)(as consulted in 2022) by the following:
-* β Cet
-* ζ Ori
-* δ CMa
-* β Cnc
-* δ UMa
-* ζ Cen
-* β Boo
-* β Lib
-* β Dra A
-* γ Sge
-* β Cap

(b) AAVSO(VSX) uses its red flag, for suspected variability, in a comparatively small number of cases, in many or all instances from NSV, but a mere subset of the Sample S selection that would be red-flagged as "suspected variables" if NSV were taken as the final arbiter. In a few instances (already discussed in the appropriate places earlier in this photometric "Section 6"), AAVSO(VSX) is able not only to conjecture variability, but to assign a conjectured variability type (using its colon notation, as, e.g. with "GCAS:" for conjectured γ Cas-type eruptive (intrinsic) variability). We order these various cases, as usual, by increasing RA, adding a few comments where necessary:
-* δ And
-* β Phe
-* τ Cet
-* β Ari
-* γ And (with the conjectural variable-type assignment "LB:")
-* β Tri
-* α Per
-* ζ Per
-* π^3 Ori
-* ι Aur
-* ε Lep
-* β Eri
-* α Aur
-* γ Ori
-* α Lep
-* λ Ori
-* α Col (with the conjectural variable-type assignment "GCAS:"; the system is classified as an instance of the "Be phenomenon" in the obspm.fr database)
-* ζ CMa (with the conjectural variable-type assignment "BCEP:")
-* β Gem (with the conjectural variable-type assignment "VAR:"; why is this assignment made, given that β Gem already is red-flagged in VSX as a mere suspected variable?)
-* ε Car (with the conjectural (and placeholder) variable type assignment "E:")
-* o UMa
-* ι Uma (a suspected variable assigned, at any rate as of 2022 Dec. 29, the symbol "S" by VSX, for "unstudied variable stars with rapid light changes": did VSX perhaps instead mean to write the colon-qualified symbol "S:"?)

-* ι Car
-* α Lyn
-* α Hya
-* θ UMa
-* ε Leo
-* η Leo
-* α Leo
-* ζ Leo
-* γ Leo
-* β UMa
-* δ Leo
-* θ Leo
-* ν UMa
-* ξ Hya
-* ε Crv
-* γ Crv
-* δ Crv
-* β Crv
-* ε Vir
-* γ Hya
-* η Boo
-* β UMi
-* α Lib
-* δ Boo
-* ι Dra
-* η Lup (AAVSO(VSX) assigns to the η Lup system the symbol "CST:," is perhaps the meaning here that constant light is more likely than the competing possibility of variability?)
-* β Sco
-* δ Oph
-* η Dra
-* β Her
-* ζ Her
-* η Her
-* ε Sco
-* η Sco
-* π Her
-* ξ Ser (with the conjectural variable-type assignment "DSCT:")
-* θ Sco
-* β Oph
-* ν Oph
-* δ Sgr (with the conjectural variable-type assignment "VAR:"; why is this assignment made, given that δ Sgr already is red-flagged as a mere suspected variable?)
-* η Ser
-* γ Lyr
-* ζ Aql
-* π Sgr
-* β Cyg
-* γ Aql (with the conjectural variable-type assignment "VAR:"; why is this assignment made, given that γ Aql already is red-flagged as a mere suspected variable?)
-* γ Cyg
-* α Pav
-* α Gru
-* θ Peg

-* η Peg
-* δ Aqr
-* α PsA
-* ε Gru
-* γ Cep

(c) AAVSO(VSX), unlike GCVS, has a special grouping for stars known to be non-variable in the V passband within some reasonable timeframe, and beyond at any rate the tiny level of around 1 millimag. in this same passband. In the VSX interface, these are the stars with the grey "N" flag (as distinct from the green "V" flag, for known variables, and the red "S" flag, for suspected variables). Within this grouping, some, but not all, stars are marked with the symbol "CST" ("constant"), for reasons not clear to this writer. Sample S is represented in the special classification as follows:

-* β Hyi (with symbol "CST")
-* η Cas (with symbol "CST")
-* θ Eri
-* δ Eri (with symbol "CST")
-* α CMa (with symbol "CST")
-* ξ Gem (with symbol "CST")
-* α CMi (with symbol "CST")
-* α UMa (with symbol "CST")
-* γ Vir (with symbol "CST")
-* ζ UMa
-* γ TrA
-* κ Oph (with symbol "CST")
-* δ Her
-* γ^2 Sgr
-* δ Cyg (with symbol "CST")
-* θ Aql (with symbol "CST")

(d) A small minority of the items in Sample S are not mentioned in AAVSO(VSX) at all, whether as known variables, as suspected variables, or as known non-variables. They are listed here (following our usual practice) in order of increasing RA:

-* α Phe
-* η Cet
-* α Hyi
-* γ Cet
-* α Ret
-* ε Tau
-* β Tau
-* β Lep
-* ζ Lep
-* β Col
-* α Car
-* γ Gem
-* α Pic
-* τ Pup
-* ε CMa
-* δ Gem
-* α Gem
-* ζ Hya
-* β Car
-* κ Vel
-* ο Leo

-* υ Car
-* φ Vel
-* λ UMa
-* μ Vel
-* ν Hya
-* ψ UMa
-* λ Cen
-* α Cru
-* β Mus
-* ι Cen
-* π Hya
-* θ Cen
-* α Cen
-* ε Boo
-* β Lup
-* ζ Lup
-* μ Ser
-* β TrA
-* τ Sco
-* α TrA
-* ζ Ara
-* ζ Dra
-* η Oph
-* β Ara
-* γ Ara
-* υ Sco
-* μ Her
-* ι^1 Sco
-* G Sco
-* ε Sgr
-* α Tel
-* λ Sgr
-* φ Sgr
-* σ Sgr
-* ξ^2 Sgr
-* ζ Sgr
-* λ Aql
-* τ Sgr
-* δ Dra
-* α Ind
-* η Cep
-* β Pav
-* ε Cyg
-* ζ Cyg
-* β Aqr
-* γ Gru
-* α Aqr
-* α Tuc
-* ι Cep
-* μ Peg
-* α Peg

6.3: Particulars regarding photometry-relevant portions of the table "Remarks" column

(1) The treatment of individual stars in "Remarks," in the table below, is best read in parallel with sub-subsections 6.2.2 through 6.2.7 above, as follows: note the particular AAVSO(VSX) symbol (for instance, "ACV" or "DCEP" or "E/GS" or "ELL," or indeed some compound symbol such as "ELL+BCEP" or "EA/GS+GCAS") assigned in VSX to the case of interest; then examine not only *(i)* whatever "Remarks" may be able to say about the photometric features of the given case (for instance, if coded as a "DCEP" star, its particular pulsational period, and additionally whatever information we may have been able to communicate regarding known long-term period changes), but also *(ii)* sub-sections 6.2.2 through 6.2.7, for the detailed discussion of that particular symbol (where there is also a full inventory of the Sample S stars to which that particular symbol is assigned in VSX; it can be helpful to note what other brightest-stars cases parallel the given case, or alternatively to note that the given case is unique in Sample S).

As an illustration of the recommended procedure, we take η Gem.

This is a hierarchical system, at present only partly resolved, and named "η Gem A" and "η Gem B" in the authority, WDS, which is normative for the leftmost ("Star Name") column in the brightest-stars table. Since η Gem A is for its part an as-yet-unresolved spectral binary, WDS writes "η Gem A" and "η Gem B" but is not as yet able to write "η Gem Aa," "η Gem Ab," and "η Gem B." Since most of the light from the hierarchical system is from the unresolved binary η Gem A, this Handbook supplement is constrained, following WDS, to place into the "Star Name" column the entry "η Gem A." On the other hand, AAVSO(VSX) operates (as remarked in sub-subsection 6.1.2 above) in most cases with the photometry of entire systems, rather than with the photometry of system components. It is consequently necessary to use "η Gem" (not "η Gem A") as the AAVSO(VSX) lookup term, if one desires to perform a lookup rather than to rely on our own (possibly out-of-date) table-entry report of the recent AAVSO(VSX) assessment.

One performs the (perhaps-desired) lookup in AAVSO(VSX) by first invoking menu item "Search" in the interface at www.aavso.org/vsx/, then entering the seven-character string eta Gem. VSX returns much information, including not only the number of photometric observations currently available in the AAVSO database (these can be studied, if desired, from the interface at www.aavso.org/vsots_zetagem, as distinct from the interface at www.aavso.org/vsx/, starting from the "Pick a Star" field), but also some AAVSO(VSX) variability classification symbol. In the particular case of η Gem, the symbol is compound, "EA/GS+SRA" (as is rather unsurprising, for a three-star hierarchical system). The "EA/GS" portion indicates variability from an eclipsing pair with an Algol-like light curve, in which bottoms and tops are nearly flat, and in which the dimmings can be assigned precise starting and ending times. The "SRA" portion, on the other hand, indicates semi-regular pulsation from a star from the giant-yet-but-not-supergiant part of the MK-phenomenology luminosity-classes "V, IV, III, II, I" sequence, and at the cool end of the MK-phenomenology "OBAFGKM" temperature-types sequence.

Examining *(i)* what it has at this stage in the development of the bright-stars supplement been found possible to write, regarding photometry, in the η Gem "Remarks," one additionally *(ii)* obtains context by looking up "EA/GS" in sub-subsection 6.2.2 and "SRA" in sub-subsection 6.2.4 (examining not only the general descriptions of the EA/GS and SRA sub-subclasses, but also the sub-subsection 6.2.2 list of Sample S stars that resemble η Gem in being assigned the AAVSO(VSX) symbol "EA/GS," and the 6.2.4 list of Sample S stars that resemble η Gem in being assigned the AAVSO(VSX) symbol "SRA": Sample S is found to contain several "EA/GS" cases, but no "SRA" case other than η Gem itself).

(2) We have attempted with our own special coding (as we soon explain) to give some indication, in "Remarks," of Sample S objects for which further research—in principle of any kind, but in current practice in this Handbook supplement particularly in photometry—may be appropriate, even under a low budget of money and person-hours. With the coding we have in view less *(a)* the amateur equipped with binoculars or a Dobsonian, able to invest no more than ~2000 USD (or CAD, or EUR), or at the other extreme *(b)* the internationally prominent professional observatory, with a capital investment far into the millions, than *(c)* the amateur or institution (for instance, the small college) able to make an initial five-figure outlay. This capital investment is to be envisaged as procuring telescope, mounting, wind shelter (rolling-roof shed? small fibreglass dome?) and off-the-shelf mass-market astronomical CCD. In the target constituency "(c)," we envisage an individual or club or small institution—for instance, in the USA a four-year privately endowed college, with small endowment—additionally able to invest a few hundred person-hours for mastering some kind of relevant image-processing software suite, to turn FITS-format files from the astronomical CCD into publishable data. One such suite is the

IRAF freeware (for decades dominant in North America, even within the more formidable constituency "(b)").

To signal what should be signalled, in an unobtrusive way, with a particular view to the needs of the specially targeted "(c)" constituency, we accordingly incorporate in "Remarks" the text-searchable word "advisable" (remarking that for such-and-such a sparsely monitored star, such-and-such further observations, of such-and-such a character might be "advisable"). In the "Remarks," we try not to use this operationally relevant word "advisable" for any other purpose.

Our signalling of research-advisability, both at present and in foreseeable future versions of "Remarks" in future years, downplays those traditionally higher-budget, constituency "(b)," branches of observation that are precision astrometry, interferometry, and precision spectroscopy, concentrating instead (we reiterate) on that potential constituency "(c)" strength that is CCD photometry.

6.4: Further photometry reading

In the present stage of developing this Handbook supplement, we do not feel able to prepare even a list of the half-dozen most important amateur-appropriate photometry resources published since the year 2000. We do, however, make several miscellaneous, in part randomly ordered, bibliographic remarks, to supplement the occasional detailed bibliographic remarks appearing in earlier "Section 6" subsections.

- As the second edition of Hearnshaw's *Analysis of Starlight* (2014anst.book.....H, mentioned in Subsection 5.1 above) is an authoritative history of spectroscopy, so in a parallel way is Hearnshaw's *Measurement of Starlight* (1996mest.book.....H, 2005mest.book.....H) an authoritative history of photometry.
- A small, yet notable, supplement to Hearnshaw is 1949MNSSA...8...95C—a public-outreach lecture by one of the leading 20th-century photometrists, indicating the state of observatory technique as the photographic plate was just beginning to give way to that single-pixel precursor of the CCD that was the photomultiplier tube.
- The already much-cited Percy book 2007uvs..book.....P, will be found suitable for readers at all levels, from the binoculars-equipped observer up to and beyond the professional enrolled in a Ph.D. program.
- The David Levy amateur handbook, originally published in 1989 under the title *Observing Variable Stars: A Guide for the Beginner*, went into a second edition perhaps variously dated to 2003 or 2005, under the new title *David Levy's Guide to Variable Stars* (2005dlgv.book.....L). David Levy's most significant upgrade is the addition of material on CCD methods.
- Helpful reading on the IS includes not only en.wikipedia.org/wiki/Instability_strip and (from a slightly more general perspective) en.wikipedia.org/wiki/Kappa%E2%80%93mechanism, but also (with terse, user-friendly insertions of relevant physics; this is part of an online course offering) astronomy.swin.edu.au/sao/downloads/HET611-M17A01.pdf.
- AAVSO advertises online photometry courses (of which, however, the present writer does not have personal experience) at www.aavso.org/courses.
- The troublesome topic of overtones, "orders," and "degrees," in the "*n, l, m*" numerical classification of pulsating-star modes (sub-subsection 6.2.4 above) is discussed in user-friendly terms at 2006ASPC..349..101K. Particularly useful is the set of examples in Figure 4, illustrating various possibilities for the subcase-rich case $l = 3$. As a preliminary to overtones, orders, and degrees in the 3-dimensional case of a spherical oscillator, it is useful to examine discussions of 2-dimensional cases, as with drumskins, Chladni plates, and bells, including www.youtube.com/watch?v=lRFysSAxWxI and blogs.sw.siemens.com/simcenter/sound-and-vibration-of-carillon-bells.

SECTION 7: Supplementary user guide, concerning the treatment of interferometry in our "Remarks" column

7.1 Preliminary remarks concerning stellar interferometry

7.1.1 The utility of high-resolution observations in stellar astrophysics:

(A.A) The imaging of stellar photospheres opens up lines of investigation closed to the traditional techniques of spectroscopy and photometry. With imaging available, it becomes possible to study the gross, large-scale, convection cells in evolved stars, and with them the related topic of mass loss in evolved stars. In particular, it might prove possible, or perhaps is already now proving possible, to tie particular large-scale photosphere inhomogeneities, notably gross convection cells, to particular features of observed circumstellar ejecta. Further, developments either now at the leading edge of stellar observation or coming in the later 2020s and the 2030s will make it increasingly feasible to image even (gross) features in the photospheres of MS (i.e. of unevolved) stars.

(A.B) With photosphere imaging comes the ability to study pulsation directly, or a little more generally to construct velocity-field photosphere maps.

High-resolution observing has also less obvious advantages for stellar astrophysics, even in the absence of outright imaging.

(B.A) Astrometry for tight binaries broadens the field of mass determination beyond what has traditionally proven possible for binaries at gross separations, in other words at the traditionally tractable separations of ≥ ~500 milliarcseconds (henceforth, mas).

Further *(B.B)* astrometry of tight binaries is indispensable in seeking a precision answer to a statistical question. It is known that the incidence of binarity is distinctively high for the MS massive (spectrally, for the O V and B V) stars, in comparison with the MS less massive stars. What, then, is the incidence of binarity in this high-mass population?

(C.A) For rapidly rotating stars, high-resolution observing makes it possible to examine rotational flattening and spin-axis orientation, even where an outright imaging capability is either absent or imperfectly developed. This information can be usefully combined with an accurate distance (optimally, at present, a *Gaia* distance) and a spectroscopic analysis of line broadening (as one portion of a star—an entire hemisphere, in the specially favourable case in which the spin axis lies in the plane of the sky—is blue-shifted, because approaching the spectrograph, and another portion red-shifted, because receding). From these three pieces of information, the speed through three-dimensional space, in the ordinary laboratory units of m/s, can be found for each of the visible points in the photosphere. The measured rotational flattening then yields a determination of the strength of the gravitational field at the various photosphere latitudes, and so yields a mass determination. If the target star happens also to be in a binary system, the usual binary-system mass determination, as described in Section 4.1.4 above (whether as traditionally performed, with low-resolution visual tools, or as performed with high-resolution equipment, under the present heading "*(B.A)*"), supplies a check on the three-part observational method. However, the three-part method also supplies a measurement traditionally thought impossible, a direct mass determination even for a star not in a binary system.

(C.B) Related to this application of rotational flattening and spin-axis orientation investigations is the successful use of high-resolution observing in determining group ages. In particular, the UMa "moving group," including hot (spectrally A) stars not gravitationally bound, but nevertheless condensed at the same time from the same molecular cloud, is reported in 2015ApJ...813...58J to have had its age determined as 414 My, to the strikingly small uncertainty ±6%. The study proceeded by determining the rotational flattening and spin-axis orientations of several stars in the group, enabling their masses to be in turn deduced. With the masses found, it was possible to assign an age to the group as a whole, upon exploiting the further facts that stars in the group are coeval, and that (in contrast with cooler stars), spectral-A stars suffer rapid decreases in mass even before evolving off the MS.

(D.A) Measurements of photosphere angular diameters (a high-resolution achievement easier than the outright imaging of photospheres, and indeed available in an adequately refined form as early as 1920) yield a quite direct determination of photosphere effective temperatures. This determination proceeds by converting the measured angular diameter into a physical diameter on the strength of a precision distance determination, as from *Gaia*, and then adding a further admittedly difficult measurement, a tally of the total power radiated by the star across the

entire electromagnetic spectrum. High-resolution observing is said in 1997IAUS..189..147B to make a useful contribution to the assigning of effective temperatures once the uncertainty in angular diameter is pushed down to values less than ±~2%. Angular-diameter information under "Remarks" for individual stars in the detailed table at the end of the present RASC Handbook article shows that this condition is typically, although not invariably, met where angular-diameter measurements are available at all—as they indeed are for something like half our RASC Handbook set of 324 nocturnal "Brightest Stars." The PASTEL catalogue of stellar atmosphere parameters (cf 2016A&A...591A.118S), as updated to 2020 March 11, gives direct effective-temperature determinations for at least ~150 stars. Direct effective-temperature determinations are in turn useful for testing, as in 2019ApJ...873...91G, the accuracy of a stellar-atmosphere computer model, when the model is used either *(a)* with the observed continuum spectrum or *(b)* with the observed line spectrum, to deliver a prediction of effective temperature.

Further, *(D.B)* it has been found possible (2011A&A...535A..59B) to determine the depths of some K-giant chromospheres, by comparing chromosphere angular diameter (at wavelengths for which the chromosphere is prominent) with photosphere diameter. 2011A&A...535A..59B even presents preliminary evidence of chromosphere inhomogeneity, in the particular case of one of our 324 nocturnal RASC Handbook "Brightest Stars," β Cet (Diphda). Where outright imaging has not been achieved, the high-resolution technique of interferometry can nevertheless distinguish between a symmetric extended source, such as a slowly rotating (non-flattened) chromospherically inactive star, and a nonsymmetric extended source, such as a slowly rotating (non-flattened) chromospherically active star, featuring outflows at its limb (thereby yielding for nocturnal stars an indication of prominences, as with the Sun's own prominences when seen in the small daytime telescope through an Hα filter).

7.1.2: Interferometry as the most powerful of the available techniques for high-resolution astronomy:

That familiar sight in the small telescope, Jupiter, varies significantly in its angular diameter, ranging (in two significant figures) from 30″ to 50″. The familiar telescopic sight furnishes an illustration of the challenges facing high-resolution stellar astronomy:

- The highly evolved, and therefore bloated, stars α Ori Aa (Betelgeuse), o Cet Aa (Mira), and α Sco A (Antares) all have angular diameters on the order of 40 mas, in other words have angular diameters on the order of a milli-Jupiter.
- Among the MS stars, the situation is still more difficult: large, hot α Lyr A (Vega) and Sun-sized, super-close τ Cet A have respective angular diameters (to one significant figure) of just 3 mas and 2 mas.

Section 5.9 discussed the difficulties facing attempts to image "Be phenomenon" circumstellar disks. Section 5.9 considered a circular tea tray, 50 cm in diameter, corresponding to the ~50″ angular diameter of Jupiter at opposition. On this scale, with 1 cm on the tea tray corresponding to 1″, the just-mentioned three evolved stars have angular diameters corresponding on the tea tray to just 0.4 mm, i.e. to just 400 microns (henceforth, μm). The less bloated α Lyr A (Vega) and τ Cet A for their part correspond to just 30 μm and 20 μm on the tray, in other words to a bit less than the 50 μm width of a rather silky-fine human hair.

In seeking tight resolution, ordinary terrestrial optical telescopes face the problem of atmospheric turbulence, limiting their resolution to roughly an arcsecond in a typical observing run at a rather good site, where the air flow is rather laminar. At sites where the air flow is instead significantly turbulent, the observatory must instead reckon with a typical resolution as bad as 2″, or worse. The atmosphere-turbulence problem is less acute at short radio-astronomy wavelengths, dwindling to insignificance at the longer radio-astronomy wavelengths (though for at least some of the radio regime there is the residual problem of ionospheric scintillation), and disappears altogether for optical telescopes in space. In the more favourable of these regimes (short-wavelength radio from ground, all wavelengths from space), resolution is limited not by the atmosphere, but by the wave nature of the incoming radio or optical photons. Wave propagation limits angular resolution to a diffraction limit, approximately given as $(180° / \pi) \times (1.22 \times (\lambda / D))$, where λ is the chosen wavelength of observation and D is the diameter of the radio telescope dish or optical telescope primary mirror.

For a radio dish of diameter 100 m (the diameter of Germany's Effelsberg, appropriate for galactic rather than for stellar studies), operating at 21 cm, the approximate diffraction limit $(180° / \pi) \times (1.22 \times (0.21\text{ m} / 100\text{ m}))$ is to one significant figure 9′ (60 times worse than the already hopelessly coarse 9″). This result is discouraging. Although the generous Effelsberg aperture favours tight resolution, and although the selected value of 21 cm for λ is immune from atmospheric turbulence, this choice of λ is too great to deliver the resolutions needed in stellar observing.

In space, at optical wavelengths, the situation is better: for HST, with a primary mirror 2.4 m in diameter, observations conducted at the cyan wavelength of 500 nm would yield a resolution of $(180° / \pi) \times (1.22 \times ((0.5/1000000)\ \text{m} / 2.4\ \text{m})) = 0.00001°$, in other words of 0.05″, or 50 mas. The situation improves still further when HST is operated at ultraviolet wavelengths, making it in principle marginally possible for HST to image gross details in the photospheres of the three above-mentioned evolved stars.

It is expensive to send a large primary mirror into space. The current state of the space-telescope art is represented by the James Webb Space Telescope (JWST), with a primary of diameter 6.5 m. This falls well short of the state of the art for Earth-based primary mirrors, where Keck 1, operating as early as 1993, has a primary of diameter 10 m, and where the European Southern Observatory "Extremely Large Telescope" (ELT), in Chile, expected to achieve first light in 2028, has a primary of diameter 39.3 m.

Fortunately, it is now possible to surpass the atmospheric seeing limit at Earth-based observatories, and to approach or reach the diffraction limit, through adaptive optics. With adaptive-optics equipment, some (appropriately small) mirror somewhere in the optical train, intercepting a (more or less severely) converged beam from the primary, is implemented as a deformable reflective membrane, backed by solenoid actuators. Some engineering details from current or planned adaptive-optics work at the input end of the Center for High Angular Resolution Astronomy (CHARA) interferometer on Mount Wilson suggest the scale of what is now feasible: a mirror which is in face-on view an ellipse, of widths 177 mm and 125 mm, is on this design backed by 69 voice-coil actuators. With adaptive optics, the distorted wave fronts reaching the observatory through Earth's atmosphere are computer-corrected in real time, to regain the planar shape they possessed when about to enter the atmosphere. To achieve this plane-wave goal, the membrane profile is adjusted on the order of 1000 times a second. (Here can be seen the appropriateness of the engineering term "voice coils," for the solenoids: the frequency of the adjustments is the approximate frequency of an opera singer managing to hit C-above-C-above-Middle-C.)

Suppose, then, a telescope with 10 m primary mirror to reach the diffraction limit through adaptive optics, and to be operated at the cyan wavelength of 500 nm. This now yields an angular resolution on the order of $(180° / \pi) \times (1.22 \times ((0.5/1000000)\ \text{m} / 10\ \text{m}))$, or between 10 mas and 15 mas. For the upcoming ELT, with a primary on the order of 40 m in diameter, this already favourable situation improves by a factor of four, yielding an angular resolution on the order of 3 mas.

However, ELT is just one telescope. Its nearest competitor is the significantly smaller "Thirty Meter Telescope" planned for Mauna Kea. To make further progress with angular resolution, it is necessary to proceed beyond large Earth-based telescopes operating at the diffraction limit. The mission of interferometry is to break through the diffraction-limit barrier, at radio and infrared and (occasionally, as an extreme case) even visible-light wavelengths, surpassing even ELT resolutions by factors of 10 or 100 or more.

7.1.3: The physical basis of interferometry:

In its essentials, the simplest form of astronomical interferometry involves a pair of receivers, separated by some "baseline." The two receivers acquire radiation from a single astronomical source, thereupon producing interference fringes, either virtually (computationally) or physically, as the two acquired beams are either virtually or physically combined.

In its simplest form, astronomical interferometry can be used to measure the angular diameter of an extended source, such as a suitably nearby star, or to measure the angular separation of a pair of point sources.

In more elaborate forms, by taking multiple pairs of receivers, astronomical interferometry can be used to produce actual images of such extended sources as nearby stars, in the process of "aperture synthesis." In the mathematical ideal, aperture synthesis involves overlaying the star with a very large number of sky-projected baselines, with a very large number of baseline orientations and a very large number of baseline lengths. For any positive integers p, q, some large ensemble of baseline lengths exists that makes the problem of image synthesis deterministic, in the following sense: by applying two-dimensional Fourier methods to the many data points from the large ensemble, a unique pixelated image p pixels wide and q pixels high is deduced. In practice, however, recovering an image is akin to the simpler problem of finding a curve-of-best-fit to a rather sparse handful of laboratory data points. In the latter problem, different candidate cures are assessed, by taking each candidate in turn and measuring the cumulative discrepancy (for instance, as sum-of-squared-differences) between data points and candidate curve. A priori assumptions, for instance that the curve has only one local maximum and one local minimum, help keep the slate of candidates down to a manageable size. Similarly, in real-life aperture synthesis, some a priori assumptions are made regarding the nature of the sought-for image (for instance, that the object being imaged has the appearance of a mildly flattened disk, not the appearance of a square or triangle), and various successive trial-run fits are made to the (sparse) data available.

The longer the baseline, or the longer the more extended of the baselines in the case of a multiple-baseline ensemble, the tighter is the resolution. Additionally, for some given baseline(s), the shorter the selected wavelength regime, the tighter is the resolution.

The state of the art in radio interferometry is best represented not by stellar but by galactic work, notably by the Event Horizon Telescope (EHT). In 2019, in a study of the black hole at the heart of the exceptionally large elliptical galaxy M87, EHT combined the notably short radio wavelength of 1.3 mm with intercontinental baselines so long as practically to span the globe, delivering a theoretical resolution (not of 25 mas, but a thousand times better) of 25 μas. In terms of the circular tea-tray, on which 1 cm corresponds to 1″, 25 μas is just 0.25 μm, in other words is roughly one two-hundredth the width of a silky-fine human hair, or one-half to one-fifth the width of an individual *Streptococcus pneumoniae* bacterium.

In optical interferometry, the state of the art is less impressive, being represented by baselines of a few hundred metres, with resolutions in the mas regime—as appropriate for studying Be-phenomenon circumstellar disks, or again for studying gross evolved-star photospheric convection cells, or for determining a star’s rotational flattening and spin-axis orientation.

Astronomical interferometry is in its essentials an upgrade of the 1801 Thomas Young double-slit experiment. In this work, light from a single source impinges on a pair of pinholes or a pair of narrow slits. (Although no relevant point of theory turns on the choice between pinholes and slits, it is common to expound Young in terms of slits, and we will follow this convention.) A fringe pattern is generated on a screen behind the slits, where the lights emerging from the two slits overlap as constructively and destructively interfering waves.

We now explain the physical arrangement in some detail. The prolixity is necessitated by the apparent absence from the available amateur-astronomy literature of any detailed no-calculus explanation, to which RASC Handbook readers could be concisely referred.

For concreteness, let each of the slits be thought of as on the order of 50 μm wide, and cut into an opaque “slitboard” held vertically. The slitboard runs east-west, with the slits themselves (“Slit W,” “Slit E”) running vertically. Let the slits be illuminated by a tiny, but bright, pinhole, thought of as cut into a “holeboard” parallel to the slitboard, and lying near, in fact just a few centimetres to the north of, the slitboard. Further, let the pinhole be visualized as lying exactly at sea level, in other words “at altitude 0 m.” The pinhole is a bright source because north of it is some intense illuminant, such as the noonday clear-sky Sun or some stadium-grade floodlamp.

To avoid presently irrelevant complications, we assume the entire experiment, from bright source at the northern extremity to screen in the southern extremity, to be conducted in a vacuum.

Further, to avoid irrelevant complications, we assume that the pigeonhole is prevented from forming an image of its Sun or lamp source on the slitboard, by having on its north side some such diffusing element as a thin sheet of opalescent glass. The diffuser is to be thought of as “perfect,” in the sense that no part of the pinhole is dimmer than any other. The pinhole is thus prevented from illuminating the slitboard in the potentially confusing manner of a cardboard shoebox pinhole camera, throwing a dim inverted image of such a thing as a bright daytime window onto its viewing port. (This arrangement, which we are taking pains to avoid, is a pleasant experiment in mere ray optics, as opposed to wave optics, suitable for a student at the outset of optics studies. One makes a pinhole in (say) the north face of a shoebox. From the south side of the shoebox, one cuts out a large opening, say 5 cm × 5 cm. Over the opening one pastes a sheet of white tissue paper. One replaces the lid on the shoebox and asks the student to view the tissue paper at the port, with her or his head placed under a lightproof blackout-cloth hood of the kind favoured by Victorian studio photographers. If the student aims the box at a daytime window, a quite clear, inverted image of the entire window is seen on the tissue paper. If the student aims the box at the Sun, a quite clear, small, ophthalmologically safe inverted image of the Sun is seen. If the pigeonhole is made gradually larger, with a knitting needle or an awl, the image of window or Sun stays the same size, while becoming both brighter and blurrier. None of this, pleasant though it is, has any particular connection with interferometry. The "perfect diffuser" is introduced here avoid the complications resulting from ray-optics scenarios in which two pigeonhole-camera images are brought into imperfect coincidence at some viewing port from a pair of pinholes, or indeed in which ray-optics projections somewhat akin to images are brought into imperfect coincidence at some viewing port from a pair of slits.)

We begin by assuming that the opalescent-glass-cum-pinhole is equidistant from the slits.

Let the screen, held vertically, be parallel to the two (vertical) boards just mentioned. There is no need to make the distance from holeboard to slitboard equal to the distance from slitboard to screen.

The arrangement is thus a sandwich, with slitboard in the middle, holeboard to the north, and screen to the south.

In a typical laboratory-demonstration arrangement, the distance between the slits is very much less than the distance from slits to screen. For a slitboard-to-screen distance of 1 m, the distance between W and E could be 0.5 mm or 0.1 mm. It is said to be in practice convenient to achieve this small W-to-E separation by cutting an excruciating narrow single slit into one's board (a fresh scalpel might be useful), then bisecting it lengthwise (so as to achieve the desired slit pair) with a human hair. Alternatively, the Internet reports a successful demonstration in which three 0.5 mm mechanical-pencil leads, say "A," "B," and "C," were arranged in the slitboard plane so as to be almost touching, with "W" then becoming the gap between A and B, and "E" becoming the gap between B and C.

Whatever mechanical details are adopted, faint bright (respectively, dark) fringes are found to appear on the so-faintly-illuminated screenboard, where the phase difference from the two slit sources is close to 0° (respectively close to 180°)—in a sense of "phase" which is perhaps intuitively clear, but to which we nevertheless return, after first developing (here in *italics*) an unavoidably elaborate caveat.

In a typical modern classroom laboratory, the slits are illuminated by a single suitably narrow low-powered laser beam impinging on the closely separated slits. Further, in a modern textbook diagram, the experiment is drawn with the source supplying orderly laser-type waves, of some definite single linear polarization. However, these modern refinements, useful though they are for optics lectures, obscure the specifically astronomical relevance of Young's 1801 experiment. Before the 1960s advent of lasers, Young's experiment was done with the slits illuminated by a mere pinhole, intercepting some such disorganized source as sunlight, or alternatively illuminated by a powerful electric lamp, such as the "carbon arc" formerly used to light streets and soccer stadia. It was essential to provide a blazing glare on the north side of the holeboard, and to maintain everything south of the holeboard in something close to photographic-darkroom conditions.

In this pre-1960s arrangement, no prior requirements of orderly phase relations or polarization are imposed. The paucity of prior requirements is in fact what makes astronomical interferometry possible. With sunlight or stadium-grade lamplight, the pinhole transmits to the slits a disorderly melange of light waves, or equivalently of photons, as a star does to the observatory.

In analyzing the pre-1960s form of Young's experiment, it suffices to ignore the quantum-physics photon account of light propagation, confining attention to the classical Maxwellian wave-physics representation. (We do, however, return briefly to the question of quantum mechanics and photons in Section 7.1.6, below.)

In the classical wave representation, light consists of fluctuating coupled electric and magnetic fields. These are the same definite-direction fields as arise in the non-fluctuating case on the one hand from silk-rubbed glass rods, on the other hand from fridge magnets. The coupled fields are generated in the case of the Sun, of a stadium-grade lamp, or of a star when electrons, bound to atoms in the given incandescent body, jump from higher to lower energy levels. The coupling is such that, for light propagating along any given straight-line path in a vacuum, when the electric field is temporarily of maximum (intermediate, minimum) strength, so also the magnetic field is temporarily of maximum (intermediate, minimum) strength.

It is usual to speak here of "phase": the electric and magnetic fields are at, say, strength zero at "phase 0°"; they rise to maximum strength at "phase 90°"; they subside to zero again at "phase 180°"; they rise to maximum strength, but point in the reverse of their respective directions-of-pointing during the previous maximum, at "phase 270°"; and they subside temporarily to zero at what can be called either "phase 360°" or (once again) "phase 0°." The entire progression, from phase 0° through increasing phases to so-to-speak 358°, 359°, and 360° (equivalently, 0°) occurs n times per second, where n gives the frequency of the oscillation (strictly, in such units as hertz, in other words reciprocal seconds) and the quantity 1/n gives the period of the oscillation (in such units as seconds).

Further, the coupling is such that the constant-period fluctuating electric field has at every instant a direction perpendicular to the direction of the constant-period fluctuating magnetic field, with this pair of directions itself at every instant perpendicular to the propagation direction of the light ray.

In all three cases (Sun, stadium-grade lamp, star) waves are emitted along the given straight line, or given ray direction, from multiple incandescent-body radiators, namely from individual atoms. In these three cases, the decrease-in-energy jump of an electron in one submicroscopic radiator within the macroscopic hot source is uncoordinated with the decrease-in-energy jumps of electrons in the other submicroscopic radiators within the same overall macroscopic hot-body source.

It is now convenient to write in our purely local, strictly RASC Handbook, idiolect not only of a wavelength on some given straight-ray path in vacuum, but of a given linear polarization condition (this we choose to abbreviate as "LPC"). For a given straight-line ray direction, and for a given wavelength and a given LPC, we write further, as an additional item of strictly RASC Handbook idiolect, of a "cadence."

For a given vacuum-straight-ray propagation direction, and for a fixed wavelength, such as 500 nm, what we are here calling an LPC is specified by giving one of the possible directions of linear polarization, in other words one of the possible directions of fluctuation of the electric field. We take this as, so to speak, 0°, 1°, … , 180°, rather than as so-to-speak 0°, 1°, … , 360°. If the chosen direction of propagation is the positive-z direction in three-dimensional xyz space, then at every instant the electrical field direction-vector and the magnetic field direction-vector lie in the xy plane. If the electric field "fluctuates in the direction 139°," then if at some time t it points in the direction 139°, as a direction in the second quadrant of the xy plane, and at t achieves maximum strength, then a quarter period-of-oscillation after t its strength has fallen momentarily to zero; and a half-period-of-oscillation after t its strength has increased to maximum, with its direction vector oriented as 139°+180°=319°, in the fourth quadrant of the xy plane; and three-quarters of a period-of-oscillation after t its strength has again fallen momentarily to zero; and a full period-of-oscillation after t it points once again in the direction 139°, once again with maximum strength.

For a given straight-ray propagation direction d, and for a fixed wavelength λ (such as 500 nm), and for a fixed LPC p (such as 139°), what is here being called, in the present RASC Handbook idiolect, a "cadence" is specified by taking a point in time and a phase. The cadence concept can be explained with a numerical example. Take light with a vacuum wavelength of 500.000000 nm*, with the LPC of 139°. The given wavelength corresponds to a frequency in the daunting hundreds of thousands of gigahertz regime, in other words in the hundreds of terahertz regime, specifically to the frequency of 599.584916* THz*, and so to an oscillation period of (1/599584916000000)* s*, or 1.66782047599076 femtoseconds (*fs*). This latter period can safely be rounded off to the nearest attosecond, as 1.668* fs*. Consider now, under the ISO-approved Universal Coordinated Time, i.e. UTC, timestamping formalism, that particular instant which is UTC=20241225T120001.001000000000000Z (in other words a millisecond past one second past Greenwich noon, on 2024 December 25). One "cadence" is specified by considering any radiation, in the given ray-direction at the given frequency in the given LPC of 139°, for which the electric vector is at some specific instant at some specific phase: for instance, at UTC=20241225T120001.001000000000000000Z at the specific phase 294°. In this formalization, one and the same cadence has numerous designations. Another is given by the (time, phase) pair (UTC=20241225T120001.001000000000000834Z, 114°). We are in this case considering an instant a half-period later, i.e. an instant 0.834 fs later, and with a phase advance of 180°, yielding a phase of 294°+180°=474°, or equivalently 474°−360°=114°.*

Any electromagnetic radiation from the holeboard, no matter how ill-organized, in a given direction d of ray propagation at a given wavelength λ can now be fully specified by stating, for every possible LPC p, and for every possible cadence c within p, the strength at every instant t of the d-directed λ-wavelength radiation with polarization p and cadence c. (What, it will be asked, about such things as radiation with "circular polarization" or "elliptical polarization" or "random polarization"? But these can all be described as mixtures of LPC conditions, at appropriate cadences.)

We may picture an ideal submicroscopic "chronicler" at some point inside Slit W or Slit E, watching through all time for what is happening at her or his particular slitboard station at d at λ in p in c. For a while, perhaps nothing happens at all: all the incoming d, λ radiations are at polarizations and cadences other than {p, c}. Eventually, perhaps, some incoming radiation presents itself at {p, c}, growing stronger for a few hundred cycles of electromagnetic oscillation (for some "short wave train"), then again dying away, and presenting itself again many femtoseconds, or even many picoseconds or many nanoseconds, later. The incoming radiation bath supplied *by the pinhole is (to reiterate) disorderly. Unless, contrary to what we are assuming here, the pinhole is illuminated with light from a spectrally dispersing prism or grating, there is a wide spread of wavelengths. Unless, contrary to what we are assuming here, the pinhole is covered with a Polaroid sheet or similar linear polarizer, all possible linear polarizations are present. Finally, even if, contrary to what we are assuming here, a spectral disperser and a polarizer were to be applied, fixing the d-direction component of the pinhole-produced radiation bath to some particular λ and p, all possible cadences would be present.*

Yet with all this the case, the optical disorder in the incoming bath is not as great as it would be if the holeboard were removed, allowing the lamp or the Sun to illuminate the slitboard directly. Since, for each altitude h above or below sea level, and for each λ, p, and c, the distance from pinhole to Slit W at h equals the distance from pinhole to Slit E at h, it follows that if light of a particular λ, p, and c impinges from the pigeonhole at altitude h on Slit W, then light of that very same λ, p, and c, of the same intensity, impinges from the pigeonhole at altitude h on Slit E. The pinhole, as a single source, has now been effectively twinned (with, for each altitude h, and for each λ, Slit W at h and Slit E at h sending to the screen what might be termed "the very same mixture of polarizations and cadences"). A set of vertical bright and dark interference fringes results on the screen.

The interference fringes sketched in modern entry-level textbooks with orderly, laser-like and linearly polarized, light are thus produced also, for an adequately small nearby pinhole, in the sunlight or lamplight conditions available in the pre-1960's laboratory, and are produced also in the case of light from those so-disorderly sources that are the more distant (to the observatory, the mere point-source) stars.

The requisite identity in the conditions in the radiations from Slit W and Slit E follows from the engineering point that the aperture in the nearby holeboard has been made a mere 50 μm *pinhole. With the pinhole, there is a reasonable approximation to a mere point source. Replace the nearby holeboard with a nearby board having an aperture several millimetres wide, and this condition is lost.*

With this caveat concluded, it is appropriate to develop some particulars more directly relevant to astronomy, leading up to a laboratory thought-experiment analogous to the imaging of a stellar photosphere in stellar interferometry.

In stellar interferometry, the line connecting the two receivers is made perpendicular to the line-of-sight running between observatory and star. The contrast between bright and dark fringes varies as the separation of the two receivers is varied and varies also with the angular diameter of the optically so-disorderly source star. That this should be so can be seen by considering four variations on the envisaged experiment.

(A) Let the given slitboard be replaced with a sequence of slitboards in which the slit pairs are of progressively wider separation. With each successive trial, the interference fringes become more closely spaced.

(B) Revert to some one convenient fixed slitboard. Now, however, introduce a sequence of single-hole holeboards, all at the same distance from the slitboard, all at the same distance from the slitboard, and each with its pinhole at the same altitude of 0 m above sea level, but with the pinhole in each successive slitboard lying farther and farther to the east. The first replacement holeboard has its hole just a little farther to the east than the original did (and therefore slightly closer to Slit E than to Slit W). The second replacement holeboard has its hole almost opposite Slit E (and therefore appreciably closer to Slit E than to Slit W). The third replacement holeboard has its hole even farther east than Slit E (and therefore still more to the east of Slit W). Some quick pencil-and-paper sketching reveals that as the hole migrates eastward, the fringe pattern (whose bright central fringe results from a condition of equal-phase illumination) migrates westward on the screen.

(C) Introduce a fresh sequence of holeboards, each with two pinholes "H1" and "H2," where H1 is equidistant from the slits, but where H2 lies to the east of H1, with both H1 and H2 at the altitude of 0 m above sea level. Light from H1 creates one set of vertical fringes on the screen, and light from H2 a different set of vertical fringes, displaced east-west from the first set in the manner illustrated in the "*(B)*" trials. The "*(B)*" trials show that the extent of this displacement depends on the distance between H1 and H2. If H1 and H2 are very close together, the sets of fringes from these two pinhole sources almost coincide. If, on the other hand, the distance of H2 from H1 is appreciable, the midpoints of the two respective sets of vertical fringes are well separated. The "*(A)*" trials now yield a crucial point: for any reasonable choice of distance between H1 and H2 (whether H1 and H2 are close together, or are more widely separated), there are various choices of slitboard, in other words various choices of

slit separation, which make the H1 bright fringes coincide with the H2 dark fringes and the H1 dark fringes coincide with the H2 bright fringes. Call these the "nulling slit separations" and call the smallest of them the "first nulling slit separation." When the chosen slitboard has a nulling separation, the fringes disappear.

It is now possible, for any reasonable separation *S* of H1 from H2, to experimentally find the first nulling separation *N* at the slitboard. From this measurable quantity *N*, and from measurements of the distances from holeboard to slitboard and from slitboard to screen, the value of *S* can be deduced.

(D) Introduce a special holeboard-with-opalescent-glass, no longer pierced by a mere pigeonhole, but featuring an appreciable aperture. For concreteness, let this be a circular aperture 5 mm in diameter. Further, let this holeboard be placed quite far away from the slitboard, so that the angle subtended by its (appreciable) hole equals the angle that was subtended by the original pinhole. If the original holeboard, with its 50 μm aperture, was placed 10 cm to the north of the slitboard, then the 5-mm aperture in the new slitboard will subtend the same angle if placed (5 mm / 50 μm) ×10 cm = 10 m away from the slitboard. We reiterate that the illumination of the hole is perfectly uniform, with the opalescent glass functioning as a "perfect diffuser." As far as the production of vertical interference fringes on the screen is concerned, nothing has changed. The nearby 50 μm aperture yielded a disorderly radiation bath (a disorderly mix of wavelengths, linear polarizations, and cadences), successfully (thanks to the slits) split from the perspective of the screen into two identical (although disorderly) radiation baths. The identity is due to the equidistant positioning of the slits from the hole. The distant 5-mm aperture in the same way emits a disorderly mix of wavelengths, linear polarizations, and cadences, successfully split from the perspective of the screen into two identical (although disorderly) slit sources, and generating a similar-looking set of fringes on the screen.

Now, however, let the holeboard be gradually moved southward, so as to bring it progressively closer to the slitboard. As the distance from holeboard to slitboard decreases, the contrast between the light and the dark fringes on the screen steadily diminishes, with the fringes eventually vanishing altogether, and continuing to be absent as the holeboard comes still close to the slitboard. The decrease in fringe contrast occurs because from the perspective of the slitboard, the holeboard source is no longer point-like, but has discernible width.

A careful development of this discernible-width point would require examination of continuously varying quantities, and therefore would require some calculus. However, a rough-yet-reasonable development can be given in a discrete-quantities approximation. What at first registers physically, as the degradation in fringe contrast is in its early stage, is scarcely more than a discernible "aperture left half" and a discernible "aperture right half." This, however, is already enough to produce a mild degradation in fringe contrast. The west half of the slitboard hole is admittedly (in the discrete-quantities approximation) a single illuminant for the slits, striking them a little off centre, and generating a vertical fringe pattern P1 on the screen. The right half of the slitboard hole is admittedly (in the discrete-quantities approximation) a single illuminant for the slits, striking them in the opposite direction off centre, and generating its own set P2 of vertical fringes. Perhaps P1 and P2 avoid cancellation, with their respective bright fringes coming rather close to meeting, and with their respective dark fringes coming rather close to meeting. However, the right half and the left half of the aperture are, so far as the slits are concerned, an independent, uncoordinated pair of illuminants, incapable of creating a fringe pattern. As the distance of holeboard from slitboard decreases still further, what registers physically are (in the discrete-quantities approximation) a discernible "aperture westmost third," "aperture central third," and "aperture eastmost third." Call these α, β, and γ. Now there are not two, but three coordinated illuminants, each generating its own set of vertical fringes (the bright fringes now somewhat less intense), and the three uncoordinated pairs {α, β}, {α, γ}, and {β, γ}. As the approach of slitboard to screen continues, what next registers physically (in the discrete-quantities approximation) are a discernible "aperture westmost portion," "aperture west-of-centre portion," "aperture east-of-centre portion," and "aperture eastmost portion." Call these α, β, γ, and δ. Each of α, β, γ, and δ generates its own set of vertical fringes, with the bright fringes now not at all intense (since each bright fringe comes from just one-fourth of the aperture). Additionally, there are now not four, but fully six, uncoordinated pairs, namely {α, β}, {α, γ}, {α, δ} {β, γ}, {β, δ}, and {γ, δ}, each of them illuminating the screen without fringe creation. With the discernibility of five sections in the steadily approaching 5-mm hole, there are five sources, say α, β, γ, δ, and ε, each generating its own set of (very low-intensity) fringes—and also rather than five, now fully ten, uncoordinated pairs. With the eventual discernibility of six sections come six sets of fringes, and additionally rather than six, now fully fifteen, uncoordinated pairs. This yields a now severe decline in fringe contrast.

With measurement of the extent to which the fringe contrast is degraded at some instant in this procedure, the angle subtended at the slits by the hole at that instant can be calculated. Even without performing the measurement and the calculation, an upper bound can be placed on the angular width of the hole, as seen from the slits, when the process has not yet reached the point of a visible degradation in fringe contrast: the reasoning is that if the angle width were greater than such-and-such a value, the fringes would, contrary to what is observed, be weakened. For this deduction of an upper bound, one might use a calibration holeboard, emitting as much light as the board under study but known to have a hole so small as to be of negligible angular diameter from the perspective of the slits. The reasoning now becomes the following: since the slits from the holeboard under study exactly resemble the slits from the calibration holeboard in their light-fringe/dark-fringe contrast, their contrast must still be at its maximum, and the angular diameter of the approaching large hole therefore must still be below the upper bound that triggers contrast degradation.

Trials *(A)* through *(D)* now indicate the possibility of a kind of map generation. Consider, on the one hand, a holeboard with some rather large number, perhaps 10, of 50 μm pinholes, unevenly spaced along some short horizontal line at (for concrete visualization) an altitude of 0 metres above sea level, and not all equally bright, and all backed by the perfectly diffusive opalescent glass. Perhaps each pinhole is lit by its own individually regulated stadium-grade lamp; or perhaps all the pinholes are lit by the Sun, but in addition to being backed by opalescent glass are fitted with grey ("neutral") filters of different densities. There is, at any rate, a short horizontal row of 50 μm pinholes, not evenly spaced, not all equally bright.

By taking a very large number of successive slitboards, all at the same distance from the row of pinholes, and recording board by board the contrast and brightest-fringe intensity of the resulting fringe patterns, one could in principle work out the placement of all the pinholes, in terms of their angular westerly or easterly separation from some arbitrarily selected "0°" reference point in the pinhole row, and additionally work out their relative brightnesses. Here, then, is an analogy to the use of interferometry to resolve a system of barely separated collinear stars. If there are just two pinholes in the row, then the setup is analogous to the use of interferometry for measuring the angular separation of a tight binary.

Next, discard the opalescent glass, and consider not a pinhole, but a "thin continuous linear source," a hot, thin horizontal incandescent short wire attached at the height of 0 m above sea level to an unpunctured board. Let the short wire be heated to varying degrees of incandescent brilliance, along its modest length, by various essentially invisible local heat sources, such as hot, dim, hydrogen-with-oxygen jets. From end to end, the modest-length wire subtends some modest angle, say 1.2″, at the slits. Let any "standard of angular resolution" finer than 1.2″, be imposed: say for definiteness, 5 mas. Then there is some finite, although large, number of slitboards, some of them with their slits perhaps quite widely separated, whose successive deployment generates a map of the glowing wire, at the desired resolution (in this case, 5 mas). (The calculations involved in generating the map are in their essence an application of one-dimensional Fourier integral transforms or Fourier integral transform inverses. But this mathematical point will not be explored here.) If instead a resolution of 1 mas is sought, then more slitboards will be needed, and some of those requisite boards may be expected to feature slit pairs more widely separated than those that sufficed for the calculation of the 5 mas map.

It is now appropriate to replace the modest-length unevenly incandescent wire with something duly akin to a stellar photosphere, namely a modest-diameter metal disk, say 5 mm across, filling the hole in that particular holeboard that previously emitted lamplight or sunlight through a 5-mm opening. (As with the wire, so also with the disk, there is no opalescent glass.) The south side of the disk faces the slits. Let the disk be unevenly heated to incandescence by some arrangement of tiny gas jets playing on its north side. Let this special holeboard-with-disk be close enough to the slits to subtend some appreciable, although small, angle, say 1.2″. Again, let any "standard of angular resolution" tighter than 1.2″ be imposed: say again, for concreteness, 5 mas. A map, indeed an image, of the disk can now be constructed, fitting the imposed standard of resolution. It is no longer enough to take slitboards whose parallel slit pairs run vertically. But let slitboards now be taken with parallel slit pairs in any arbitrary orientation: some boards have vertically running parallel pairs, some have horizontally running parallel pairs, some have parallel pairs running at a rise-to-eastward-run ratio (a "slope") of 1, some have parallel pairs running at a slope of −0.1, some have parallel pairs running at a slope of 5.7, or −403.7, or whatever; and for any given parallel-pairs slope (in other words, for any orientation with respect to the horizontal), there are a large number of different slit separations. This vast ensemble of slitboards achieves what is in the astronomy interferometry literature called a "(quite dense) sampling of the *uv* plane."

A situation now arises reminiscent of epsilon-delta definitions in the mathematics of limits: let any standard of angular resolution, no matter how dauntingly tight, be given; there then exists a (perhaps dauntingly dense) sampling of the *uv* plane that succeeds in delivering an image tight to at least the desired standard. The calculations involved in the delivery use two-dimensional Fourier methods. Here is a laboratory equivalent (not, as previously, to the interferometric study of a tight binary, but) to the outright imaging of a stellar photosphere.

The distant unevenly incandescent 5-mm disk is to be contrasted with a previous key assumption, of a distant 5-mm hole backed by "perfectly opalescent glass," and therefore uniformly lit. If the illumination is uniform, no interference fringes result; if, on the other hand, the illumination departs from uniformity to however small a degree, then in the mathematical ideal some interference fringes, however faint, are present. (We are admittedly working here with the mathematical ideal of a perfectly continuous Universe. The actual Universe has a granular character, with light quantized into photons.)

In a specially refined form, stellar interferometry is performed with beams that are spectrally dispersed, allowing the study of monochromatic fringe systems, as a probe of varying stellar depths. In actual laboratory practice, polychromatic fringes, resulting from putting to the north of the holeboard some such broad-spectrum illuminant as sunlight or a stadium lamp, prove adequately convenient. With a broad-spectrum illuminant, and with typical laboratory choices for slit separation, the fringes emerge clearly enough, with only a little troubling colouration. (This can be seen from the figure captioned "Photo of the double-slit interference of sunlight," at en.wikipedia.org/wiki/Double-slit_experiment.) The introduction of a prism or grating monochromator to the north of the holeboard would gravely weaken the bright fringes, making the fringe pattern harder to observe. Nevertheless, we may now fancifully envisage a more elaborate non-uniform disk, a metal-calcium-vapour-glass sandwich. The metal is on the north side, the glass on the south. Some epoxy sealant around the disk rim prevents the calcium vapour from escaping its metal-and-glass confinement. Embedded in the glass are several tiny electrodes. A power supply maintains a severe voltage drop between each of these electrodes and the circular metal plate, making the calcium vapour emit calcium-discharge lights, not necessarily all of the same intensity, in several regions of the assemblage. Notable in the emission is the violet calcium-discharge-tube wavelength of 393.4 nm, or "Fraunhofer K light." By placing a rotatable prism between the disk south side and the various slitboards, one can then set up first an observing run in which all the various slitboards are illuminated in some quite red regime, then an observing run in which all the various slitboards are illuminated in some quite violet regime. This pair of observing runs yields two images: first an image of the simulated photosphere, Fourier-computed from the prism red setting, and second an image of the simulated chromosphere, Fourier-computed from the prism violet setting. Given equipment for spectral dispersion, light can be selected first from the photosphere, then from the overlying chromosphere, in the spirit of the already-cited (Section 7.1.1, above) chromosphere investigation which is 2011A&A...535A..59B.

Given sufficiently detailed spectral dispersion at the stellar interferometer input, images can in fact be constructed of different photosphere strata (since the various photosphere-dominated spectral lines are themselves formed at various different photosphere depths). Further, with appropriate spectral selections, images can be constructed not only of the overlying chromosphere, but of winds and jets, at still higher stellar altitudes, by exploiting the fact that such high-altitude structures shine at their own characteristic emission-line wavelengths. Interferometry consequently delivers not only 2-dimensional, but to some extent even 3-dimensional, stellar imaging.

7.1.4: Some historically and currently influential astronomical interferometers:

Interferometry began at Marseilles, in work published in 1874 by Éduard Jean-Marie Stephan. (Stephan is nowadays more often recalled as the discoverer of the "Stephan's Quintet" galaxy conglomeration in Pegasus.) Observations were made with just two receivers and a modest baseline: the primary mirror was covered with an opaque mask, at opposite sides of which slits had been cut. Stephan's arrangement was a pioneering species of the "aperture masking" interferometry still practiced on some telescopes in recent years, although with primary mirrors larger than what was available in 1874. (Notably, on the *JWST* space mission, the "Near Infared Imager and Slitless Spectrograph" instrument, NIRISS, offers the option of aperture-masking interferometry, with a seven-hole disk and a set of filters, for the possible detection of exoplanets.)

Stephan's 1870s mirror, the largest then in existence, was 0.8 m in diameter. This yielded a baseline of slightly under 0.8 m. Stephan surely observed across the whole visible-light passband rather than at any one selected spectral wavelength, and surely with just an eye at the eyepiece as his means for assessing fringes. He duly obtained a result from a sample of bright stars: from the fact that clear fringes were produced from each star in his sample, in other words from the fact that no null, or even fringe-degradation approach to null, was obtained from any star in his sample, and from the fact that his chosen baseline yielded a theoretical resolution of 160 mas, Stephan correctly deduced that each star in his sample was of a still smaller angular diameter.

Further progress, in at any rate a proof-of-concept or engineering prototype sense, was reported in 1891 by Albert A. Michelson. Michelson obtained not mere upper bounds, but actual angular-diameter measurements, for those 1″ or 2″ sources that are the four Galilean satellites of Jupiter. Since the angular diameters of the satellites were already known by other means, this served as a check on the adequacy of his conceptualization and equipment.

As early as 1896, physicist-astronomer Karl Schwarzschild (nowadays more often recalled as the originator of the "Schwarzschild radius" in the theory of non-rotating black holes) was reporting an interferometric measurement of binary angular separation.

Effective work on single stars became available by 1920, from Michelson and Francis G. Pease, when the 1891 ideas were put into full production. The 1920 apparatus, on the 2.5-m ("100-inch," "Hooker") Mount Wilson reflector, yielded a roughly 6-m baseline, without spectral dispersion. The receivers were a pair of flat acquisition mirrors at the ends of a 6-m metal rod or girder, affixed to the sky end of the telescope trusswork and perpendicular to the telescope optical axis. Starlight was directed first along the girder by the acquisition mirrors (arranged at angles of 45° to the girder), then down into the telescope. (Polychromatic) starlight fringes were found to be visible to the eye even though atmospheric turbulence set them into rapid motion, inconveniently precluding photography. Since the distance between the acquisition mirrors was adjustable, the distance yielding degradation of fringes (i.e. yielding the desired fringe-contrast null, or the desired approach to null) could be investigated. Further, the loss of fringe contrast, in an approach to null, could be investigated by making a comparison with the fringe contrast achieved on the same night by a distant calibrator star, safely assumed to be of negligible angular diameter. From the degradation in fringe contrast, the angular diameter of the target star could be inferred. Here, then, was a breakthrough: with a roughly 6-m baseline, working in the entire visible-light passband, Michelson and Pease could reach a resolution of some tens of mas.

Interferometry advanced again after World War 2, with the advent of radio astronomy. In radio, not only is the problem of tropospheric turbulence alleviated or (in the case of longer wavelengths, such as the astrophysically useful 21 cm) negligible, and the problem of ionospheric radio scintillation not prohibitively severe: it is additionally possible to combine the signals from two widely separated antennas in a single observatory. For example, signals can be combined from two parabolic dishes, each with its own collection point at the paraboloid focus. Each antenna feeds its own receiver, with the (electrical) receiver outputs then led by cables to a central analysis station. Since the mission of this central facility is in essence to work out where fringes would have occurred had the incoming radio beams at the two dishes been physically combined (as by imaginary duct-like metal waveguides, converging to one single receiver in the central lab), this technique might perhaps be called "virtual fringe creation." Prominent implementations of the technique are the Karl G. Jansky Very Large Array (VLA) in New Mexico (formally commissioned in 1980) and the Atacama Large Millimetre/submillimetre Array, or ALMA, in Chile (operating from 2011 onward).

More radically, it is even possible in virtual fringe creation to use as receivers a pair of electrically unconnected radio telescopes. The long wavelengths in radio yield correspondingly low frequencies, with 21-cm radiation having a frequency of just 1.4 GHz, in other words a frequency within (not the daunting EHF or SHF, but merely the tractable, engineer-friendly) UHF regime. At such low frequencies, two radio telescopes thousands of kilometres apart, as at the Event Horizon Telescope (EHT), can have their signals recorded with precision timestamping. Current clocks, resolving nanoseconds and picoseconds, are precise enough to enable the timestamped data to then be combined at a computer, yielding virtual fringes.

Postwar radio interferometry rather rapidly evolved to a point at which by combining multiple pairs of receivers in multiple baselines, with the various pairs oriented in multiple directions on the plane of the sky to yield a not-too-sparse sampling of the *uv* plane, images of extended sources could be constructed. The procedure was in its essentials as described for the glowing back-heated imaging experiment of Section 7.1.3 above. The 2019 EHT study of M87, in particular, yielded an image of the M87 galactic central accretion disk, showing a featureless dark area delimited by the event horizon of a black hole. The event horizon itself spans a space about 1.5 light-days wide. At the distance of M87, this length subtends an angle of just ~16 μas. However, the strong gravitational field just outside the event horizon produces an optical lensing effect, yielding in the image an enlarged dark space, a so-called "dark hole shadow" ~40 μas wide (and incidentally making it seem that the accretion disk is viewed more or less face-on: it is in fact viewed more or less edge-on, but with photons from its far side managing to reach the interferometer, thanks to the severe local curvature of spacetime). The data accumulated from the EHT receivers ran to about 5 petabytes, with transport to the central computer performed by physically transporting approximately a half-tonne of hard drives. The EHT team has subsequently published a similar imaging result for the black hole at the centre of our own galaxy. Here the aperture-synthesis processing was still more elaborate than for M87, relying on a facility not yet commissioned at the time of the M87 work, the Frontera supercomputer at the Texas Advanced Computing Center. A glance at Frontera specifications shows how different this facility is from a computer as commonly conceived, and consequently how demanding are computations in two-dimensional Fourier analysis: in place of a single node, there are over 8000 separate nodes, each running either 32 or 56 cores, and each addressing its own individual 128 or 192 gigabytes of RAM, with the entire rack-upon-rack-upon-rack liquid-cooled installation drawing ~6.5 megawatts from the electrical power source. (This is equivalent to the grid load of a typical USA community with a population of somewhere between 1000 and 5000.)

From the 1950s onward, optical astronomy has sought to repeat the interferometry successes of radio astronomy. Already at the shorter radio wavelengths, and still more so at optical wavelengths, atmospheric conditions cause some crucial relative-phase information to be lost when taking mere pairs of receivers. In particular, what is lost is some absolute-phase information (as distinct from mere phase-difference information) required for distinguishing, from a single orientation of the baseline, between a symmetric disk and a non-symmetric light distribution, as in the case of a tight binary. With absolute-phase information lost, these two cases can only be distinguished by taking multiple orientations of the interferometer baseline, as when Earth's diurnal rotation causes the interferometer baseline to rotate in the plane of the sky. Still worse, the lost absolute phase information is an expected input for aperture-synthesis imaging—not (if this present RASC Handbook author has understood essentials correctly) in the Section 7.1.3 unevenly-incandescent-disk thought experiment, but nevertheless under the sparse *uv*-plane sampling conditions imposed by actual observatory practicalities. On the other hand—such are the assurances from those more knowledgeable in interferometry than the present RASC Handbook author—the necessary absolute-phase information is generated when receiver pairs are supplanted with receiver triples, yielding the so-called "closure phase," in a procedure in which atmospherically induced drifts in absolute phase ("absolute phase errors") in some sense cancel. Adequately detailed particulars of the procedure would seem to be available from en.wikipedia.org/wiki/Closure_phase.

A special difficulty arises at optical wavelengths, even after the problem of atmospheric turbulence has been addressed upstream through adaptive optics, and even after the problem of missing absolute-phase information has been addressed farther downstream by taking closure-phase triples. Where in radio multiple receivers can be operated independently, the frequencies of optical radiation are too high to allow the computational synthesis of fringes from timestamped signals at physically unconnected receivers. Where the astrophysically useful 21-cm signal has a frequency of 1.4 GHz, in the engineer-friendly UHF regime, a signal in even the mid-infrared N band, at the optically long wavelength of 10 μm (0.01 mm), has the impossibly high frequency of 30,000 GHz, or 30 THz.

The electrical combining of signals from two photometric telescopes, each with a single-pixel detector, and with cabling feeding the electrical signals to a central point in the observatory, was indeed achieved late in 1955 by the team of R. Hanbury Brown and R.Q. Twiss, at Jodrell Bank in Lancashire. In 1956, Hanbury Brown and Twiss published their determination of the angular diameter of the sole star bright enough for their equipment, α CMa A (Sirius). Despite the inconvenience of working with a star that never rises far off the Lancashire horizon, they succeeded in obtaining a measure of 6.8 mas ±7%. This, with its uncertainty, is nearly consistent with the best determination present known to us at the Handbook, namely 5.993 mas ±2%, as reported from France in the 2021 September 13-or-14 release of the Centre Jean-Marie Mariotti angular-diameters catalogue (JMDC; 2016yCat.2345….0D, cdsarc.u-strasbg.fr/viz-bin/cat/II/345). With the Jodrell Bank proof-of-concept to hand, a team led by Hanbury Brown proceeded to construct a production interferometer at Narrabri, in the conveniently arid New South Wales inland. This production facility, detailed in 1967MNRAS.137..375H, had two receivers, deployed on a circular broad-gauge railway track that yielded a range of baselines from 10 m to 188 m. Each telescope was implemented as a large, but optically imprecise, mirror, 6.5 m in diameter. Starlight was brought to an imprecise focus, as a patch around 25 mm wide, which then passed to the cathode of that sensitive single-pixel detector that was the postwar photomultiplier tube.

Hanbury Brown's Narrabri apparatus could not push deeper than approximately magnitude 2. When his work ended in the 1970s, with the exhaustion of the set of feasible targets, 32 stars had been measured.

For all its success, the Hanbury Brown interferometer was a departure from what today has of necessity become the mainstream in astronomical interferometry. The two photomultiplier tubes constituted not an interferometer of Michelson's type (whose essentials can be described, as in this article, without quantum mechanics), but a so-called "intensity interferometer," in whose subtle theoretical basis quantum mechanics plays a central role. In the intensity interferometer, the continually varying intensity of the (tropospherically scintillating) bright target star became a pair of electrical signals, each continually integrated over some short, continually sliding, time window through a readout limitation inherent in photomultiplier tubes. The central facility, to which the cabling ran, measured a photon correlation, a distinctively quantum-mechanical effect, by tracking the two continually integrated intensities as seen by the two photomultipliers. Information about the absolute phase or phase-difference, as distinct from the intensity, of the starlight reaching the receivers was lacking.

For progress toward the goal of aperture-synthesis imaging, it has instead been necessary to return to Michelson interferometry, making all possible use of the phase-difference information conveyed by fringes. In place of virtual fringe synthesis, as in radio-astronomy aperture synthesis imaging, it is necessary to produce the actual physical fringes in some beam-combining facility. Progress has at this point come at heavy financial cost, being dependent on the (gradually increasing) ability of observatory constructors to implement optical trains some hundreds of metres long while maintaining tolerances on the order of a single micron. It is necessary in this engineering to dampen vibrations, and additionally to compensate for tiny expansions or contractions of optical assemblies as the night temperature fluctuates from moment to moment.

Michelson's 6-metre girder cannot be scaled up to yield multi-hundred-metre baselines meeting the requirements of optical stability. Instead, Michelson's single telescope is in current engineering replaced with multiple telescopes, feeding their starlight along systems of mirrors (or in some implementations along runs of optical fibre, including that ultra-thin photonics-and-telecommunications innovation that is "single-mode fibre") into a central beam-combining laboratory. The telescopes themselves could in principle be replaced by mere sighting tubes, in other words by telescopes of mere "power 1." Even with adaptive optics at powerful telescopes, the fringes are found to wander rapidly around the final fringe-photographing detector chip. The problem of fringe migration can be addressed in a crude way by taking short exposures, lasting mere milliseconds. Nowadays, however, the problem is instead addressed by a real-time corrective "fringe tracking" step, akin to the adaptive optics deployed earlier in the optical train: the drift is tracked, with the fringe set continually forced to some consistent position on the megapixels-area detector surface, through electromechanical actuators. With fringe tracking, feasible exposure times are increased from a few milliseconds to hundreds of seconds. This allows not only our Handbook 324 nocturnal "Brightest Stars," and stars of the almost-naked-eye magnitudes 7 and 8, to be studied, but also puts appreciably fainter stars within reach. It is reported in en.wikipedia.org/wiki/List_of_astronomical_interferometers_at_visible_and_infrared_wavelengths that the European Southern Observatory Chile-based Very Large Telescope Interferometer (VLTI) either is now or is projected to be pushing down to mag. 14, and that the same magnitude limit is projected for that not-as-yet-completed USA facility that is the Magdalena Ridge Observatory Interferometer (strictly MROI, but "MRO" in the Wikipedia table).

Further, fringe tracking makes it easier to work with spectrally dispersed fringes, since the multiple separate systems of (now gravely dimmed) monochromatic fringes can be held in place over the entire detector surface, with the two spectral extremes not being lost as fringe-system migrations spill first over one, then over the other, detector edge.

Although in principle acquisition telescopes of "power 1" would suffice for interferometry, large primary mirrors are in practice desirable, for reaching faint targets, especially once spectral dispersion is applied. As far as the acquisition of faint starlight is concerned, the state of the art is represented by VLTI. Light at VLTI can be combined from selections among the four "Auxiliary Telescopes" (ATs), each with a primary mirror of diameter 1.8 m, or alternatively from the four "Unit Telescopes" (UTs), each with a primary mirror of diameter 8.2 m. The ATs are moveable, on a system of tracks, to yield multiple baselines, for the best possible (although still sparse) sampling of the *uv* plane. The UTs are fixed. This arrangement yields for the UTs baselines of constant length, but nevertheless (thanks to Earth's diurnal rotation) of sky orientations that helpfully vary as the night progresses.

The maximum available VLTI baseline is ~200 m. This is a barrier that cannot be surmounted, since the VLTI mountaintop site does not allow the boring of significantly longer light-conducting tunnels. VLTI progress in resolution therefore must come not from the construction of longer baselines, but from overcoming the increasingly severe mechanical-stability challenges arising when infrared optics are supplanted with optics for the progressively shorter red, orange, yellow, green, cyan, blue, … wavelengths.

First fringes were achieved at VLTI with the "VLT Interferometer Commissioning Instrument" (VINCI) in 2001. VINCI was followed by the "Astronomical Multi-Beam combineR" (AMBER), as the first VLTI combiner to yield a selection of closure phases, by selecting one of the four possible triples from the four AT or four UT inputs. Also following VINCI was the two-telescope "Mid-infrared Interferometric Instrument" (MIDI) combiner.

Now, however, a second generation has arrived at VLTI, with the "Precision Integrated-Optics Near-infrared Imaging ExpeRiment" (PIONIER), and perhaps still more notably with the "Multi AperTure mid-Infared SpectroScopic Experiment" (MATISSE) and the facility called "GRAVITY" (not an acronym). All three of these beam combiners support aperture-synthesis imaging.

MATISSE marked the introduction of capabilities in the near-infrared M and L bands, as well as the already-used mid-infrared N band, with angular resolutions in the L band as tight as ~3 mas. It has become possible with MATISSE to achieve detections on the single-au scale for stars on the order of 500 ly away. This single-au distance represents a typical distance for the "water ice line" in planet-forming disks around young stars, and so possibly marks the outer boundary of the rocky-planet formation region. The spectral dispersion of MATISSE makes it possible to isolate spectral features of water and polycyclic aromatic hydrocarbons.

When GRAVITY is configured for the special application of position measurements, in other words for pure astrometry, it becomes possible to measure the angular separation of two closely separated sources to a precision of ±30 μas. In aperture-synthesis imaging, GRAVITY, like MATISSE, has achieved a precision of ±3 mas.

As far as optical baseline length is concerned, the state of the art is perhaps represented by CHARA on Mount Wilson, with six telescopes recently operating, and with a seventh either anticipated or very recently commissioned. With 6 telescopes, the maximum possible CHARA baseline is 331 m. Among current interferometers, only CHARA can deliver the sub-mas resolution needed for discerning gross photosphere features, such as large-scale convective cells, on giants, as distinct from gross photosphere features on the interferometrically less challenging supergiants. At CHARA, the "Classic Interferometry with Multiple Baselines" (CLIMB) beam-combiner has worked to a resolution of ~0.5 mas, in the 6-telescope arrangement. The CHARA "Precision Astronomical Visible Observations" (PAVO) beam-combiner proceeds still further, reaching ~0.2 mas in a 6-telescope arrangement. The success of PAVO is due to its working in an exceptionally short wavelength regime, of just 600 nm to 900 nm (with spectral dispersion into 23 separate channels). The short-end limit, 600 nm, is not infrared at all, but lies well within the visible segment of the spectrum, in the orange rather than in the red.

Also at use at CHARA are, or have been, the "Visible spEctroGraph and polArimeter" (VEGA) and the "Michigan InfaRed Combiner" (MIRC).

Apart from VLTI and CHARA, the Navy Precision Optical Interferometer (NPOI) in Arizona has made extensive contributions to stellar angular-diameter studies, even though working with modest telescope apertures (perhaps even with siderostats feeding "telescopes of power 1"?). NPOI has used a 97-metre baseline. An upgrade appears now to be underway, with the eventual introduction of four infrared telescopes, each of aperture 1.8 m, and also with an increase in baseline to 432 m.

At Magdalena Ridge in New Mexico, the already-mentioned MROI is under construction, as a facility potentially rivalling or surpassing CHARA and NPOI in baseline length. First fringes, from some limited set of telescopes, may be achieved as early as 2024. In its completed form, MROI is to consist of 10 telescopes, each of diameter 1.4 m, operating in the near- and mid-infrared, with a maximum baseline variously reported as 340 m or 400 m. MROI is to achieve a resolution of 0.6 mas if operated at the near-infrared wavelength of 1 μm.

A possible next stage in interferometry, beyond MROI, is the "Planet Formation Imager," as suggested in 2018ExA….46..517M: aperture-synthesis imaging not only of circumstellar disks, but of some circumplanetary disks in young planetary systems, could be achieved with an array of 12 telescopes, each of 3-m aperture, operating in the near- and medium-infrared, with a set of baselines extending as far as 1.2 km. A proposal for such a project might become an input to the USA Decadal Review of 2030.

Future decades might see a revival of efforts at multi-telescope spaceflight interferometry, more ambitious than the already-mentioned single-telescope aperture-masking capability on *JWST*. This development, if it occurs, would constitute positive news, in the wake of the disappointing budget-driven cancellations of two NASA spaceflight interferometer projects, the "Space Interferometry Mission Lite" (*SIM*) and the "Terrestrial Planet Finder" (*TPF*).

The article en.wikipedia.org/wiki/List_of_stars_with_resolved_images has a convenient, although not necessarily complete, tabulation of current results in the imaging of stellar photospheres, in almost all cases from aperture synthesis in near-IR interferometry. It can be seen from this table that whereas in current imaging, our "Sample S" of visually brightest stars predominates, results have been obtained also for a few visually fainter stars (with, e.g. starspots imaged both on σ Gem Aa and on ζ And A; the former shines at magnitude 4.2, while the latter varies between 3.9 and 4.1).

7.1.5: Can amateurs contribute in stellar interferometry?

The large 1920-onward impact of interferometry in astronomy is comparable to the large 1930s-onward impact of electron microscopy in microbiology. The engineering requirements of electron microscopy are unfortunately too severe to make this a promising domain for the field naturalist. What, now, of interferometry? Must this field be forever conceded to well-funded institutions, as electron microscopy is, or can amateur astronomers contribute?

A contribution is possible in at any rate one specialized area. In 1970A&A.....6..85L, stellar-interferometry pioneer Antoine Labeyrie introduced "speckle interferometry" as a technique for working a telescope through turbulent air right down to, although not beyond, its $(180° / \pi) \times (1.22 \times (\lambda / D))$ diffraction limit. In speckle interferometry, short-exposure images are taken of the continually shifting apparent disk of the target star. What to casual inspection appears under high power to be a mere restless (under good conditions, perhaps arcsecond-wide) pool of light, conveying perhaps the impression of a luminescent puddle heated to boiling, is found in high-speed stop-motion photography to be an assemblage of ever-shifting speckles, each corresponding to the diffraction-limited apparent angular size the star would have if the atmosphere were absent. Analysis of the photographic speckle records allows inferences to be drawn regarding the star itself, down to the $(180° / \pi) \times (1.22 \times (\lambda / D))$ limit. One chapter in the second (2012) edition of R.W. Argyle, ed., *Observing and Measuring Visual Double Stars* (in the Springer International Publishing "Patrick Moore Practical Astronomy Series") is said to address amateur possibilities in speckle interferometry. Further, an early article, 1992ASPC…32..577T, from a CHARA team, indicates that useful double-star interferometric interferometry can be done even by the amateur equipped with a 0.2-m telescope. The technique becomes progressively more useful as the diameter D of the telescope is made larger. In the specific case of Canada, amateurs might some day hope to use Ontario's DDO to achieve results in the speckle interferometry of close binaries. (A starting point, for preliminary accuracy-checking, might conceivably be the tight α CMi binary. As noted under "Remarks" for α CMi A (Procyon) in the long table at the end of this article, Charles Worley of the US Naval Observatory (USNO) asserted some decades ago that he was the only living astronomer to have seen the white dwarf that is α CMi B at the eyepiece with his own eye. One might speculate that a detection at the margin of feasibility for the ordinary eyepiece becomes readily feasible in speckle.)

DDO access has been readily available to the amateur community, without competing demands from professionals, under municipal arrangements finalized in 2018. The DDO D value of 1.88 m is perhaps as large as the D of any telescope currently made available on all clear nights, without professional scheduling-committee restrictions, to any of the world's various amateur communities.

7.1.6: How might this present treatment of interferometry be developed and extended?

(A) To reiterate: the present article ignores the quantum-mechanical or granular character of the Universe, pretending that everything in optics is at even super-fine levels of measurement capable of subdivision. A duly careful extension of this present treatment would take photons into account, going so far as to discuss the mysteries of "single photon interference."

Experiment not only indicates that light propagates as discrete photons, with some finite, in principle determinable, number of photons emitted in any given time interval from any luminary, but additionally suggests that photons are localized in space and time. The suggestion is conveyed by the fact that a detector surface capable of responding to individual photons, and very dimly illuminated, registers each photon arrival at some particular timestamp *t* at some particular coordinates *(x,y)* (at any rate in the sense of some one pixel, perhaps just 4 μm square) on the detector surface. Replace, now, the screen of Section 7.1.4 with a detector, consisting of a few millions of microscopic pixels. Let each pixel be sensitive enough to register the arrival of a single photon, and let the readout electronics supply for each detected photon arrival its particular value of *(x,y)*. Replace the various holeboards with a punctiform dim source, emitting on average just one photon per second. (One possible such source would be a faint star, so distant as to be of negligible angular diameter.) As the weeks and months and years and decades pass, a log is kept of the arrival points *(x,y)*. Mysteriously, the points group themselves into arrival-dense and arrival-sparse fringes, corresponding exactly to the bright and dark fringes generated when Slits W and E are illuminated by the bright nearby 50 μm pinhole with diffuser glass, or that optical counterpart that is the distant 5-mm aperture backed by perfect diffuser glass, of Section 7.1.4. How can this be? How can a photon arriving at, say, *t* = 20241226T134522Z know that particular *(x,y)* had received a photon at, say, *t* = 20241226T134521Z, or at *t* = 20240724T235959Z?

It is now usual to reply that a single photon is capable of "interfering with itself." This form of words leaves the paradox largely unalleviated, however, since each individual photon is indicated by the detector surface to be tightly localized in space (to, say, a tolerance of ± 2 μm, for 4 μm square pixels) when its journey ends, despite the much wider separation of Slits W and E.

It might be too much to demand that a duly careful RASC Handbook extension of the present treatment explain the seeming paradox. Such a treatment could, on the other hand, outline the various suggestions advanced, since at least the 1920s or 1930s, by the various authoritative interpreters of quantum mechanics, and indicate how close (or even how far?) the physics community now is to reaching a conceptual consensus. Among these interpreters are the debating opponents Einstein and Bohr. Likely to be relevant also is the literature surrounding the paradoxical "Schrödinger's cat," and the (related?) literature on the "Einstein-Podolsky-Rosen paradox." Something might even have to be written on attempts to supplant normal Boolean-algebra propositional logic with a special "quantum logic" that rejects the commonsense equivalence between "both *p* and either *q* or *r*" and "either both *p* and *q* or both *p* and *r*" (where, for definiteness, we might take "either…or….." inclusively, as meaning "at least one of …, ….. is the case"; but the same heterodoxy is asserted by quantum logicians also for "either…or….." taken exclusively, as meaning "exactly one of …, ….. is the case").

The treatment would ideally be undertaken not by this present RASC Handbook article author, but by someone with proper credentials, such as an Upper Second or a First from the Oxford "Honour School of Physics and Philosophy" (a serious university effort, now decades old, and admitting about a dozen qualified students every year, at confronting physics with the resources of conceptual analysis, notably including logic: ox.ac.uk/admissions/undergraduate/courses/course-listing/physics-and-philosophy).

Failing such conceptual depth, it might at least be possible in an upgrade of this present RASC Handbook article, by some writer or other (perhaps the present writer, in later years), to make a few quantitative points: for (e.g.) the near-infrared regime, how tight can the imposed standard of angular resolution for (e.g.) aperture-synthesis imaging become before the unavoidable graininess of photons vitiates the idealized light-as-waves experimentation in Section 7.1.4?

(B) A different kind of upgrade to the present RASC Handbook article would involve not the conceptual underpinnings, but some details of the calculations. It should be possible for some writer or other (perhaps this present writer, in later years) to fill in a few Fourier details. One would like to see at least the scenario of the two-pinhole holeboard, with slitboard and screen, worked out in one-dimensional Fourier terms, with the various fringe patterns from the various selected slitboards related in one-dimensional Fourier-series or one-dimensional Fourier-integral-transform, or one-dimensional inverse Fourier-integral transform, terms to the holeboard.

Our comments on the formidable Frontera supercomputer, as a machine for two-dimensional Fourier calculations, notwithstanding, not all this mathematical work is likely to prove difficult. One resource is Mary Boas's *Mathematical Methods in the Physical Sciences* (now at Wiley in its third (2006) edition, but known to this present RASC Handbook article writer from the Wiley second (1983) edition). Boas, working in one dimension, gives the usual kind of brisk and non-rigorous introduction to Fourier series, and then proceeds in a non-rigorous way to render the upgrade of series into Fourier integral transforms at least plausible. Surely this is a resource that can be coupled, given some effort, with any reasonable physics-course treatment of interference—perhaps already with that universal first-year resource that is Halliday-and-Resnick, in one of its many editions, but perhaps with some edition of the more detailed Eugene Hecht *Optics* (in which the Fourier analysis of aperture-synthesis imaging is taken even into the daunting two-dimensional case), coupled with its Eugene Hecht "Shaum's Outline" companion.

7.2: Interferometric aspects of the brightest-stars "Remarks" table summarized

The "Remarks" column of the long table forming the final part of this article includes those interferometric results known to this RASC Handbook writer.

Perhaps all the really major imaging results, up to 2022 or 2023 or so, have been duly documented (such as that major result that is the imaging of the α Leo A photosphere). It is also perhaps the case that most, or at least the majority, of binarity results up to 2022 or 2023 or so have been duly documented (for instance, the imaging of the β Per Aa1 (Algol), β Per Aa2 eclipsing binary; or again the imaging of ε Aur A, as partially eclipsed by the disk around its companion ε Aur B; or again, but at a humbler level, the mere (direct) detection of some companion, as with α Vir Aa (Spica), in a situation that prior to the development of interferometry would have yielded at best an (indirect) detection of a companion, through the procuring of spectral-binary (in our table notation, "SB") or double-lined spectral binary (in our table notation, "SB2") spectrograms)). The present table is also rather complete as regards the interferometric determination of stellar diameters, thanks to the already-cited JMDC. The JMDC catalogue is a compilation of directly determined stellar angular diameters, giving both direct determinations through interferometry and direct determinations through (lunar or planetary or asteroidal) occultations. We have used the latest JMDC results available to us, in the 2021 September JMDC entries, and have also documented that fraction of "Brightest Stars" cases in which the 2021 September JMDC lacks an entry.

There remains the problem of more minor brightest-star interferometric results. Here the present version of the "Brightest Stars" table is likely to have significant gaps.

We now summarize the interferometry results presented in the long table. Two scale-setting questions arise for each of the 324 nocturnal "Brightest Stars" in the long table: (1) What would be the observed angular width of a circumstellar disk physically filling, without overflowing, the Earth's orbit around the Sun, and seen face-on, at the given star's distance? In other words, what angle would be subtended at Earth by an object 2 au wide, at the given star's distance? Answering this question gives one some idea of the feasibility or infeasibility of interferometrically imaging a debris disk or dust disk around the given star, or of interferometrically detecting some rather close binary-system companion. (2) What would be the observed angular diameter of the Sun, at the given star's distance? In other words, what angle would be subtended at Earth by an object two solar radii wide, at the given star's distance? Answering this question gives one some idea of the feasibility or infeasibility of interferometrically imaging the photosphere of the given star.

In constructing this summary, distances have been taken from the "***D***", or distance-in-light-years, column in the long table, rather than from the "***π***," or parallax-in-milliarcseconds, column in the long table. This is because in a few cases ***D*** has not been computed directly from ***π***, perhaps because ***π*** is poorly known. The use of significant figures, with a distance sometimes given to three significant figures, sometimes to two, sometimes to just one, reflects the ongoing difficulty (discussed in Section 3 above) in determining stellar distances, even given such modern resources as *HIPPARCOS*.

It will be noted from the summary how very much more distended most of the 324 tabulated nocturnal "Brightest Stars" are than the Sun, in various cases extending even beyond the proportions of Earth's own circumsolar orbit.

D (ly)	Angular width (mas) of 2 au	Angular width (mas) of 2 $R_\odot$	Status in "Remarks"

from RA 00h00 onward:

α And Aa	97	67	0.31	orbit of Aa, Ab studied
β Cas A	55	120	0.55	gravity darkening of photosphere studied; ang. diam. measured (2.103 mas)
γ Peg A	400	16	0.08	ang. diam. measured (0.435 mas)
β Hyi	24.3	268	1.25	[no interferometry known to us]
α Phe	~85	~77	~0.36	[no interferometry known to us]
δ And Aa	106	62	0.29	ang. diam. measured (4.136 mas)
α Cas A	230	28	0.13	limb darkening studied ang. diam. measured (5.608 mas)
β Cet	96	68	0.32	chromosphere depth studied, with a signature of chromosphere structure noted; (photospheric) angular diameter repeatedly measured (5.510 mas)
η Cas A	19.4	336	1.56	ang. diam. measured (1.894 mas)
γ Cas A	600	11	0.05	ang. diam. studied (≤ 0.9 mas)
from RA 01h00 onward:				
β Phe AB	~180	~36	~0.17	[no interferometry known to us]
η Cet A	124	52.6	0.245	chromosphere depth studied; (photospheric) angular diameter measured (3.698 mas)
β And A	200	33	0.15	ang. diam. measured (13.749 mas)
δ Cas A	99	66	0.31	[no interferometry known to us]
γ Phe	230	28	0.13	[no interferometry known to us]
α Eri	140	47	0.22	oblateness, rotation studied; Be-phenom. disk formation studied, with imaging; ang. diam. measured (1.92 mas)

τ Cet A	11.9	548	2.55	ang. diam. measured (2.072 mas, 2.015 mas)
α Tri A	63	104	0.48	[no interferometry known to us]
β Ari A	59	110	0.51	AB orbit studied
ε Cas	400	16	0.076	ang. diam. measured (0.471 mas)
α Hyi	72	91	0.42	[no interferometry known to us]

from RA 02h00 onward:

γ And A	400	16	2	ang. diam. measured (7.814 mas)
α Ari	66	99	0.46	ang. diam. measured (6.792 mas)
β Tri	130	50	0.2	ang. diam. measured (1.05 mas)
o Cet Aa	300	20	0.1	Aa,Ab orbit studied; ang. diam. abundantly measured (e.g. 39.4 mas and 44.6 mas at 700 nm; e.g. 28.3 mas at 2190 nm)
γ Cet A	80	80	0.4	[no interferometry known to us]
θ Eri A	100	60	0.3	[no interferometry known to us]

from RA 03h00 onward:

α UMi Aa	430	15	0.071	ang. diam. measured (3.28 mas)
α Cet	250	26	0.12	ang. diam. measured (13.238 mas)
γ Per Aa,Ab	240	27	0.13	γ Per Aa,Ab orbit studied; ang. diam. measured for one of these two stars, as 3.894 mas

ρ Per	310	21	0.098	ang. diam. measured (16.555 mas)
β Per Aa1	90	70	0.3	Aa1,Aa2 orbit studied (55-frame animation compiled); ang. diam. of Aa1 measured (1.35 mas)
α Per A	510	13	0.059	[no interferometry known to us]
δ Eri	29.5	221	1.0	ang. diam. measured (2.386 mas)
δ Per Aa	500	13	0.061	angular diameter measured (0.544 mas poles, 0.610 mas eqtr)
γ Hyi	~214	~30.5	~0.142	ang. diam. measured (8.79 mas)
η Tau Aa	400	16	0.08	[no interferometry known to us]
ζ Per A	800	8	0.04	ang. diam. measured (0.54 mas)
γ Eri A	200	33	0.15	ang. diam. measured (9.332 mas)
ε Per A	600	11	0.05	[no interferometry known to us]
from RA 04h00 onward:				
λ Tau	480	14	0.063	[no interferometry known to us]
α Ret A	162	40	0.19	ang. diam. measured (2.618 mas)
ε Tau Aa	150	43	0.20	Aa,Ab orbit studied; ang. diam. measured (2.592 mas)
θ Tau Aa	150	43	0.20	Aa,Ab orbit studied
α Dor A	169	38.6	0.180	[no interferometry known to us]
α Tau A	67	97	0.45	mass loss studied, via “MOLsphere” inhomogeneities; angular diameter measured (21.099 mas)
π^3 Ori A	26.3	248	1.15	ang. diam. measured (1.409 mas)
ι Aur	500	13	0.06	ang. diam. measured (7.004 mas)

from RA 05h00 onward:

ε Aur A	~1450	~4.50	~0.02	eclipse by disk-shrouded object imaged (but “Aa,Ab” unresolved); ang. diam. of the primary in the unresolved ε Aur A two-star system measured (2.210 mas)
ε Lep	210	31	0.14	[no interferometry known to us]
η Aur	240	27	0.13	ang. diam measured (0.453 mas)
β Eri A	89	73	0.34	[no interferometry known to us]
μ Lep	190	34	0.16	[no interferometry known to us]
β Ori A	900	7	0.03	ang. diam. measured (2.606 mas)
α Aur Aa,Ab	43	150	0.71	Aa,Ab orbit studied; angular diameter measured for Ab (6.09 mas); 1977 reported angular-diameter measurement for Aa cannot now be taken as reliable (but astrophysical theory does indicate that Aa has physical diameter ~1.4 times physical diameter of Ab)
η Ori Aa	1000	6.5	0.03	[no interferometry known to us]
γ Ori A	250	26	0.12	ang. diam. measured (0.785 mas)
β Tau	130	50	0.23	ang. diam. measured (1.09 mas); imaged
β Lep A	160	41	0.19	[no interferometry known to us]
δ Ori Aa	700	9	0.04	[no interferometry known to us]
α Lep A	2000	3	0.015	ang. diam. measured (1.77 mas)
β Dor	1000	6.5	0.03	angular diameter of this (pulsating) Cepheid measured in a 6-episode timeseries, 1.6022 mas min, 1.8160 mas max

λ Ori A	~1100	~6	~0.03	ang. diam. measured (0.226 mas)
ι Ori Aa	2000	3	0.015	[no interferometry known to us]
ε Ori A	2000	3	0.015	ang. diam. measured (0.660 mas)
ζ Tau	400	16	0.08	Be-phenomenon disk studied
α Col A	260	25	0.12	[no interferometry known to us]
ζ Ori Aa	960	6.8	0.032	Aa,Ab orbit studied; angular diameter of ζ Ori Aa measured (0.556 mas)
ζ Lep	~70.5	~92.5	~0.430	ang. diam. measured (0.670 mas)
κ Ori	600	11	0.05	ang. diam. measured (0.44 mas)
β Col	87	75	0.35	[no interferometry known to us]
α Ori Aa	500	13	0.06	extended molecular outer atmosphere studied; dust halo studied through aperture-masking interferometry in polarimetry mode; speckle-interferometry "Aa,Ab" binarity assertion now discounted via better interferometry; angular diameter measured (43.15 mas)
from RA 06h00 onward:				
β Aur Aa,Ab	81	81	0.37	[no interferometry known to us]
θ Aur A	166	39.3	0.18	[no interferometry known to us]
η Gem A	400	16	0.076	ang. diam. measured (11.789 mas)
ζ CMa Aa,Ab	360	18	0.084	Aa,Ab orbit studied, at any rate in speckle interferometry
β CMa A	~490	~13	0.062	ang. diam. measured (0.542 mas)
μ Gem A	230	28	0.13	ang. diam. measured (15.118 mas)
α Car	~310	~21	~0.098	ang. diam. measured (6.920 mas)
ν Pup	370	18	0.082	[no interferometry known to us]

γ Gem Aa	110	59	0.28	ang. diam. measured (1.39 mas)
ε Gem A	800	8	0.04	ang. diam. measured (4.677 mas)
α CMa A	8.6	760	3.53	ang. diam. measured (5.993 mas)
ξ Gem	58.7	111	0.517	ang. diam. measured (1.401 mas)
α Pic	100	65	0.3	[no interferometry known to us]
τ Pup	180	36	0.17	[no interferometry known to us]
κ CMa	700	9	0.04	[no interferometry known to us]
ε CMa A	410	16	0.074	ang. diam. measured (0.80 mas)

from RA 07h00 onward:

σ CMa A	1100	5.9	0.028	[no interferometry known to us]
o^2 CMa	3000	2	0.01	[no interferometry known to us]
δ CMa	2000	3	0.015	ang. diam. measured (3.60 mas)
L_2 Pup A	210	31	0.14	circumstellar dust disk imaged
π Pup Aa	800	8	0.04	[no interferometry known to us]
δ Gem A	60	110	0.51	[no interferometry known to us]
η CMa A	2000	3	0.015	ang. diam. measured (0.75 mas)
β CMi A	~162	~40.3	~0.187	Be-phenomenon disk studied
σ Pup A	190	34	0.16	[no interferometry known to us]
α Gem A α Gem B	52	125	0.58	[no interferometry known to us]
α CMi A	11.5	567	2.64	ang. diam. measured (5.448 mas)
β Gem A	33.8	193	0.898	ang. diam. measured (8.134 mas)

ξ Pup A	1200	5.4	0.025	[no interferometry known to us]
χ Car	500	13	0.06	[no interferometry known to us]

from RA 08h00 onward:

ζ Pup	1080	6.04	0.028	ang. diam. measured (0.42 mas)
ρ Pup A	64	102	0.47	[no interferometry known to us]
γ Vel Aa	~1100	~5.9	~0.028	ejecta studied within the unresolved Aa colliding-winds spectral binary system; distance studied; angular diameter of the primary star within the unresolved Aa colliding-winds spectral binary system measured (0.44 mas)
β Cnc A	300	20	0.1	ang. diam. measured (5.167 mas)
ε Car A	600	10	0.05	[no interferometry known to us]
ο UMa A	~179	~36.4	~0.169	[no interferometry known to us]
δ Vel Aa	81	81	0.37	Aa,Ab orbit studied
ε Hya A	130	50	0.23	[no interferometry known to us]
ζ Hya	~157	~41.5	~0.193	ang. diam. measured (3.196 mas)

from RA 09h00 onward:

ι UMa A	47.3	138	0.641	[no interferometry known to us]
λ Vel A	540	12	0.056	[no interferometry known to us]
a Car	500	13	0.061	[no interferometry known to us]
β Car	113	57.7	0.268	ang. diam measured (1.59 mas)

ι Car	800	8	0.04	[no interferometry known to us}
α Lyn A	~203	~32.1	~0.149	ang. diam. measured (7.538 mas)
κ Vel	600	11	0.05	[no interferometry known to us]
α Hya A	180	36	0.17	ang. diam. measured (9.36 mas)
N Vel	240	27	0.13	[no interferometry known to us]
θ UMa A	44.0	148	0.690	postulated “Ab” SB companion sought, but in vain, in speckle interferometry; angular diameter measured (1.662 mas)
ο Leo Aa	135	48.3	0.225	Aa,Ab orbit studied; angular diameter of Aa measured (1.347 mas)
l Car	2000	3	0.015	pulsational variation in angular diameter measured (2.6905 mas min, 3.2726 mas max)
ε Leo	250	26	0.12	ang. diam. measured (2.587 mas)
υ Car A	~1400	~4.7	~0.022	[no interferometry known to us]
φ Vel A	1600	4.1	0.019	[no interferometry known to us]
from RA 10h00 onward:				
η Leo A	1300	5.0	0.023	B detected in speckle interf.? (assertion of detection has also been questioned)
α Leo A	79	83	0.38	inclination and low latitudes darkening measured, photosphere imaged, angular diameter measured (1.664 mas)
ω Car	340	19	0.089	[no interferometry known to us]
q Car A	660	9.9	0.046	[no interferometry known to us]
ζ Leo A	270	24	0.11	[no interferometry known to us]

λ UMa	140	47	0.22	ang. diam. measured (0.757 mas)
γ Leo A γ Leo B	130	50	0.23	ang. diam. of γ Leo A measured (7.7 mas)
μ UMa	230	28	0.13	ang. diam. measured (8.538 mas)
p Car	500	13	0.06	[no interferometry known to us]
θ Car	460	14	0.066	[no interferometry known to us]
μ Vel A	~117	~55.8	~0.259	[no interferometry known to us]
ν Hya	144	45.3	0.211	[no interferometry known to us]

from RA 11h00 onward:

β UMa	80	82	0.38	oblateness studied, and in turn used, with other oblateness studies and non-interferometric data, to assign an age to the entire (coeval) UMa moving group
α UMa A	120	54	0.25	ang. diam. measured (6.419 mas)
ψ UMa	145	45	0.21	ang. diam. measured (4.131 mas)
δ Leo A	58	110	0.52	ang. diam. measured (1.328 mas)
θ Leo	165	39.5	0.184	ang. diam. measured (0.769 mas)
ν UMa A	400	16	0.08	ang. diam. measured (4.561 mas)
ξ Hya Aa	130	50	0.23	ang. diam. measured (2.394 mas)
λ Cen Aa	400	16	0.08	[no interferometry known to us]
β Leo A	36	180	0.84	structure of circumstellar debris disk studied; angular diameter measured (1.339 mas)

γ UMa A	83	79	0.37	oblateness studied, and in turn used, with other oblateness studies and non-interferometric data, to assign an age to the entire (coeval) UMa moving group; angular diameter measured (0.922 mas)
from RA 12h00 onward:				
δ Cen Aa	400	16	0.08	[no interferometry known to us]
ε Crv	320	20	0.095	[no interferometry known to us]
δ Cru	350	19	0.087	[no interferometry known to us]
δ UMa A	81	81	0.37	oblateness studied, and in turn used, with other oblateness studies and non-interferometric data, to assign an age to the entire (coeval) UMa moving group; angular diameter measured (0.804 mas)
γ Crv	154	42.4	0.197	ang. diam. measured (0.75 mas)
α Cru A α Cru B	~320	~20	~0.095	[no interferometry known to us]
δ Crv A	87	75	0.35	[no interferometry known to us]
γ Cru A	89	73	0.34	[no interferometry known to us]
β Crv	146	44.7	0.208	[no interferometry known to us]
α Mus Aa	320	20	0.095	[no interferometry known to us]
γ Cen A γ Cen B	130	50	0.23	[no interferometry known to us]
γ Vir AB	39	170	0.78	[no interferometry known to us]
β Mus Aa	340	19	0.089	Ab detected
β Cru A	300	20	0.1	ang. diam. measured (0.722 mas)
ε UMa A	83	78	0.37	B detected in speckle interf.

δ Vir A	~198	~32.9	~0.153	ang. diam. measured (10.565 mas)
α CVn A	110	59	0.28	[no interferometry known to us]

from RA 13h00 onward:

ε Vir A	110	59	0.28	ang. diam. measured (3.318 mas)
γ Hya A	134	48.7	0.226	ang. diam. measured (3.71 mas)
ι Cen	59	110	0.51	[no interferometry known to us]
ζ UMa Aa	90	70	0.3	Aa,Ab orbit studied; oblateness of celestial-sphere neighbour ζ UMa Ca (Alcor; ζ UMa Aa is Mizar) studied, and in turn used, with other oblateness studies and non-interferometric data, to assign an age to the entire (coeval) UMa moving group; angular diameter of ζ UMa Ca measured (0.6845 mas)
α Vir Aa	250	26	0.12	Ab and Ac detected; distance deduced from Aa,Ab orbit without recourse to parallax; angular diameter of Aa measured (0.87 mas)
ζ Vir A	74	88	0.41	ang. diam. measured (0.852 mas)
ε Cen Aa	400	16	0.08	Ab detected; angular diameter of Aa measured (0.48 mas)
η UMa	104	63	0.292	ang. diam. measured (0.834 mas); imaged
ν Cen	440	15	0.069	[no interferometry known to us]
μ Cen Aa	510	13	0.059	Aa,Ab separation measured
η Boo A	37	180	0.82	ang. diam. measured (2.134 mas)
ζ Cen	380	17	0.080	[no interferometry known to us]

from RA 14h00 onward:

β Cen Aa,Ab	360	18	0.084	Aa,Ab orbit studied, both in speckle interferometry and in aperture-masking interferometry
π Hya	~101	~64.6	~0.300	[no interferometry known to us]
θ Cen A	59	110	0.51	[unclear whether ang. diam. measurement is available, since there is possibly a clerical error in the JMDC catalogue]
α Boo A	37	180	0.82	ang. diam. measured (21.373 mas)
ι Lup	340	19	0.089	[no interferometry known to us]
γ Boo Aa	87	75	0.35	Ab detected in speckle interf.
η Cen	310	21	0.097	[no interferometry known to us]
α Cen B	4.3	1500	7.06	α Cen AB orbit studied; α Cen B angular diameter measured (5.999 mas)
α Cen A	4.3	1500	7.06	α Cen AB orbit studied; α Cen A angular diameter measured (8.502 mas)
α Lup A	460	14	0.066	[no interferometry known to us]
α Cir A	54.1	121	0.561	[no interferometry known to us]
ε Boo A	200	33	0.15	[no interferometry known to us]
β UMi A	131	49.8	0.23	ang. diam. measured (10.301 mas)
α Lib Aa	76	86	0.40	α Lib Ab detected in speckle interferometry

from RA 15h00 onward:

β Lup	380	17	0.080	[no interferometry known to us]
κ Cen Aa	400	16	0.08	Aa,Ab orbit studied in speckle interferometry
β Boo	230	28	0.13	ang. diam. measured (2.484 mas)
σ Lib	290	22	0.10	ang. diam. measured (11.33 mas)
ζ Lup A	117	55.8	0.259	[no interferometry known to us]
δ Boo A	122	53.5	0.249	ang. diam. measured (2.764 mas)
β Lib	190	34	0.16	[no interferometry known to us]
γ UMi	490	13	0.062	[no interferometry known to us]
γ TrA	184	35.5	0.165	[no interferometry known to us]
δ Lup	900	7	0.03	[no interferometry known to us]
ε Lup Aa	500	13	0.06	Ab detected
ι Dra A	101	64.6	0.300	ang. diam. measured (3.559 mas)
α CrB	75	87	0.40	ang. diam. measured (1.202 mas)
γ Lup A	400	16	0.08	γ Lup AB orbit studied
α Ser A	74	88	0.41	ang. diam. measured (4.77 mas)
μ Ser A	170	38	0.18	μ Ser B detected in speckle interf.
β TrA A	40.4	161	0.751	[no interferometry known to us]

from RA 16h00 onward:

π Sco Aa	600	11	0.05	[no interferometry known to us]
T CrB A	2500?	2.6?	0.012?	[no interferometry known to us]
η Lup A	440	15	0.069	[no interferometry known to us]

δ Sco A	440	15	0.069	δ Sco AB orbit studied, δ Sco A "Be phenomenon" disk imaged, δ Sco A angular diameter measured (0.46 mas)
β Sco Aa	400	16	0.08	[no interferometry known to us]
δ Oph A	171	38.1	0.18	ang. diam. measured (9.93 mas)
ε Oph A	106	61.5	0.286	ang. diam. measured (2.966 mas)
σ Sco Aa1	700	9	0.04	Aa1,Aa2 orbit studied
η Dra A	92	71	0.33	ang. diam. measured (3.47 mas)
α Sco A	600	11	0.05	photosphere imaged, with also a velocity map constructed, detailing some downdrafts and upwellings; angular diameter measured (39.759 mas)
β Her Aa	140	47	0.22	β Her Ab detected in speckle interferometry; angular diameter of β Her Aa measured (3.472 mas)
τ Sco	500	13	0.06	ang. diam. measured (0.338 mas)
ζ Oph	370	18	0.082	ang. diam. measured (0.54 mas)
ζ Her A	35	190	0.87	ζ Her "Ab" detected in speckle interferometry (but since this pair is only sparsely studied, "Aa,Ab" designations are not as yet WDS-official; angular diameter of ζ Her "Aa" measured (2.266 mas)
η Her A	109	59.8	0.278	ang. diam. measured (2.493 mas)
α TrA A	390	16.7	0.078	ang. diam. measured (9.24 mas)
ε Sco	64	102	0.47	[no interferometry known to us]
μ^1 Sco A	500	13	0.06	[no interferometry known to us]
κ Oph	91	72	0.33	ang. diam. measured (3.608 mas)

from RA 17h00 onward:

ζ Ara	490	13	0.062	ang. diam. measured (7.09 mas)
ζ Dra A	330	20	0.092	ang. diam. measured (0.488 mas)
η Oph AB	90	70	0.3	[no interferometry known to us]
η Sco A	73	89	0.42	[no interferometry known to us]
α Her Aa	400	16	0.08	limb darkening studied; episode of copious mass loss studied; speckle-interferometry attempt, at BTA-6, to detect the historically suspected companion of α Her Ab has yielded no detection; angular diameter measured (36.026 mas)
π Her	380	17	0.080	ang. diam. measured (5.159 mas)
δ Her Aa	75	87	0.40	Aa,Ab orbit (sparsely) studied
θ Oph A	440	15	0.069	[no interferometry known to us]
β Ara	600	11	0.05	[no interferometry known to us]
γ Ara A	1100	5.9	0.028	[no interferometry known to us]
β Dra A	380	17	0.080	ang. diam. measured (3.225 mas)
υ Sco	600	11	0.05	[no interferometry known to us]
α Ara A	300	22	0.1	"Be phenomenon" disk studied
λ Sco Aa,Ab	400	16	0.08	Aa,Ab orbit studied
α Oph A	49	130	0.62	rotation-induced oblateness imaged for a star in the α Oph A binary system; "Aa,Ab" orbit studied (although WDS does not yet use the designations "Aa", "Ab"); angular diameter of a star in the α Oph A binary system measured (1.855 mas)

ξ Ser Aa	105	62.1	0.289	[no interferometry known to us]
θ Sco A	300	22	0.1	[no interferometry known to us]
κ Sco	480	14	0.063	[no interferometry known to us]
β Oph	82	80	0.37	ang. diam. measured (4.511 mas)
μ Her Aa	27.1	241	1.12	ang. diam. measured (1.88 mas)
ι^1 Sco A	2000	3	0.02	[no interferometry known to us]
G Sco A	126	51.8	0.241	[no interferometry known to us]
γ Dra A	154	42.4	0.197	ang. diam. measured (9.86 mas)

from RA 18h00 onward:

ν Oph	150	43	0.20	ang. diam. measured (2.789 mas)
γ^2 Sgr	97	67	0.31	[no interferometry known to us]
η Sgr A	~146	~44.7	~0.208	[no interferometry known to us]
δ Sgr A	350	19	0.086	[no interferometry known to us]
η Ser A	~60.5	~108	~0.501	ang. diam. measured (3.062 mas)
ε Sgr A	~143	45.6	~0.212	ang. diam. measured (1.44 mas)
α Tel	280	23	0.11	[no interferometry known to us]
λ Sgr A	78	84	0.39	[no interferometry known to us]
α Lyr A	25.0	261	1.21	rotation studied; angular diameter measured (3.28 mas)
φ Sgr	240	27	0.13	binarity detected (separation 17.7 mas; we may in due course expect to see "φ Sgr A", "φ Sgr B" entries in WDS)

β Lyr Aa1	~960	~6.8	~0.032	Aa1,Aa2 orbit studied; Aa1,Aa2 motions animation compiled; circumbinary Aa1,Aa2 dust disk now amenable to some analysis
σ Sgr Aa	230	28	0.13	Aa,Ab positions measured (at any rate once)
ξ^2 Sgr	400	16	0.08	[no interferometry known to us]
γ Lyr A	600	11	0.05	ang. diam. measured (0.734 mas)

from RA 19h00 onward:

ζ Sgr AB	90	70	0.3	[no interferometry known to us]
ζ Aql A	83	79	0.37	ang. diam. measured (0.888 mas)
λ Aql	120	54	0.25	ang. diam. measured (0.57 mas)
τ Sgr	120	54	0.25	[no interferometry known to us]
π Sgr AB	500	13	0.06	[no interferometry known to us]
δ Dra A	97	67	0.31	ang. diam. measured (3.254 mas)
δ Aql Aa	51	130	0.59	Ab detected in speckle interf.
β Cyg Aa	330	20	0.092	β Cyg Ab,Ac detected in speckle interferometry; β Cyg Aa angular diameter measured (4.834 mas)
δ Cyg A	160	41	0.19	ang. diam. measured (0.884 mas)
γ Aql A	390	17	0.078	ang. diam. measured (7.056 mas)
χ Cyg A	~500	~13	~0.06	angular width fluctuations studied (yielding distance when combined with spectroscopic measurements of line-of-sight velocity fluctuations): 34.0 mas, 40.0 mas, 43.5 mas

α Aql A	16.7	391	1.82	photosphere, and rotationally induced oblateness, imaged; one of the angular widths of the rotationally distorted disk measured in a separate and more rudimentary study (3.309 mas)
η Aql A	1000	7	0.03	ang. diam. measured (1.804 mas)
γ Sge	260	25	0.12	ang. diam. measured (6.225 mas)
from RA 20h00 onward:				
θ Aql Aa	290	22	1.4	[no interferometry known to us]
β Cap Aa	300	22	0.1	β Cap Aa,Ab orbit studied (where β Cap Ab is itself an unresolved binary)
γ Cyg A	2000	3	0.02	ang. diam. measured (1.018 mas)
α Pav A	180	36	0.17	ang. diam. measured (0.80 mas)
α Ind A	98	66	0.31	[no interferometry known to us]
α Cyg A	~1400	~4.7	~0.022	ang. diam. measured (1.017 mas)
η Cep A	46.5	140	0.652	ang. diam. measured (2.882 mas)
β Pav	135	48	0.225	[no interferometry known to us]
ε Cyg Aa	73	89	0.42	ε Cyg Ab detected; ε Cyg Aa ang. diam. measured (4.61 mas)
from RA 21h00 onward:				
ζ Cyg Aa	140	47	0.22	ang. diam. measured (2.821 mas)
α Cep A	49.1	133	0.618	photosphere imaged; angular diameter measured (1.577 mas)
β Cep Aa	700	9	0.04	ang. diam. measured (0.28 mas); angular-diameter pulsational variation also studied

β Aqr A	500	13	0.06	ang. diam. measured (2.704 mas)
μ Cep A	3000?	2?	0.01?	ang. diam. measured (20.584 mas)
ε Peg A	700	9	0.04	ang. diam. measured (7.459 mas)
δ Cap A	38.7	169	0.784	[no interferometry known to us]
γ Gru	210	31	0.14	[no interferometry known to us]

from RA 22h00 onward:

α Aqr A	~520	~13	~0.058	ang. diam. measured (3.066 mas)
α Gru A	101	64.6	0.300	ang. diam. measured (1.02 mas)
θ Peg	90	70	0.3	ang. diam. measured (0.862 mas)
ζ Cep	800	8	0.04	ang. diam. measured (5.234 mas)
α Tuc	200	33	0.16	[no interferometry known to us]
δ Cep A	900	7	0.03	ang. diam. measured (1.018 mas)
ζ Peg A	210	31	0.14	ang. diam. measured (0.562 mas)
β Gru	180	36	0.17	[no interferometry known to us]
η Peg Aa	210	31	0.14	η Peg Aa,Ab orbit studied in speckle interferometry; ang. diam. measured (3.471 mas)
ε Gru	130	50	0.23	[no interferometry known to us]
ι Cep	115	56.7	0.264	ang. diam. measured (2.646 mas)
μ Peg	106	61.5	0.286	ang. diam. measured (2.496 mas)
δ Aqr	160	41	0.19	[no interferometry known to us]
α PsA Aa	25.1	260	1.21	alignment of circumstellar debris disk studied; angular

				diameter of α PsA Aa measured (2.223 mas)
from RA 23h00 onward:				
β Peg A	~196	~33.3	~0.155	ang. diam. measured (17.982 mas)
α Peg	133	49.0	0.228	ang. diam. measured (1.052 mas); imaged
γ Cep A	46	140	0.66	ang. diam. measured (3.254 mas)

APPENDIX: Glossary of acronyms and similar designation

The following is a glossary of the acronyms and similar designations used in the essay and table. We omit, as sufficiently obvious, a small handful of universally known acronyms (e.g. NASA), designations of chemical elements and chemical compounds (e.g. CO, for carbon monoxide), and the like. We do include some designations of particular satellites or similar space missions (e.g. *BRITE*, *MOST*).

- AAT: Anglo-Australian Telescope (3.9 m, Siding Spring Mountain, New South Wales, Australia)
- AAVSO: American Association of Variable Star Observers
- AAVSO(VSX): AAVSO International Variable Star Index (www.aavso.org/vsx)
- ALMA: internationally funded Chile-based radio interferometer ("Atacama Large Millimetre/submillimetre Array")
- AMBER: spectro-interferometric beam-combining facility at VLT ("Astronomical Multi-BEam combineR")
- AGB: asymptotic giant branch (as a region in the two-dimensional MK luminosity-versus-temperature stellar classification space)
- Astron. Alm.: *The Astronomical Almanac*, as the joint annual publication, in print and to a reduced extent online, of the United States Naval Observatory and HM Nautical Almanac Office; "Section H" (not necessarily always up to date in the online version) provides V magnitudes, B–V and V–I colours, and MK types for several hundred bright stars; Astron. Alm. particulars can be had from asa.hmnao.com and aa.usno.navy.mil/publications/asa
- AT: one of four "Auxiliary Telescopes" at VLTI, each of aperture 1.8 m, each movable on a track to enable operators to vary the interferometer baseline length (contrast with UT)
- au: astronomical unit (the formal 2012 IAU definition is in effect a precisification, in the (SI) laboratory unit of metres, of the earlier epoch-of-Kepler au concept; before 2012 the concept was defined in astronomical, as distinct from laboratory, terms—before 1976 as the half the sum of the Earth-to-Sun distance at perihelion and the Earth-to-Sun distance at aphelion, and from 1976 onward with a gravitation-theory precisification of that half-of-sum concept)
- BeSS: database of hot emission-spectra stars, notably including "Be phenomenon" stars, maintained at LESIA (Paris-Meudon): basebe.obspm.fr/basebe/
- *BRITE*: *BRIte Target Explorer*, a.k.a. *Canadian Advanced Nanospace eXperiment 3* (*CanX-3*: constellation of precision-astrometry satellites (6 attempted, 5 successfully deployed), as a Canada-

Austria-Poland collaboration; first launch was in 2013)

- BSC5: Yale Bright Star Catalog, Version 5
- BSG: blue supergiant
- BTA-6: Bolshoi Teleskop Alt-azimutalnyi-6 *(*Большой Телескоп Альт-азимутальный-6, "Large Alt-Azimuth Telescope 6": 6-m telescope on north side of Caucasus Mountains, Russia)
- CADARS: Catalogue of Absolute Diameters and Apparent Radii of Stars (doi.org/10.1051/0004-6361:20000451)
- *Cassini*: a frequently used name for the ESA *Cassini-Huygens* mission
- CDS: Centre de Données astronomiques de Strasbourg; the entity maintaining the SIMBAD database
- CHARA: the Mount Wilson optical interferometer (Center for High Angular Resolution Astronomy)
- CLASSIC [not an acronym?]: the original two-beam combiner at CHARA, later developed into the three-beam combiner CLIMB
- CLIMB: three-beam combining facility at CHARA ("CLassic Interferometry with Multiple Baselines")
- CME: coronal mass ejection
- CNO cycle: the carbon-nitrogen-oxygen-catalyzed cycle under which the hotter stars fuse hydrogen into helium
- COAST: the Cambridge optical interferometer (Cambridge Optical Aperture Synthesis Telescope)
- CODEX: a series of computer codes for the numerical simulation of stellar atmospheres (Cool Opacity-sampling Dynamic EXtended)
- *CORIOLIS*: USA-but-not-NASA satellite launched 2003; mission involves not only instrumentation for Earth ocean-environs monitoring, but also solar-wind monitor SMEI (Solar Mass Ejection Imager)
- DAO: Dominion Astrophysical Observatory (on Vancouver Island, British Columbia)
- DDO: David Dunlap Observatory (at Richmond Hill, in the Toronto suburbs)
- DR2: Data Release 2 (at *Gaia*)
- EHF: Extremely High Frequency (the portion of the radio spectrum extending from 30 GHz to 300 GHz)
- EHT: Event Horizon Telescope (an intercontinental collaboration in radio-astronomy aperture-synthesis imaging, noted for imaging black-hole shadows at the heart both of M87 and of our own galaxy)
- ELT: Extremely Large Telescope (ESO observatory under construction in Chile, with 39.3 m primary mirror)
- ESA: European Space Agency
- ESO: European Southern Observatory (multiple sites, in northern Chile)
- FDU: First Dredge-Up (as a stage in stellar evolution, soon after a star evolves out of the MS)
- FUV: far ultraviolet
- *GALEX*: "GALaxy Evolution eXplorer" (a NASA mission)
- GCPD: General Catalogue of Photometric Data (University of Lausanne, Switzerland)
- GCVS: General Catalogue of Variable Stars (Sternberg Astronomical Institute, Moscow)
- GRAVITY [a name, not an acronym]: one of the second-generation beam-combining facilities at VLTI, used both for precision astrometry and for interferometric aperture-synthesis imaging
- GTR: general theory of relativity
- Hp: a visible-light passband used for photometry at *HIPPARCOS*
- HM Nautical: "His Majesty's Nautical" (for UK publications and UK agencies)

- HR diagram, HR plot: two-dimensional luminosity-versus-temperature plot for the members of some given population of stars; it is useful to distinguish the "observational" (phenomenological, MK-classification) and the "theoretical" HR diagrams
- *HST*: *Hubble Space Telescope*
- IAU: International Astronomical Union (Paris)
- IR: infrared; the principal named passbands in infrared astronomy, as tabulated in en.wikipedia.org/wiki/Infrared_astronomy, are I,J,H,K,L,M in near-infrared (to 5.0 µm), N and Q in mid-infrared (7.5 µm to 25 µm), Z in far infrared (28 µm through 40 µm); one might propose, as a mnemonic, "**I**ndiana **J**ones **H**ec**K**les **M**e **N**ow **Q**uite **Z**ealously"
- IRAF: Image Reduction and Analysis Facility: a suite of software tools, for astronomical tasks including aperture photometry and the "extraction of one-dimensional spectra" from raw spectrograms, available free of charge from the National Optical Astronomy Observatory (USA); very widely used at North American professional observatories, and quite widely also, but in competition with MIDAS, at professional observatories outside North America: ast.noao.edu/data/software
- IS: Instability Strip (as a region in the two-dimensional luminosity-versus-temperature stellar-classification space)
- ISM: interstellar medium
- ISO: International Organization for Standardization / Organisation internationale de normalisation / Международная организация по стандартизации (the short designation "ISO" for this Geneva-headquartered standards-coordinating organization, with its three official languages, is not an acronym, but has been asserted (perhaps inaccurately) to be a reference to classical Greek ίσος, "equal")
- *IUE*: *International Ultraviolet Explorer* (space telescope: NASA, ESA, and United Kingdom; 1978–1996)
- JMDC: the "JMMC Measured Stellars Diameter Catalog," an initiative of JMMC, the "Centre Jean-Marie Mariotti" (a network, with headquarters in Grenoble, of French bodies active in astronomical interferometry): for latest version, search under the term "JMDC" in the search engine at vizier.cds.unistra.fr
- *JWST*: *James Webb Space Telescope*
- LESIA: Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique (physically at Paris-Meudon): lesia.obspm.fr
- LPV: long-period variable
- LSR: Local Standard of Rest (as reference frame for kinematics of bodies in our own galaxy)
- $M_\odot$: solar mass
- mas: milliarcsecond
- MATISSE: "Multi AperTure mid-Infared SpectroScopic Experiment" (one of the second-generation beam-combining facilities at VLTI)
- MIDI: "Mid-infrared Interferometric Instrument" (one of the first-generation beam-combining facilities at VLTI)
- MIRC: "Michigan InfaRed Combiner" (a beam-combining facility at CHARA)
- MK: Morgan-Keenan (two-dimensional phenomenological, non-theoretical, stellar classification scheme, with "MK luminosity classes" and "MK temperature types")
- MROI: Magdalena Ridge Observatory Interferometer (interferometer under development at Magdalena Ridge in New Mexico)
- *MOST* (*Microvariability and Oscillations of Stars/Microvariabilité et Oscillations STellaire*): Canadian space telescope for precision photometry; launched in 2003, deactivated in 2019
- MS: Main Sequence (as a region in the two-dimensional luminosity-versus-temperature stellar

classification space; it is useful to distinguish the "observational MS," in other words the empirical MK luminosity class V, from the "theoretical MS")

- My: megayears
- NCP: North Celestial Pole
- NIRISS: "Near InfRared Imager and Slitless Spectrograph" (an instrument on JWST, designed to be capable of exoplanet spectroscopy)
- NPOI: "Navy Precision Optical Interferometer": an interferometer in Arizona
- NSV: New Catalogue of Suspected Variable Stars (Sternberg Astronomical Institute, Moscow)
- OBAFGKMLTY: the temperature-ordered sequence of MK types, with O the hottest and Y the coolest; until the discovery of brown dwarfs, in types L, T, and (very recently) Y, the sequence was simply OBAFGKM, recalled by 20th-century students with the unfortunate mnemonic "Oh Be A Fine Girl Kiss Me" (implementing gender-neutrality, and allowing for the three progressively cooler brown-dwarf types, one might instead propose "**O**h **B**e **A** **F**ine **G**ymnast, **K**iss **M**e **L**ike **T**his, **Y**owee"); outside this sequence are the special MK labels (marking gross chemical anomalies) W (for the Wolf-Rayet stars; these turn out to be hot, like O stars), C (for stars whose photospheres are rich in carbon; these turn out to be cool, like K or M) and S (for stars with chemically anomalous photospheres, these are in terms of spectral phenomenology intermediate between M and C, and turn out to be cool); C is the current label for a group that was in earlier decades divided into R and N: additionally, the special "D" and "P" flags are used, in a more colloquial MK spirit, for planetary nebulae hosts and white dwarf "stars"
- OGLE: Optical Gravitational Lensing Experiment: a large long-term (1992-present) variability survey conducted largely from Las Campanas in Chile, under the leadership of Warsaw University, noted both for stellar-variability results and for exoplanet results
- OHP: Observatoire de Haute-Provence (France)
- PA: position angle
- PASTEL: [derivation of name or acronym not known to us]: a catalogue of stellar-atmosphere parameters: for latest version, search under the term "PASTEL" in the search engine at vizier.cds.unistra.fr
- PAVO: "Precision Astronomical Visible Observations" (a beam-combining facility at CHARA)
- PIONIER: "Precision Integrated-Optics Near-infrared Imaging ExpeRiment" (a second-generation beam-combining facility at VLTI)
- PTI: Palomar Testbed Interferometer
- $R_{\odot}$: solar radius
- R*: stellar radius (with reference to some given, reasonably spherical, star)
- R_{eq}: equatorial radius (with reference to some given rotationally flattened star)
- RGB: red-giant branch (as a region in the two-dimensional luminosity-versus-temperature stellar classification space)
- *ROSAT (Röntgensatellit)*: Germany-UK-USA joint X-ray astronomy satellite (1990–1999)
- R_{pol}: polar radius (with reference to some given rotationally flattened star)
- RSG: red supergiant
- SAAO: South African Astronomical Observatory
- SB: spectral binary, whether double-lined or single-lined
- SB2: double-lined spectral binary
- SETI: search for extraterrestrial intelligence
- SHF: Super High Frequency (the portion of the radio spectrum extending from 3 GHz to 30 GHz)

- SI: Système International d'Unités; the internationally agreed system of second-metre-kilogram-ampere-kelvin-mole-candela laboratory units, at one time implemented with recourse to some physical artefacts (including most notoriously the "standard kilogram," in a vault at the Bureau International des Poids et Mésures in France), but since a 2019 decision defined in a way that can be reproduced by any duly equipped laboratory, independently of artefacts; SI, in its various iterations through the decades, is a 1960 precisification of the earlier internationally agreed "MKS system," from 1889
- SIM: Space Interferometry Mission (a cancelled NASA project)
- SIMBAD: Set of Identifications, Measurements and Bibliography for Astronomical Data (database for astronomical objects outside the solar system, maintained by the Centre de Données astronomiques de Strasbourg (CDS), at simbad.u-strasbg.fr/simbad)
- SGB: sub-giant branch (as a region in the two-dimensional luminosity-versus-temperature stellar classification space)
- SMEI: Solar Mass Ejection Imager, as an instrument on the *CORIOLIS* satellite
- SN: supernova
- SNR: supernova remnant
- STIS: Space Telescope Imaging Spectrograph System (an instrument on *HST*)
- SWB: stellar-wind bubble
- *TESS*: *Transiting Exoplanet Survey Satellite* (NASA)
- *TPF*: *Terrestrial Planet Finder* (a cancelled NASA project)
- UHF: Ultra High Frequency (the portion of the radio spectrum extending from 300 MHz to 3 GHz)
- UT: one of four "Unit Telescopes" at VLTI, each of aperture 8.2 m, each in a fixed position on the observatory site (contrast with AT (track-mounted, movable))
- UV: ultraviolet
- V: the visible-light passband in the UBVRI photometric passband system that best approximates the response of the human eye, as lying between the blue ("B") and red ("R") visible-light passbands
- VEGA: "Visible spEctroGraph and polArimeter" (a beam-combining facility at CHARA)
- VINCI: "VLT Interferometer Commissioning Instrument" (the first of the first-generation beam-combining facilities at VLTI)
- VLA: Very Large Array (interferometric radio telescope facility in New Mexico, capable of aperture-synthesis imaging)
- VLT: a Chile-based facility of the European Southern Observatory (Very Large Telescope)
- VLTI: the interferometer at VLT
- VSX: AAVSO International Variable Star Index (www.aavso.org/vsx)
- WFC3: Wide Field Camera 3 (an instrument on *HST*)
- WFPC2: Wide Field and Planetary Camera 2 (an instrument on *HST*)
- WD: white dwarf
- WDS: Washington Double Star Catalog: www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/WDS
- *WIRE*: *Wide-field Infrared Explorer* (a.k.a. *Explorer 75*, a.k.a. SMEX-5); a NASA space telescope, 1999–2000
- WR: Wolf-Rayet (as a type of star)
- ZAMS: zero-age Main Sequence (the subregion of the MS comprising stars that have just begun stable core-hydrogen fusion)

History of recent revisions to both essay and table

Recent revisions are tracked with UTC YYYYMMDDThhmmssZ timestamping, in the "major.minor.patch" version-numbering scheme common in software development.

- 20250911T151030Z/11.2.1: Corrected Schedar, Diphda, and Aldebaran to be BOLD
- 20250731T131930Z/11.2.0: Precessed RA, DEC to epoch 2026.5. Updated information on multiple-star systems in "Remarks", both in the first row and in subsequent rows, using the WSD information available around 2025 April. Added several IAU-official star names, to reflect IAU nomenclature rulings in 2024 and 2025. Added some confirmed exoplanet detections and exoplanet candidates, working from https://exoplanet.eu/catalog/, and removed the exoplanet flag from the erroneously flagged δ Vel Aa. This version was sufficiently polished to support the print edition of the 2025 Handbook, and was in principle also sufficiently polished to support uploading to the online-version server. (But since the differences from version 11.1.0 were rather small, it was not clear that an upload would be warranted: this would depend on the workload of the RASC editorial desk; a more ambitious version 12.0.0 was in progress, with completion anticipated in the final calendar quarter of 2025.)
- 20240808T193630Z/11.1.0: Precessed RA, DEC to epoch 2025.5. Updated multiple-star-system separations in all and only instances in which such data could be fitted into the first row of "Remarks." Supplied updated first-row photometry information for the variables o Cet Aa (Mira), T CrB A, and χ Cyg A. (When these updates were done, a T CrB A nova outburst was awaited, but had not yet occurred.) Made a few minor additions of substance, including a glossary entry for ISO. Made minor adjustments at the levels of both copy-edit and formatting. This version was sufficiently polished to support the print edition of the 2025 Handbook, but was not yet sufficiently polished to support uploading to the online-version server. In particular, there was no attempt to harmonize the (in occasional cases updated) first row of "Remarks," which supports the print edition, with the (not as yet updated) subsequent rows (visible in the online version, and yet not visible in the print edition).
- 20240630T031000Z/11.0.2: Made minor changes including punctuation, layout, and some grammar/spelling
- 20240522T134630Z/11.0.0: Added long interferometry section ("Section 7") to essay. Added to the "Remarks" cell for each star entry a comment on the status of JMDC-catalogued direct determinations (generally via interferometry, in a few cases via occultations) of stellar diameter. In a few cases, added also other information on interferometry. Updated AAVSO(VSX) photometry information, while not at this point attempting an update in WDS astrometry. Made other minor updates. This version 11.0.0 was sufficiently polished to support uploading to the online-version server (but was prepared in the realization that the RASC editorial team might also choose to make small adjustments, to be documented here, before their upload, in which case what would be uploaded by that team would instead be version 11.*x*.*y*, with *x* most likely = 0 and *y* most likely some small positive integer).
- 20230809T08153000Z/10.0.0: Precessed RA, DEC to epoch 2024.5. Updated multiple-star-system separations and variable-star info in all and only instances in which such data could be fitted into the first row of "Remarks." This version was sufficiently polished to support the print edition of the 2024 Handbook, but not yet sufficiently polished to support uploading to the online-version server. (In particular, there was no attempt to harmonize the (in many cases updated) first row of "Remarks," which supports the print edition, with the (not as yet updated) subsequent rows (visible in the online version, and yet not visible in the print edition).)
- 20230214T144000Z/9.1.1: Made all hyperlinks (notably, literature references) blue-underlined and active; created bookmarks for sections and subsections; removed the word "Subsection" in headings.
- 20230208T183000Z/9.1.0: Changed AU to the abbreviation "au"; changed en dash to em dash in running text; changed all single and double quotes to "curly quotes"; changed all hyperlinks to blue-

underlined. (Even though so marked, not all the identified hyperlinks actually link to anything. This problem was addressed in version 9.1.1.)

- 20230202T210000Z/9.0.0: Added to version 8.0.0 two hitherto overlooked, but occasionally bright, stars, χ Cyg A and μ Cep, and in part as a consequence of this addition checked and adjusted the numbers of stars asserted to be present in Sample S and some salient supersets of Sample S. Added long photometry section ("Section 6") to essay. Added to the Remarks cell for each table entry a summary of AAVSO(VSX) situation (whether the given lone star or binary system or nested-binaries system is flagged at AAVSO(VSX) as a confirmed variable, as a suspected variable, or as a confirmed non-variable; and if one of these three flags is present, then also what variability classification symbol, if any, is assigned at AAVSO(VSX)). This version 9.0.0 was sufficiently polished to support uploading to the online-version server (but was prepared in the realization that the RASC editorial team might also choose to make small adjustments, to be documented here, before their upload, in which case what would be uploaded by that team would instead be version 9.*x*.*y*, with *x* most likely = 0 and *y* most likely some small positive integer).
- 20220816T235901Z/8.0.0: Precessed RA, DEC to epoch 2023.5. Overhauled photometry, *(a)* taking m_v and B−V values from GCPD where possible, and otherwise from the various post-1990 sources used by SIMBAD, *(b)* indicating in m_v and Remarks columns all cases of confirmed variability, suspected variability, and confirmed non-variability documented at AAVSO(VSX). This version was sufficiently polished to support the print edition of the 2023 Handbook, but not yet sufficiently polished to support uploading to the online-version server.
- 20220311T033032Z/7.0.1: Performed significant editing and formatting, particularly in the use tabs and in the fitting of long remarks into available space; corrected a few spelling errors. Removed all instances of "http://" as these are redundant in a URL; also removed italics on HST (only use italics on full text, i.e. *Hubble Space Telescope*)
- 20220303T210237Z/7.0.0: Performed sufficient updating of the 5.x.x version series to support not only the print edition of the 2022 Handbook, but also to support uploading to the online-version server. With the now-noted binarity of ζ CMa Aa,Ab, the count of Sample S (in the essay) was increased from 322 stars to 323 stars. Also in the essay, the former Section 4 was reassigned as Section 5, and a rather long Section 4 was inserted, discussing the astrophysics of binaries. Concomitantly with this addition of this essay section, astrometric detail was added, under "Remarks," to perhaps roughly one out of every four table entries, in a general review of the treatment of binaries, and underlining was added in the leftmost column of the table to flag cases in which a binary system possesses a published orbital solution. Apart from many small revisions in the table, extended "Remarks" treatments were inserted for two stars of special interest, δ Sco A (amateur photometry and amateur spectroscopy is particularly needed during and around the time of periastron passage, in 2022 May) and α Her Aa.
- 20210811T201642Z/6.0.0: Performed sufficient updating of the 5.x.x version series to support the print edition of the 2022 Handbook, but without sufficient updating to support uploading to the online-version server.
- 20210807T203107Z/5.2.0: Made various copy-edit corrections (such as insertion of missing punctuation, correction of a few spelling errors), and additionally on the side of scientific substance made a few corrections or amplifications (chiefly as follows: amplified the essay elucidation of "n," "nn" in MK types; improved an essay remark on rotation in stellar evolution; made essay correction regarding protracted-versus-brief membership of SGB; corrected essay list of Be-phenomenon stars (the phenomenon is not observed in Adhara); added "SGB" to glossary of acronyms; improved table discussion of exoplanet status for α Tau A (Aldebaran); corrected table magnitude range for α Ori Aa (Betelgeuse); corrected table typo for angular distance in α Cru AB (Acrux and companion; correct value is 3.5″, not 35″); corrected table typo for magnitude of η Oph B (correct value is 3.3, not 7.3); updated α PsA Aa (Fomalhaut) table entry to reflect the fact that HST-imaged "exoplanet" Dagon (2008) has now faded below the imaging threshold, and is therefore now believed to be an expanding, and therefore an increasingly tenuous, debris cloud rather than a true exoplanet); this version is a supplement to the 2021 Handbook, with the upcoming 6.x.x series intended to support instead the 2022 Handbook.

- 20210217T042710Z/5.1.1: Made minor adjustments to tabs and spacing for paragraphs before creating online PDF.
- 20210216T161213Z/5.1.0: Made minor adjustments (small points of syntax, spelling, punctuation, or similar, with much bibcode error correction). Added a long paragraph with five methods for retrieving a full-text, all-illustrations PDF from a typical astronomical bibcode citation. Corrected a mistake of astrophysical substance, in the subsection 4.8 discussion of onset-of-helium-core-fusion (violence in the onset of core-helium fusion is characteristic of the less massive, not of the more massive, incipient fusers-of-core-helium). This yielded a work sufficiently updated to support uploading to the online-version server.
- 20210128T145046Z/5.0.0: Made major revisions of the 4.0.0 version series, by adding several thousand words to the introductory online essay, with stellar-evolution background and a detailed briefing on the amateur-relevant "Be phenomenon" and "shell spectra" (and to a lesser extent by expanding "Remarks," most notably for α Eri (Achernar), ζ Tau (Tianguan), and α Aql A (Altair); other work on "Remarks" included routine updates for such things as binary position angles and celestial-sphere distances, and also comparison of our MK types against MK types as assigned by Astron. Alm. for epoch 2021.5, with the MK discrepancies logged). The work was not yet sufficiently polished to support uploading to the online-version server.
- 20200815T190800Z/4.0.0: Performed sufficient updating of the 3.x.x version series to support the print edition of the 2021 Handbook, but without sufficient updating to support uploading to the online-version server.
- 20191231T235959Z~/3.x.x series: Supplemented previous editions of this online publication in various ways, most notably by adding the (rather prolix) results of (rather detailed) primary-literature inspections for o Cet Aa (Mira), α UMi Aa (Polaris), β Per Aa1 (Algol), α Tau A (Aldebaran), ε Aur A (Almaaz), α Ori Aa (Betelgeuse), γ Vel Aa, α Leo A (Regulus), α Vir Aa (Spica), ζ Oph, and α Lyr A (Vega).
- 20181231T235959Z~/2.x.x series: Supplemented the 1.x.x version series with some (rather detailed) primary-literature inspections for selected familiar bright stars, thereby expanding "Remarks."

	Star Name	RA (2026.5) h m	Dec ° ′	m_V	$B-V$	MK Type	π mas	M_V	D ly	μ ″/y	PA °	V_{rad} km/s	Remarks	
	Sun			−26.75	0.63	G2 V		4.8	8 lm					
α	And Aa	0 09.8	+29 14	2.07†	−0.11	B9p IV: (HgMn)	34	−0.3	97	0.214	140	−12 SB2†	slight var.: range 0.04 in V passband, 23.19 h the SB2 components α And Aa, α And Ab (period 96.7 d) are now interferometrically measured, yielding orbital value $e = 0.5$ or 0.6 ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ slight variability, possibly of α CVn A ("α^2 CVn") type, with range of mag. 0.04 in V, period 23.19 h (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; variability classification symbol = "**ACV:**")	**Alpheratz**
β	Cas A	0 10.6	+59 18	2.27†	0.34	F2 III	60	1.2	55	0.554	109	+12 SB†	slight var.: 2.25–2.29 in V, 0.1010 d second-brightest of the δ Sct variables (the brightest is α Aql A (Altair)) (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; variability classification symbol = "**DSCTC**") ¶ rapid rotator: 2011ApJ...732...68C finds the rotation to be > 90% of breakup rate, and radius at poles to be ~24% less than radius at equator, with β Cas A of mass ~2 M☉, seen nearly pole-on; β Cas A is notable for being cooler than typical rapid rotators, lying just barely on the rapid side of the F5 "rotation	Caph

													break," and additionally is notable for being old enough to have evolved off the MS, having in its MS career been an A star rather than an F star (generally, rotation slows as an aging star increases in radius: but our table of bright stars does harbour at least one other such evolved rapid rotator in type F, namely θ Sco A); an envelope at this modest photospheric temperature is dominated by convection not only at the equator but even at the (~1000 K hotter) poles; consistently with this picture of an envelope everywhere convective, interferometry of β Cas A is found to yield results for low latitudes gravity darkening inconsistent with 1920's von Zeipel law (the law is accurate only if an envelope is radiative); 2011ApJ...732...68C suggests that in its process of evolution off the MS (in which a core contracts, an envelope expands) β Cas A has been efficient in transferring angular momentum from core to envelope ¶ 2011ApJ...732...68C Fig. 4 presents imaging (as a single star, not as a binary) of β Cas A, from CHARA interferometry ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.103 mas ± 0.7%, in passband 550-850 nm, from the PIONIER beam-combining facility at VLTI ¶ β Cas A is SB, of period 27 d, as yet unresolved, even in interferometry (so WDS is as yet unable to write "β Cas Aa," "β Cas Ab")
γ	Peg A	0 14.6	+15 20	2.83†	−0.22	B2 IV	8	−2.6	400	0.009	168	+4 SB	slight var.: pulsator, 2.82–2.86 in V band, 3.64 h Algenib γ Peg, as a multi-star assemblage, presents both β Cep-type and 53 Per-type variability: but we at the *Handbook* do not know how the combination of variabilities is distributed among the two stars that constitute the γ Peg A SB and the faint celestial-sphere neighbours γ Peg B (mag ~13) and γ Peg C (likewise mag. ~13) (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; variability classification symbol = "**BCEP+SPB**") ¶ the JMDC 2021 Sep. 13-or-14 edition reports just one interferometric measurement of angular diameter, as 0.435 mas ± 0.9% (with limb-darkening correction, in the near-infrared I passband), from the VEGA beam-combining facility at CHARA ¶ E(B–V) =+0.01
β	Hyi†	0 27.1	−77 06	2.80†	0.62	G1 IV	134.1	3.5	24.3	2.243†	82	+23†	exoplanet now discounted? star now known to be non-var. ¶ included in NSV, but classified at AAVSO(VSX) as non-variable (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed non-variability; variability classification symbol = "**CST**") ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ high space velocity (interloper from more remote galactic region?)
α	Phe	0 27.6	−42 10	2.39†	1.09†	K0 IIIb	38.5	0.3	~85	0.426	147	+75 SB	Ankaa m_v, B−V values are for the combined light of the SB system ¶ AAVSO(VSX) situation as of 2024 April 05: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)
δ	And Aa	0 40.8	+31 00	3.26†	1.28†	K3 III	~30.9	0.7	106	0.142	126	−7 SB†	possible slight var.: type unknown (range 0.1 in V band?) one of the rare instances in which a resolved SB has been resolved with direct imaging, rather than with interferometry (although angular diameter of δ And Aa has been found through interferometry): 2015ApJ...809...11B reports

a single 2014 observation via Palomar (5 m) Stellar
Double Coronagraph, working in near IR with adaptive
optics; angular separation was 0.4″, yielding Aa-to-Ab
distance ~12 au, with *e*~0.5; since system is large,
period is long (~20000 d?)
¶ there seem (as of Sep. 2021) to be no reports of
interferometric resolution of this SB
¶ the JMDC (2021 Sep. 13-or-14 edition)
most recent reported interferometric measurement
of angular diameter with limb-darkening correction
is 4.136 mas ± 1%, in the near-infrared J passband,
from the Mark III beam-combining facility at Mount Wilson
¶ possible slight variability, range 0.1 in V:
further photometric study advisable?
(AAVSO(VSX) assessment as of 2024 April 05:
status flag = suspected variable;
no AAVSO observations found;
no conjectural variability classification symbol assigned)
¶ m_v, B−V values are for the combined light
of the δ And Aa,Ab system
¶ δ And Ab (mag. 10.0) is asserted in
2015ApJ...809...11BWD to be likely not a WD, as had
been previously believed, but instead likely an MS star
of MK type K (with the authors additionally
noting, as one alternative
possibility (in this case a remote alternative
possibility), that δ And Ab might be a pair of low-mass
MS stars)

α Cas A 0 42.0 +56 41 2.22† 1.17 K0 IIIa ~14.3 −2.0 230 0.060 122 −4 V? **Schedar**

AAVSO(VSX) assessment as of 2024 May 11:
status flag = confirmed variability;
13133 AAVSO observations found;
variability classification symbol = “**ROT:**”
(possible, but not certain rotational modulation,
from starspots);
V-passband range = 0.001;
period = 2.4124 d
¶ limb darkening observed interferometrically
¶ the JMDC (2021 Sep. 13-or-14 edition)
most recent reported interferometric measurement
of angular diameter with limb-darkening correction
is 5.608 mas ± 1%, at 800 nm,
from the Mark III beam-combining facility at Mount Wilson
¶ α Cas D (mag. 9), PA 283°, 71″ (2023), is
mere line-of-of-sight coincidence, not gravitationally
bound to α Cas A

β Cet+1P? 0 44.9 −17 50 2.04† 1.02 K0 III† ~33.9 −0.3 96 0.235 82 +13 V? **Diphda**

slight var.: type unknown, range 0.004 in V
further photometric study advisable?
(AAVSO(VSX) assessment as of 2024 May 11:
status flag = confirmed variability;
a single AAVSO observation found;
variability classification symbol = simply “VAR”;
period = 167.78523 d)
¶ anomalous in being X-ray-bright and yet a slow rotator
¶ evolutionary status uncertain (helium core ignited
already, or still contracting?)
¶ Astron. Alm. (epoch 2021.5) assigns MK type
G9 III CH–1 CN 0.5 Ca 1
¶ 2011A&A…535A..59B, using the VEGA beam-
combining facility at CHARA, compares photospheric
and chromospheric radii (chromosphere is deep),
and finds some suggestion of chromosphere asymmetry
¶ the JMDC (2021 Sep. 13-or-14 edition)
most recent reported interferometric measurement
of (photospheric) angular diameter with
limb-darkening correction
is 5.510 mas ± 0.05%, at 2300 nm,
from the AMBER beam-combining facility at VLTI

η Cas A† 0 50.7 +57 58 3.44† 0.57† G0 V† 168 4.6 19.4 1.222 117 +9 SB? Achird

B:7.36, K4 Ve, 13.5″, PA 62°→328°, 1779→2023
orbit 480 y; SB status has been asserted for
η Cas A, and yet is said by WDS (as viewed 2024 Dec. 07)
to be not confirmed; possibility of variability in
η Cas system now discounted;
our m_v, B−V values are for the combined light
of η Cas AB (the corresponding values for
η Cas B alone are 7.51, 1.39); overall field
is crowded with dim
stars, the brightest of which, apart from η Cas A

													and η Cas B, are the well-separated η Cas G (mag. 9.5; 420″, PA 259° (2012); rectilinear-solution analysis of proper motions, 1852→2012, does not reveal any orbital motion) and the very widely separated η Cas H (mag. 8.5; 701″, PA 355° (2012); analysis of proper motions covers only 1991→2012, and rectilinear-solution analysis of proper motions seems unavailable as of at any rate 2021 Sept. 14) ¶ AAVSO(VSX) assessment as of 2024 May 11: status flag = confirmed non-variability; 179 AAVSO observations found; variability classification symbol = "**CST**" ¶ Astron. Alm. (epoch 2021.5) assigns MK type F9 V ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.894 mas ± 6%, in mid-infrared 8000 nm - 18000 nm passband, from the KIN beam-combining facility at the W.M. Keck Observatory
γ	Cas A†	0 58.3	+60 52	2.39v†	−0.13	B0 IVnpe (shell)†	5	−4.2	600	0.026	98	−7 SB	var.:1.6—3.0 (V); B:10.9, 2.1″, PA 255°→259°, 1888→2002 orbit >1500 y ¶ first "Be phenomenon" discovery (Secchi, 1866); additionally the prototype for the γ Cas type of eruptive irregular variables; background on Be phenomena and γ Cas-type variability is given in www.aavso.org/vsots_gammacas; 2002ASPC..279..221H summarizes the observational history, including major shell-spectrum phases in 1935–1936 and 1939–1940; despite its historical importance, however, Cas A cannot safely be taken as a typical "Be phenomenon" star, since it presents the peculiarity of hard thermal (and variable) X-ray emission (cf 2013A&ARv..21...69R p. 42, and also e.g. 2012A&A...537A..59N), derived from magnetic heating (perhaps from magnetic star-disk interaction, perhaps from disk intrinsic magnetic field); rotationally flattened (period = 1.21 d, axial tilt=45°); one of only three Be-phenomenon stars so far observed (via polarimetry, not via interferometry) to produce ejecta disks with differing position angles at different outbursts (2013A&ARv..21...69R p. 42; the other two known instances of this geometrical variation are Pleione and 59 Cyg, both too faint to be in this *Handbook* table of brightest stars); in addition to the eponymous "γ Cas-type variability" that, as violently eruptive, dominates the photometry of the γ Cas system, and the X-ray variability, the system is noted at AAVSO(VSX) as possibly presenting λ Eri-type variability (Be-star light variations due to non-radial pulsation or, alternatively and perhaps as in this possible case, rotational modulation: cf en.wikipedia.org/wiki/Lambda_Eridani_variable, which notes that λ Eri-type variability is not used as a classification at GCVS, and that AAVSO(VSX) for its part documents fewer than 20 known or suspected instances); as of at least 2007, AAVSO has called for amateur assistance with photometry: γ Cas A has been as bright as V mag. 1.6, as faint as V mag. 3; four recent AAVSO reports, from the same observer, working in the V band, are 2.16 (2022 Feb. 13), 2.20 (2022 Jan. 10), 2.16 (2024 March 25), 2.18 (2024 March 31) (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; 66382 AAVSO observations found; variability classification symbol = "**GCAS+X+LERI:**"; period = 1.21598 d) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric study of angular diameter, yielding 0.9 mas as an upper bound on the north-south angular width (in R band, without limb-darkening correction, and without prejudice either to the question of equatorial angular diameter

													or to the question of angular width of circumstellar disk: this study, with the pioneering two-telescope "I2T" beam-combining facility at a now-dissolved astronomical station of France's Côte d'Azur Observatory, is published as 1984PASJ...36..231V) ¶ dimming through ISM dust, ~0.35 mag.	
β	Phe AB†	1 07.3	−46 35	3.31v?†	0.89†	G8 III + G8 III	16	0.3:	~180	0.088	293	−1	AB similar, 0.7″, PA 26°→67°, 1891→2022 orbit 168 y, highly eccentric; masses and mags. of A, B are nearly equal ¶ our m_v, B−V values are for β Phe AB combined light ¶ possible variable, 3.22−3.32 in V: as of 2024 April 05, AAVSO(VSX) notes existence of NSV entry, but finds no record of AAVSO observations, has status flag = suspected variable, has no variability classification symbol, and is not yet able either to assign a conjectural variability type or to deny variability (further photometric study advisable?) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
η	Cet A+2P	1 09.9	−10 02	3.44	1.16	K1.5 III CN1†	26.3	0.6	124	0.257	123	+12V	 ¶ Astron. Alm. (epoch 2021.5) assigns MK type K2⁻ III CN 0.5 ¶ AAVSO(VSX) situation as of 2024 April 05: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), a fortiori no variability classification symbol ¶ [2011A&A…535A..59B](2011A&A…535A..59B), using the VEGA beam- combining facility at CHARA, compares photospheric and chromospheric radii (chromosphere is deep); the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of (photospheric) angular diameter, as 3.698 mas ± 4% (with limb-darkening correction, in near-infrared R band); this is from the above-cited [2011A&A…535A..59B](2011A&A…535A..59B))	
β	And A+1P	1 11.2	+35 46	2.05†	1.58	M0 IIIa†	17	−1.8	200	0.209	123	+3 V	slight slow irreg. var.: 2.01–2.10 in V passband (AAVSO(VSX) assessment as of 2024 May 11: status flag = confirmed variability; 1615 AAVSO observations found; variability classification symbol = "**LB**") ¶ Astron. Alm. (epoch 2021.5) assigns MK type $M0^+$ IIIa ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 13.749 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson	Mirach
δ	Cas A	1 27.6	+60 22	2.68†	0.13	A5 IV	32.8	0.2	99	0.301	99	+7 SB†	slight var. 2.68–2.76 in V (ecl. of β Per type?) δ Cas A, as an (unresolved) SB, has been previously asserted to be eclipsing: AAVSO(VSX) asserts variability, but only with possible-and-yet-not-certain β Per-type variability (AAVSO(VSX) assessment as of 2024 May 11: status flag = confirmed variability; 256 observtions found; variability classification symbol = "**EA:**"; period = 759 d) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ E(B–V) =+0.27	Ruchbah
γ	Phe	1 29.5	−43 11	3.40v†	1.57	K7 IIIa†	14	−0.9	230	0.209	185	+26 SB	SB period 194.1 d; also irreg. var.: 3.39–3.49 in V passband SB variability is of β Lyr type; there is additionally slow, irregular variability (unsurprising for a binary containing a cool and evolved star) (AAVSO(VSX) assessment as of 2024 May 11: status flag = confirmed variability; no AAVSO observations found; variability classification symbol = "**EB/GS+LB**")	

													¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ Astron. Alm. (epoch 2021.5) assigns MK type M0⁻ IIIa	
α	Eri	1 38.7	−57 06	0.45v†	−0.16	B3 Vnpe (shell?)†	23	−2.7	140	0.095	114	+16 V	var.: Be type, 0.44–0.54 in V passband, 1.263 d AAVSO(VSX) does not assert eclipsing, but does assert the slight variability typical of “Be phenomenon” stars lacking outbursts (this is in many “Be phenomenon” cases found to be λ Eri-type variability) (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; only 2 AAVSO observations found; variability classification symbol = “**BE**”) ¶ brightest of the “Be phenomenon” stars (but first recognized as such only recently, ~1976); an active Be phase that began between Dc. 2012 and early Jan. 2023 (after a period of inactivity, with α Eri presumably diskless, over the previous 7 years) was first noted in amateur spectroscopy, in Brazil; Balmer hydrogen-α line indicates a slow, steady buildup of the Be disk, over a period of ~1.6 y, with polarization suggesting that disk was slightly less dense in 2014 than it had been in 2013; 2017A&A...601A.118D, a case study of α Eri, presents for the first time in astrophysics images (from interferometry) of a disk forming around a Be-phenomenon star (with H-band (IR) emission from the disk extending to an outer radius of between 1.7 and 2.3 stellar equatorial radii, in good agreement with current computations in the general theory of the Be phenomenon); it is possible that plane of α Eri disk is inclined to plane of stellar equator; rapid variations in polarization indicate that in addition to its disk, α Eri possesses rings, due to episodic ejections of gas consignments from its photosphere ¶ 2012A&A...545A.130D reports deductions from VLTI (AMBER beam-combining facility) interferometric data, yielding α Eri angular diameter (at equator, 2.45 mas ± 4%), rotation axis inclination, rotation axis position angle, at a time when the "Be-phenomenon" happened to be either quenched or negligible; JMDC (2021 Sep. 13-or-14 edition), on the other hand, which confines itself to direct diameter determinations as opposed to deduced determinations, reports no modern (intensity-and-phase) interferometric investigation of angular diameter, and on the other hand does report two pioneering intensity-interferometer studies, from 1967 and 1974, from the Narrabri Observatory (now Paul Wild Observatory) in Australia; the latter gives 1.92 mas ± 4%, with limb-darkening correction, at the very short wavelength of 438.5 nm ¶ α Eri is a notably rapid rotator (< 2.1 d, near breakup speed) within the (currently small) population of stars interferometrically resolved; period in or near the disk phases varies, either because gas is injected (“decreted”) from photosphere into Be disk or because Be-disk gas is re-accreted onto photosphere; interferometry as performed when α Eri is temporarily without its Be disk reveals oblateness (cf e.g. www.eso.org/public/unitedkingdom/news/eso0316) ¶ although 2008A&A...484L..13K reports companion, at Dec. 2007 angular separation < 0.15″, WDS has not, as of 2024 Dec. 07, asserted binarity; the orbital motion of this companion seems to not be correlated with the repeated formation and disappearance of the Be disk	**Achernar**
τ	Cet A+8P?	1 45.4	−15 48	3.50	0.73	G8 V†	~274.0	5.7	11.9	1.921†	296	−16† V	on original Frank Drake (1960) SETI target list mass < 1 M⊙ (unusual in Sample S, although typical in Population P) ¶ high space velocity, low metallicity: interloper from	

													thick galactic disk ¶ further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 11: status flag = suspected variable; 65 AAVSO observations found; no conjectural variability classification symbol assigned; V-passband range stated as “3. 5−?”) ¶ the JMDC (2021 Sep. 13-or-14 edition) two most recent reported interferometric measurements of angular diameter with limb-darkening correction, both from 2014, are 2.072 mas ± 0.5% (550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ, and 2.015 mas ± 1% (8000 nm - 13000 nm mid-infrared passband, from the KIN beam-combining facility at the W.M. Keck Observatory) ¶ on original Frank Drake (1960) SETI target list **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
α	Tri A	1 54.6	+29 43	3.42†	0.49	F6 IV	52	2.0	63	0.234	177	−13 SB	slight var.: 3.41−3.42 in V passband, 1.74 d (AAVSO assessment as of 2024 May 11: confirmed variability; a single AAVSO observation found; classification symbol = “ELL”; period = 1.736315 d) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	Mothallah
β	Ari <u>A</u>†	1 56.1	+20 56	2.65v†	0.14	A4 or A5 Va†	56	1.4	59	0.148	138	−2 SB2†	possibly variable (2.56−2.70 in V passband?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 11: status flag = suspected variable; seems no AAVSO observations found; no conjectural variability classification symbol assigned) ¶ β Ari B (mag. 5.2 in near-IR or Johnson R band or similar) is SB companion of β Ari A, and yet AB has also been resolved interferometrically as an exceedingly tight (~0.1″) binary (15 measurements, 1988→2005, with two quite similar published orbital solutions (*e* is high in both solutions, at ~0.9; A-to-B distance is 0.08 au min, 1.2 au max; period is 107 d)) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ 2003AJ....126.2048G discusses MK type	Sheratan
ε	Cas	1 56.3	+63 48	3.37†	−0.16	B3 IV:pe (shell?)†	8	−2.2	400	0.037	121	−8 V	slight var., 3.35−3.37 in V passband (SX Ari type?) instance of “Be phenomenon”; but additionally, AAVSO(VSX) documents slight variability, possibly of the SX Ari type (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; 156 AAVSO observations found; variability classification symbol = “**SXARI:**”) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter, as 0.471 mas ± 1.5% (with limb-darkening correction, in visible-red R band, from the VEGA beam-combining facility at CHARA) ¶ He-weak (cp α And, α Tel)	Segin
α	Hyi	1 59.6	−61 26	2.85	0.28	F0n III–IV†	45	1.1	72	0.265	84	+1 V	rapid rotator (< 30 h) ¶ metal-rich ¶ AAVSO(VSX) situation as of 2024 April 05: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), a fortiori no variability classification symbol assigned ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
γ	And A	2 05.5	+42 27	2.26†	1.37†	K3 IIb†	9	−3.1	400	~0.065	~139	−12 SB	B: 5.3, B9 V, 9.5″ (2021); C: 6.5, A0 V; BC 0.3″ BC orbit 63.7 y ¶ m_v, B−V values are for γ And A; the combined-light values for γ And ABC are 2.11, 1.21	Almach

													¶ Astron. Alm. (epoch 2021.5) assigns MK type K3$^-$ IIb ¶ AAVSO(VSX) assessment as of 2024 April 05: status flag = suspected variable; 1726 AAVSO observations found; range 2.09–2.12 in V; variability classification symbol = “**LB:**” ¶ limb darkening observed interferometrically ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 7.814 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson
α	Ari +1P	2 08.7	+23 35	2.01†	1.15	K2 IIIab	~49.6	0.5	66	0.240	128	−14 SB	slight slow irregular variability, 2.00−2.03 in V **Hamal** **(**AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; no AAVSO observations found; variability classification symbol = “**LB**”) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 6.792 mas ± 0.6%, at 700 nm, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ calcium weak
β	Tri	2 11.1	+35 07	3.00†	0.14	A5 IV	26	0.1	130	0.154	105+10	SB2†	possible var.: type unknown (max light is ~3.0 in V?) period of this unresolved SB is 31.39 d, with orbit (at least two solutions published) rather elongated (*e*=0.4 or 0.5; inter-component distance possibly 0.17 au min, 0.42 au max) ¶ as of 2024 April 05, AAVSO(VSX) notes existence of NSV entry, and states mag. range as “3.02−? V,” but finds no record of AAVSO observations, and is not yet able either to assign a conjectural variability type or to deny variability (further photometric study advisable?) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter, as 1.05 mas ± 10% (with limb-darkening correction, in 8000 nm - 13000 nm mid-infrared passband, from the KIN beam-combining facility at the W.M.Keck Observatory) ¶ IR excess (circumstellar matter? possible signature of planetesimals)
ο	Cet Aa†	2 20.7	−2 51	4.95v†	1.55	M5–10 IIIe†	11†	1.7	300†	0.238	178	+64 V	long-period var., 2−10.1 (V); max 2025 April? Mira† recent ο Cet Aa maxima 2019 Nov. (V~2.3), 2020 Sep. .–Oct. (V~3.0), 2021 Aug. (V~2.6), 2022 late July (V~3? but daylight hampered observations near maximum), 2023 June? (daylight precluded observations near maximum); recent minimum was 2023 late Dec. (V~9); AAVSO reports V band mag. 6.66 on 2024 Feb. 25: 2009ApJ...691.1470T discusses variability, including variation in dominant (~330 d) pulsation period and the question of longer-period variations (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; 102554 AAVSO observations found; classification symbol = “**M**”) ¶ times of maxima are, and times of minima are not, independent of wavelength: minima are at least coarsely correlated with maximum diameter of ο Cet Aa ¶ prototype of the ο Ceti-type variables, mass ~1 M$_\odot$: the first O-rich AGB star with a CI detection (2018A&A...612L..11S) ¶ physical radius ~2 au in visual, ~4 au in IR, still greater upon taking instead the “radio photosphere,” which itself increases in radius as progressively longer radio wavelengths are selected: 2015ApJ...808...36M draws parallels with α Ori Aa, attributing radio inhomogeneities in both cases to convective cells (and cf also 2016A&A...592A..42K, which summarizes some recent radio work); wavelength-dependence of angular diameter is made rather vivid by noting a subset of the many JMDC (2021 Sep. 13-or-14 edition) interferometry reports: (1) at 700 nm, measurements of 39.4 mas, 42.0 mas, 43.4 mas, 44.6 mas, at ± 7% or 8% or 9% (without

													limb-darkening correction, in all four cases with aperture-masking interferometry at the William Herschel Telescope, Roque de los Muchachos Observatory, in the Canary Islands); (2) in near-infared K band (midpoint is 2190 nm), measurements of 28.6 mas and 28.3 mas ± 3% or 5% (again without limb-darkening correction, in both cases from the AMBER beam-combining facility at VLTI) ¶ Ab (VZ Cet) WD, 10.4, 0.4″ (2023), orbit ~500–600 y; what is seen as o Cet Ab (with professional equipment), and indeed probably seen as itself variable (over and above the long-period variability o Cet Aa) may be not the WD itself, but an accretion disk around the WD, captured from the o Cet Aa wind ¶ nearest instance of (weak) symbiotic binarity, and the only symbiotic to be observed in all wavelength regimes from X-ray to (mm, also cm) radio; interferometry (in IR) is available from VLT, and *CASSINI* has yielded (via Saturn-ring occultations) tomographically recovered imaging (2016MNRAS.457.1410S); *GALEX* has found bow shock, tail (length 13 ly) in ISM: mass-loss rate ~2.5e-7 $M_\odot$ /y; asymmetric atmosphere is discussed in 2016MNRAS.457.1410S ¶ 2018A&A...620A..75K reports dust trail linking Aa,Ab (consistently with other reports of Aa-to-Ab mass transfer) ¶ 2016A&A...592A..42K (2017A&A...599A..59K) discusses o Cet Aa dust nucleation generally, with reference to aluminum (resp. titanium) species: in o Cet Aa, it is silicates that dominate the spectrum (in contrast with less-evolved stars, in which alumina features are spectrally dominant); 2016A&A...590A.127W discusses SiO gas, o Cet Aa inner dust shells: it seems still an open question whether o Cet Aa dust formation is cyclic, as part of the photometrically evident pulsation cycle, or proceeds independently of the pulsations ¶ X-ray emission from o Cet Aa was reported in 2005 (2005ApJ...623L.137K, as the first X-ray detection from an AGB star), and OH, SiO maser emission has also been reported (cf, e.g. 2017MNRAS.468.1703E); further, 2015A&A...577L...4V asserts a hot spot, proposing magnetic activity as the cause ¶ 2016A&A...590A.127W summarizes history of modelling: models generally agree that near o Cet are alternating circumstellar layers of infall and outflow, and that at greater radii is an accelerating outflow, from dust-driven winds: recent observations have tended to agree with overall results from running CODEX (e.g. 2014A&A...565A.119S) ¶ 2016A&A...586A..69P discusses discrepancies in distance determinations (350 ly, 380 ly, 340 ly, and (least reliable?) *HIPPARCOS* 300 ly) ¶ Aa,Ab orbit would, if better known, yield improved total mass of Aa,Ab system, thereby advancing the overall theory of AGB stars ¶ of the various celestial-sphere neighbours of the o Cet Aa,Ab binary, only the widely separated o Cet C , at mag. ~9.6, is brighter than mag. 10 (astrometry particulars: AC separation 114.6″→121.8″, PA 92°→68°, 1782→2017) ¶ protoplanetary disk was detected around Ab in 2007 ¶ Astron. Alm. (epoch 2021.5) assigns MK type M5.5–9e III ¶ Fabricius noted variability in 1956; Hevelius proposed the name Mira in 1642 ¶ for entry-level briefing-with-bibliography, cf www.aavso.org/vsots_mira2.updating www.aavso.org/vsots_mira; and for summary of recent primary literature, cf first section of 2016MNRAS.460..673N	
γ	Cet A†	2 44.7	+3 21	3.46†	0.09†	A2 Va	41	1.5	80	0.207	225	−5 V	B: 6.2, 1.9″, PA 283°→300°, 1825→2023 orbit ≥ 320 y ¶ m_v, B−V values are for the combined light of γ Cet AB ¶ AAVSO(VSX) situation as of 2024 April 05: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable),	Kaffaljidhma

													a fortiori no variability classification symbol assigned) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
θ	Eri A	2 59.3	−40 12	2.91†	0.12†	A5 IV	30	0.5	100	0.057	293	+12 SB2	B: 4.1, A1 Va, 8.2″, PA 82°→90°, 1835→2020 ¶ θ Eri A is also known as θ^1 Eri ¶ m_V, B−V values are for the combined light of θ Eri AB ¶ AAVSO(VSX) situation as of 2024 April 05: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), a fortiori no variability classification symbol assigned) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	**Acamar**
α	Cet+1P?	3 03.7	+4 12	2.53†	1.64	M2 III†	13	−1.9	250	0.078	188	−26 V	slight var., 2.45–2.54 in V variability is possibly of a slow-irregular type (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; 3 AAVSO observations found; variability classification symbol = "**LB:**") ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 13.238 mas ± 2%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ radio source (due to stellar wind) ¶ notably deficient in carbon ¶ Astron. Alm. (epoch 2021.5) assigns MK type M1.5 IIIa	**Menkar**
α	UMi Aa†	3 06.7	+89 22	2.01†	0.60†	F5–8 Ib	7.5†	−3.6	430†	~0.046	~105?	−17 SB	slight Cep. var, 4.0 d; B: 9.1, F3 V, 18.4″ (2016) the brightest of the Cepheids, but not a classical Cepheid, matching instead the "s-Cepheid" light-curve phenomenology of 1995A&A...303..137B ¶ AAVSO(VSX) as viewed 2024 April 05 gives V-mag. range 1.96–2.03, period ~3.9720 d (the corresponding values on 2022 July 13 were 1.97–2.00, ~3.9696 d); period is increasing ~4.4–4.9s/y, with sudden change around 1963, and with *CORIOLIS* satellite suggesting a further recent change: period change is often in Cepheid theory linked to evolution, but this may not be the whole story here (in particular, pulsation-driven mass loss through stellar wind, as affirmed by some recent authors (denial also published) would increase the rate of period change) (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; 884 AAVSO observations found; variability classification symbol = "**DCEPS**") ¶ pulsation mode (1st overtone? 2nd? fundamental?), evolutionary history (1st crossing of IS? or 3rd crossing?), and distance are controverted by various 2010-through-2018 authors (we here use *Gaia* DR2 distance for α UMi B as a proxy, assuming with the current literature that B is indeed gravitationally bound with Aa,Ab) ¶ α UMi Aa is first Cepheid with mass determined through purely dynamical means (via the Aa,Ab orbit: Aa is single-lined SB, and Aa, Ab have been resolved with HST, as first announced (0.17″) in 2008AJ....136.1137E (orbit ~30 y)) ¶ 2000A&A...360..399W warns that peculiarity of the α UMi Aa light curve makes this particular Cepheid perhaps not a suitable anchor point for determining the overall Cepheid period-luminosity relation (essential though a determination of that relation is for calibrating the cosmic distance scale) ¶ α UMi Aa is important as a case study in the "Cepheid mass discrepancy" problem (Cepheid masses deduced from pulsation periods are found to be too low in comparison with masses from stellar-evolution modelling) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter, as 3.28 mas ± 0.6% (with limb-darkening correction, at 740 nm, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ) ¶ strictly a three-star system, UMi Aa+	**Polaris**

														UMi Ab+UMi B; Aa,Ab has period 29.6 y, inter-component distance 6.7 au min, 27 au max, 17 au average (orbital solution has been published); B experiences Aa,Ab as essentially a point mass, with period ≥ 42,000 y, separation at least 2400 au (no orbital solution published) ¶ m_v, B−V values are for the combined light of UMi Aa,Ab,B; the corresponding values for α UMi B are 8.20, 0.49 ¶ α UMi Aa, Ab,B is approaching NCP: closest approach will be 14′, in ~2105 ¶ B has E(B–V)=0.0 ¶ 2018ApJ...863..187E summarizes recent work
γ	Per Aa,Ab†	3 06.7	+53 37	2.93v†	0.70	G8 III† + A2? V?	13	C1.5	240	0.006	175	+3	SB2†	composite spectrum, orbit 14.6 y, next eclipse 2035 eclipse duration < 2 weeks; eclipse variation is significantly above threshold of naked-eye detection, with AAVSO(VSX) giving V-mag. range 2.91−3.21 (ranges in Johnson U and B bands are still larger); this is a system of the β Per type (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; 2990 AAVSO observations found; variability classification symbol = "**EA/GS**") ¶ angular separation of Aa,Ab is always ≤ 0.3″, putting this binary, for part of its orbit, just within the limits of feasibility for traditional micrometer astrometry (but interferometry has also been done); orbit is highly elliptical, with *e*=0.79 on the better of two published orbital solutions; amenability of this binary to spectroscopic orbit solution (via radial velocities: radial-velocity data are available since ~1900) and to interferometry make it a useful candidate for stellar-mass studies, and therefore a useful test for theoretical predictions of luminosity classes and spectral types from given masses (1999A&A...348..127P) ¶ Aa is mag. ~3.6 and Ab is mag. ~3.8; our m_v, B−V values are for γ Per Aa,Ab combined light ¶ Aa,Ab are HD18925, HD18926, but not necessarily in that order (there is, then, an identification uncertainty for us at the *Handbook*): JMDC (2021 Sep. 13-or-14 edition) *(a)* reports only one measurement for HD18925 (from 2014; beam-combining facility and observatory are not readily obtained from JMDC) lacking limb-darkening correction, and only one measurement (from 2018, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ) with limb-darkening correction), as 3.894 mas ± 0.5%; and *(b)* reports no measurement for HD18926 ¶ Astron. Alm. (epoch 2021.5) assigns MK type G5 III
ρ	Per	3 06.9	+38 57	3.39v†	1.65	M4 II	11	−1.6	310	0.167	129	+28		semireg. var.: 3.3–4 in V passband, ~50 d, ~120 d, ~250 d rough period ~50 d, with possibly also longer (rough?) period(s) (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; 22889 AAVSO observations found; variability classification symbol = "**SRB**") ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 16.555 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson
β	Per Aa1†	3 09.9	+41 03	2.12v†	−0.05	B8 V†	36	−0.1	90	0.003	119	+4	SB	Aa=compos. spectrum Aa1,2 ecl,;2.09-3.30 in V, 2.9 d Algol Aa2 is K2IV? ¶ in older terminology, β Per Aa1 = β Per A, β Per Aa2 = β Per B, β Per Ab = β Per C: but WDS, following the current terminology, uses the "B" and "C" for other purposes (since there are optical neighbours B,C,D,E,F,G,H; all are between 5″ and 100″ from the Aa1,Aa2,Ab triple, and all are fainter than mag. 10); system is hierarchical, with outlying Ab experiencing the close Aa1,Aa2 pair (Aa1−Aa2 distance is just 14.14 $R_\odot$) as essentially a point mass; angular separation between Aa1,Aa2 and Ab is ~0.1″

(WDS 1973, 2010); orbital solutions have been published both for the tight binary that is is β Per Aa1,Aa2 and for the wider binary that is β Per Aa,Ab

¶ among the most visually prominent of the eclipsing binaries, and for theoreticians the most familiar of the semidetached binaries (i.e., binaries in which one of the two Roche equipotential surfaces is fully occupied, the other not)

(AAVSO(VSX) assessment as of 2024 April 05:
status flag = confirmed variability;
27500 AAVSO observations found;
variability classification symbol = "**EA/SD**";
period 2.86735 d
(as viewed 2021 Jan. 28,
AAVSO(VSX) gives period 2.86736 d,
and as viewed 2022 Mar. 03 gives period 2.86734 d))

¶ Aa2 is tidally locked, in a rapid circular orbit with Aa1; the consequent rapid spin of Aa2 causes dynamo action in Aa2 convection zone, with Aa2 consequently having complex magnetosphere (mass-transfer stream possibly even deflected out of Aa1,Aa2 orbital plane by magnetics; 2012ApJ...760....8R; Aa2 has additionally a meridional coronal loop, approximately as high as the diameter of Aa2 (the size exceeds what has been anticipated from modelling) believed pointing at all times to Aa1), X-ray emission, varying radio morphology (double-lobed when radio-brightest) and CME episodes (2017ApJ...850..191M suggests the 1997 Aug. 30 superflare event supplies "arguably the best candidate" for a non-solar CME)

¶ the (unsteady) Aa2-to-Aa1 mass transfer, while ongoing, and indeed responsible for an annulus around Aa1, is no longer copious (in contrast with the copious transfer still present in, e.g. β Lyr)

¶ it is not the (now modest) unsteady mass transfer, but possibly instead the Applegate mechanism (1992ApJ...385..621A), implicating a stellar magnetic activity cycle, which dominates the Aa2,Aa1 period variation (increase-decrease-increase cycle, not quite strictly periodic, 32 y: there are additionally period modulations of 1.9 y and 180 y; full amplitude of the Aa1 Aa2 period variation is ~0.8 s; such alternating period changes in binaries are still not, however, well understood

¶ it is the (several My ago rapid and copious) mass transfer that resolves the "Algol paradox" of a lower-mass more evolved (in this case, sub-giant) star in orbit with a higher-mass less evolved (indeed MS) star; masses are well known in this particular case: 2015MNRAS.451.4150K, having disentangled the β Per Aa1, Aa1, Ab spectra, determines their masses within ± 2%, corroborating 2012ApJ...752...20B

¶ β Per Aa2 elemental abundances below corona and flare (investigated in 2015MNRAS.451.4150K) are of special interest, since mass transfer has stripped off Aa2 outer layers, opening the Aa2 interior to spectroscopic inspection

¶ 1983ApJ...273L..85K reports discovery of Chandrasekhar eclipse-induced stellar limb polarization from β Per Aa1, in a wide optical passband

¶ MK type K2 IV is assigned to Aa2 in at least 3 recent papers,

												whereas the older 1993ApJ...410..808L has the slightly hotter MK type K0 IV; what is essential here is the agreed “IV” (as opposed to “V”), indicating evolution of this (secondary) star off the MS (and Astron. Alm. (epoch 2021.5) assigns MK type B8 V for Aa1, as we do here, and for one companion (is this Aa2, or is it Ab?) the uncertainty-flagged “F:,” without luminosity class) ¶ β Per Ab, spectrally Am with some F1V characteristics, orbits the β Per Aa1,Aa2 binary with period ~680 d, without eclipsing ¶ 2012ApJ...752...20B presents CHARA interferometry (~0.5 mas, H (near-IR) band) of the β Per Aa1,Aa2,Ab system (finding orbital plane of Ab to be nearly perpendicular to Aa1,Aa2 orbital plane), and also summarizes earlier interferometry; a ~55-frame animation from this paper can be conveniently viewed at en.wikipedia.org/wiki/Algol ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter, as 1.350 mas ± 7% (in 8000 nm - 13000 nm mid-infrared passband, with limb-darkening correction said to be negligible, from the KIN beam-combining facility at the W.M.Keck Observatory) ¶ E(B-V)=+0.03 ¶ 2013ApJ...773....1J suggests that β Per system variability is documented in the “Cairo Calendar” papyrus (New Kingdom, dated to 1271–1163 BCE); al-Sufi (Persia, ca 964 CE) is, however, silent on question of β Per variability ¶ AAVSO has briefing notes, with some history, at www.aavso.org/vsots_betaper; 1910ApJ....32..185S is the discovery paper for β Per Aa1,Aa2 secondary minimum, from the beginnings of photoelectric-cell photometry; 1998A&AT...15..357P analyzes “Algol paradox” history; arxiv.org/pdf/astro-ph/0611855.pdf, “Appendix B.,” is a tabular history of β Per-pertinent investigations from antiquity to 1999; in this same K. Wecht 2006 Lehigh Univ PhD thesis, Table 2.5.1 summarizes 1966-through-1983 observational coverage, as tabulated in the less Web-accessible 1986 work of Budding	
α Per A+1P?	3 26.2	+49 57	1.79†	0.48†	F5 Ib	~6.4	−4.2	510	0.035	138	−2 V	in open cluster Melotte 20, a.k.a. Collinder 39 near edge of HR diagram IS (slightly too hot to be a straightforward Cepheid); entered into NSV as suspected variable; AAVSO(VSX) status as of 2024 April 05: 1767 AAVSO observations found; range 1.72−1.86 in V; VSX indicates existence of NSV entry, but is not yet able either to assign a conjectural variability type or to deny variability (further photometric study advisable?) ¶ m_V, B−V values seem unavailable in GCPD; we take values from 2002yCat.2237….0D ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	**Mirfak**
δ Eri	3 44.5	−9 41	3.53†	0.92	K0 IV	111	3.7	29.5	0.749	353	−6	earlier suggestion of var. now discounted (AAVSO(VSX) assessment as of 2024 May 11: status flag = confirmed non-variability; seems no AAVSO observations found; classification symbol = “**CST**”) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter, as 2.386 mas ± 0.8% with limb-darkening correction, at 2178 nm, from the VINCI beam-combining facility at VLTI	Rana
δ Per Aa	3 44.8	+47 52	3.01†	−0.12	B5 IIIn†	6	−3.0	500	0.050	149	+4 SB	**[THIS STAR ONLY IN ONLINE VERSION OF TABLE]** slight var.: (γ Cas type?) 2.99–3.04 in V passband	

													(but WDS indicates possible variability of the type presented by α CVn A (“α² CVn”) (a star discussed later in this table); AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; 126 AAVSO observations found; classification symbol = “**GCAS:**” (indicating that γ Cas type is conjectured but not certain)) ¶ the δ Per Aa,Ab pairing is tight and sparsely observed (discovery attributed at WDS to *HIPPARCOS*; Ab mag. ~6.2, 0.3″ (1991)) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric investigation (from the VEGA beam-combining facility at CHARA) of angular width for this rotationally flattened star, yielding polar diameter 0.544 mas and equatorial diameter 0.610 mas (in the visible-light R band, with limb-darkening correction for both measurements, with uncertainty ± ~1% for both measurements) ¶ cluster affiliation is controverted ¶ Astron. Alm. (epoch 2021.5) assigns MK type B5 III ¶ E(B–V) =+0.04	
γ	Hyi	3 46.8	−74 09	3.24†	1.61	M2 III	15.2	−0.8	~214	0.126	24	+16	slight semireg. var.: 3.22−3.29 in V passband (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; 20 AAVSO observations found; classification symbol = “**SRB**”) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter, as 8.79 mas ± 0.1% (from the AMBER beam-combining facility at VLTI, with limb-darkening correction, at 2300 nm) ¶ evolutionary status is uncertain	
η	Tau Aa	3 49.1	+24 11	2.87†	−0.09	B7 IIIne†	8	−2.6	400	0.048	156	+10 V? SB	brightest member of Pleiades ¶ m_V, B−V values seem unavailable in GCPD; we take values from 2002yCat.2237….0D ¶ η Tau Aa,Ab is known as a binary both from spectroscopy and from occultation (but this tight pair seems not to have been resolved interferometrically, at any rate as of 2024 Dec. 07; it is therefore on the strength of occultation alone that WDS is able to write “η Tau Aa,” “η Tau Ab”), with Ab of mag. 4.6; additionally, in this crowded part of the celestial sphere, WDS catalogues as neighbours of the tight Aa,Ab binary B, C, Da, Db, E, F, G, H; of these neighbours to Aa, not only Ab, but also B, C, Da, and Db are brighter than mag. 10, and possess astrometric data from as early as the 19th century (except that the tight Da,Db pair was first resolved in the 21st century, through speckle interferometry); 1972JBAA...82..431K describes the 18.6-year 1940-through-2050 cycle of lunar occultation possibilities ¶ rapid rotator (2.29 d?), with “Be” and “shell-spectrum” phenomena (BS5: “rotationally unstable”), making this star an appropriate target for periodic low-cadence (e.g. once-yearly) amateur-spectroscopy monitoring ¶ the JMDC 2021 Sep. 14 edition reports no interferometric measurements of angular diameter, and does report one occultation measurement (as 1.6 mas in the visible-light B passband, without limb-darkening correction, without a stated uncertainty, from the lunar occultation of 1973 Feb. 11) ¶ the overall η Tau assemblage is known to present both rotational (spotted) and slowly-pulsating-B variability, at the millimagnitude level (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; no AAVSO observations found; variability classification symbol = “**ROT+SPB**”) ¶ significant dimming by ISM dust; E(B–V)=+0.03	Alcyone

ζ	Per A†	3 55.8	+31 58	2.87†	0.11†	B1 Ib	4	−4.0	800	0.011	150	+20 SB	B: 9.2, B8 V, 12.8″, PA 205°→208°, 1824→2020 orbit ≥ 50,000 y ¶ since the SB that is ζ Per A is not as yet resolved, even in interferometry, WDS is not as yet able (at any rate as of 2024 Dec. 07) to write “ζ Per Aa,” “ζ Per Ab”; ζ Per B experiences ζ Per Aa,Ab as essentially a point mass, and is too slow in its orbit to yield spectroscopic (radial-velocity) data; further, WDS gives, as celestial-sphere neighbours of the wide and slow ζ Per Aa,Ab−B pairing, ζ Per C, D, and E (with the A,E angular separation, as measured in 2012, wide, at 120″) ¶ m_v, B−V values are for ζ Per A; GCPD gives the corresponding values for ζ Per AB combined light as 2.85, 0.12 (and for ζ Per B, gives 9.16 and 0.23; and for ζ Per D, gives 9.90 and 0.33; further, for the elusive ζ Per E gives 10.35, 0.71) ¶ as of 2024 April 05, AAVSO(VSX) flags this as confirmed variable (in 2022, had been flagged as mere suspected variable, without assignment of variability classification symbol), notes existence of NSV entry, notes existence of 35 AAVSO observations, gives possible range 2.80−2.93 in V, and assigns variability classification symbol **ACYG** (further photometric study advisable?) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (0.540 mas ± 1%, with limb-darkening correction, at 734 nm, from the VEGA beam-combining facility at CHARA) ¶ significant dimming by ISM dust; E(B–V) =+0.33 (pronounced reddening)	
γ	Eri A	3 59.3	−13 26	2.95†	1.59	M1 IIIb†	16	−1.0	200	0.129	151	+62	slight var.: (slow-irreg. type?) 2.88−2.96 in V (AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; 7 AAVSO observations found; variability classification symbol = “**LB:**”) ¶ Ca, Cr weak ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (9.332 mas ± 2%, with limb-darkening correction, at 800 nm, from the Mark III beam-combining facility at Mount Wilson) ¶ further photometric and spectroscopic studies advisable? (Kaler, at stars.astro.illinois.edu, writes, “must be one of the least-studied of the cooler bright stars”) ¶ Astron. Alm. (epoch 2021.5) assigns MK type M0.5 IIIb Ca–1	Zaurak
ε	Per A†	3 59.6	+40 05	2.89†	−0.18	B0.5 IV†	5	−3.6	600	0.028	149	+1 SB2	B: 8.9, B9.5 V, 8.8″, PA 10°→12°, 1821→2020 orbit ≥ 16,000 y; since the SB2 has not yet been resolved, even in interferometry, WDS is not as yet able (at any rate as of 2024 Dec. 07) to write “ε Per Aa,” “ε Per Ab”; ε Per B experiences the unresolved SB2 that is ε Per A as essentially a point mass, and is too slow in its orbit to yield spectroscopy (radial-velocity) orbital data; further, WDS gives, as celestial-sphere neighbours of the wide and slow ε Per AB pairing, ε Per C and D, with D a little brighter than mag. 10 (at mat 9.25), and at the wide angular separation of 163″ from ε Per A; the unresolved SB2 that is ε Per A does have published orbital solutions, with period 14.069 d (indicating a tight pairing), and with *e*=0.5 ¶ slight variable, of β Cep type (2.89–2.91 in V; AAVSO(VSX) assessment as of 2024 April 05: status flag = confirmed variability; 1081 AAVSO observations found; variability classification symbol = “**BCEP**”); one of the most extreme spectroscopic variables (periods 2.27 h and 8.46 h)	

													¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ E(B–V) =+0.10	
λ	Tau	4 02.2	+12 34	3.49v†	−0.12	B3 V	7	−2.4	480	0.017	209	+18 SB2†	ecl.: 3.37–3.91 in V, 3.953 d; secondary is A4 IV system is of β Per type; AAVSO(VSX), as viewed 2022 July 08 and again on 2024 April 06, gives period 3.9529478 d, eclipse duration 14.231 h (AAVSO(VSX) assessment on 2024 April 06: status flag = confirmed variability; 3630 AAVSO observations found; variability classification symbol = “**EA/DM**”) ¶ shape distortion (mutual tides), reflection effect, some evidence of mass transfer ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
α	Ret A	4 14.8	−62 24	3.33	0.92	G8 II–III	20.2	−0.1	162	0.065	40	+36 SB?	AAVSO(VSX) situation as of 2024 April 06: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), a fortiori no variability classification symbol assigned ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (2.618 mas ± 3%, with limb-darkening correction, in the near-infrared K band, from the AMBER beam-combining facility at VLTI)	Rhombus
ε	Tau Aa +1P†	4 30.2	+19 14	3.53†	1.01†	K0 III†	22.2	0.3	150	0.113	110	+39 V?	in Hyades; Aa,Ab 0.2″ (2005), mags. ~3.6, ~6.0 as of 2024 Dec. 07, WDS records just one (interferometric) measurement of the ε Tau Aa,Ab binary ¶ m_v, B−V values seem unavailable in GCPD; we take m_v value from 2002yCat.2237….0D and calculate B−V from 2009ApJ…694.1085V with 2002yCat.2237….0D ¶ AAVSO(VSX) situation as of 2024 April 06: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), a fortiori no variability classification symbol assigned ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.592 mas ± 2%, in the 500 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ metals-rich ¶ first known instance of a planet-host in an open cluster; unusually massive among the currently known planet-hosts ¶ Astron. Alm. (epoch 2021.5) assigns MK type G9.5 III CN0.5 **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	Ain
θ	Tau Aa†	4 30.2	+15 56	3.41†	0.19†	A7 III	22	0.1	150	0.112	104	+40 SB†	system Aa-plus-Ab is a.k.a. θ^2 Tau; in Hyades companion in elongated orbit, with published orbital solutions (period is 140.728 d; *e*=0.73; 0.23 au min, 1.3 au max); we here state mag. for Aa,Ab combined light (separately these are mag. ~3.7, mag. ~4.9, making Aa alone a little fainter than what this table consider a “bright star,” even though the naked-eye bright point that is θ Tau Aa,Ab is the brightest Hyades member; one of the components in the Aa,Ab pair, typically presumed to be Aa, is a δ Sct variable, with V range somewhat less than 0.1 mag., for which 12 periods are known, 1.64 h to 2.22 h, the ranges in some cases small (0.5 millimag., 30 millimag.); this is one of the intensely studied cases of δ Sct variability); the SB system θ Tau Aa,Ab forms a wide pair with the bright SB system θ Tau Ba,Bb, a system a.k.a. θ^1 Tau (mag. ~3.9; astrometry of Aa,Ab with respect to Ba,Bb is 340″→337″, PA 346°→347°, 1800→2019); not only the Aa,Ab	Chamukuy

													but also the Ba,Bb pair has a published orbital solution; Aa,Ab and Ba,Bb are in turn gravitationally bound, with each of the two tight pairs in this quadruple of stars experiencing the other tight pair as essentially a point mass; the entire Aa,Ab,Ba,Bb system, notably including at least three of the four individual masses, has been much studied since the 1990s, drawing on data from occultation, spectroscopy, and interferometry, even though the various challenges include some troublesome rotational broadening of spectral lines, since both Aa and Ab are rapid rotators; determination of masses, plus (helpfully, even *HIPPARCOS*-independent, via orbit model) determination of distances, confers on this Aa,Ab,Ba,Bb system, as on several other stars in the Hyades, a special stellar-astrophysics significance, as isochrone-anchored data points for plotting the empirical (i.e. the theory- free) mass-luminosity relation, and therefore for constraining models of stellar evolution (1997ApJ...485..167T recapitulates the strategic position as follows: "The Hyades is unique in this respect. In no other case have dynamical masses been determined over a range covering much of the Main Sequence /…/ for stars of the same age and known chemical composition.") ¶ m_v, B−V values seem unavailable in GCPD; we instead use 1993A&AS..100..591O ¶ AAVSO(VSX) assessment as of 2024 April 06: status flag = confirmed variability; 59 AAVSO observations found; range 3.35−3.42 in V; variability classification symbol = "**DSCTC+E:**" ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ the θ Tau Aa name "Chamukuy," IAU-official since 2017, is the Yucatec Mayan name for a small bird	
α	Dor <u>A</u>†	4 34.6	−54 59	3.26v†	−0.10†	A0p V: (Si)†	19	−0.3	169	~0.059	~79?	+26	A: 3.6; B: 4.6, B9 IV; 0.2″ (2023); orbit 12 y orbit very elongated, with A-to-B distance 1.9 au min, 17.5 au max ¶ m_v, B−V values are for α Dor AB combined light ¶ α Dor system present slight variability, 3.236−3.276 in V, period 2.94247 d (en.wikipedia.org/wiki/Alpha_Doradus has light curve, from *TESS*), of the α CVn A ("α^2 CVn") type (AAVSO(VSX) assessment as of 2024 April 06: status flag = confirmed variability (although no AAVSO observations found); variability classification symbol = "**ACV**") ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ Astron. Alm. (epoch 2021.5) assigns MK temperature type A0p Si (and does not assign an MK luminosity class)	
α	Tau A +2P?†	4 37.4	+16 34	0.87†	1.54	K5 III†	49	−0.7	67	0.199	161	+54 SB	slight irregular var., 0.86–0.89 in V passband (AAVSO(VSX) assessment as of 2024 April 06: status flag = confirmed variability; 998 AAVSO observations found; variability classification symbol = "**LB:**"); recent literature proposes oscillations, and also proposes rotational modulation from modest photospheric-activity features (with possibly an activity cycle (2015A&A...580A..31H): the features could be (cool) starspots, but could alternatively be large convection cells; the general topic of activity in K giants is not yet well understood) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 21.099 mas ± 1% at 800 nm, with the Mark III	**Aldebaran**

													beam-combining facility at Mount Wilson: this result is rather close to the classic Michelson-interferometer determination of 20 mas at Mount Wilson (uncertainty not available to us at RASC *Handbook*), reported by Pease in 1931, near 575 nm (Mount Wilson 2.5-m telescope, with rigid 15-m beam holding the small starlight acquisition mirrors at the telescope sky end; the 15-m beam was the successor to the 6-m rigid beam with which Michelson and Pease obtained their 1920 angular-diameter measurement for α Ori Aa) ¶ foreground star, not true Hyades member; among the nearest of the red giants; evolution has proceeded beyond the “FDU” stage that accompanies helium-core contraction on RGB ¶ 49 lunar occultations occurred over the period 2015 Jan. 29/2018 Sep. 03 (and yet there is a surprisingly large scatter in the occultation determinations of α Tau angular diameter; 1972JBAA...82..431K describes the overall 18.6-year 1940-through-2050 cycle of lunar occultation possibilities) ¶ in contrast with its celestial-sphere neighbour α Ori, α Tau is of modest mass (with recent literature variously offering ~1.2 $M_\odot$, ~1.3 $M_\odot$, ~1.5 $M_\odot$): Appendix C of 2018ApJ...865L..20F tabulates values for mass, luminosity, radius, age, and several other parameters, on the strength of five separate 2008-through-2012 spectroscopy investigations ¶ 2013A&A...553A...3O reports “MOLsphere” (molecule- harbouring atmosphere) inhomogeneities, from VLTI/AMBER, thereby helping advance the still poorly understood topic of RGB mass loss (especially in a context in which dust condensation might appear not to play a significant role; in general, it is RGB mass loss that is puzzling, AGB mass loss that is straightforward) ¶ Astron. Alm. (epoch 2021.5) assigns MK type $K5^+$ III ¶ although 2019A&A...625A..22R casts doubt on 2018ApJ...865L..20F, 2015A&A...580A..31H exoplanet assertion, exoplanet is asserted in NASA exoplanet catalogue (as viewed 2021 Aug. 07, 2024 Dec. 07)	
π^3	Ori A	4 51.3	+7 00	3.19†	0.45	F6 V	124	3.7	26.3	0.464	89	+24 SB2	possible slight var. (3.15−3.21 in V passband?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 06: status flag = suspected variable (but only one AAVSO observation found); variability classification symbol = “**ROT**” (in 2022, AAVSO had not yet been able to assign a classification symbol)) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter (limb-darkening correction said to be negligible) is 1.409 mas ± 4%, in 8000 nm - 13000 nm mid-infrared passband, from the KIN beam-combining facility at the W.M.Keck Observatory	Tabit
ι	Aur	4 58.7	+33 12	2.68†	1.53	K3 II	7	−3.2	500	0.016	155	+18V	var.?: (2.63–2.78?); poss. “+2P” (brown dwrfs?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 06: status flag = suspected variable; 88 AAVSO observations found; no variability classification symbol assigned) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 7.004 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ X-ray “hybrid star” (unusual combination of (hot) corona, cool wind) ¶ dimming by ISM dust, ~0.6 mag.	Hassaleh
ε	Aur A	5 03.9	+43 52	2.98†	0.54†	F0Iab?†	~2†	−8.0:	~1450†	~0.003	n.a.	−3 SB†	slow ecl.: 2.92–3.83 in V, ~27.1 y (dim ~700 d) more formally, period has been asserted as 9896.0 ± 1.6 d (although AAVSO(VSX) has 9892 d): as again discussed twice below, there are spectroscopic, as distinct from photometric, phenomena	Almaaz

indicative of an eclipsing mass before the
onset, and continuing after the end, of the
photometric eclipse;
AAVSO(VSX) assessment as of 2024 April 06:
status flag = confirmed variability;
34320 AAVSO observations found;
variability classification symbol = "**EA/GS**"
¶ m_v, B−V values are for ε Aur AB combined light
¶ Astron. Alm. (epoch 2021.5) assigns MK type A9 Ia
¶ ε Aur B MK type is ~B5 V
¶ ε Aur ranks among the longest-period eclipsing
binaries (exceeding even V383 Sco, with period 13.5 y;
WW Vul, with period 13.9 y;
and VV Cep, with period 20.3 y:
the current long-period record, however, is
possibly held by TYC 2505-672-1, at
~69.1 y [with dimming ~3.45 y])
¶ determination of orbit elements has proven
troublesome, with 2012A&A...544A..91M urging caution
even in respect of recent careful studies
¶ it is remarkable that, even though the eclipsing
entity is physically very extended (because the eclipse
is protracted), and even though orbital dynamics indicates
that the entity is quite massive, nevertheless
no visible radiation from an
eclipsing body is readily observable
(i.e. it is remarkable that this SB is
essentially a single-lined SB)
¶ although the (notably protracted) ε Aur eclipse
is largely flat-bottomed, nevertheless even during eclipse
the (dimmed) spectrum of the primary can be seen,
with no visible-wavelength colour
preference in the attenuation
(except that there are absorption
lines, as from a semi-transparent
atmosphere around the eclipsing mass,
at the start and the end of the dimming);
the 1937ApJ....86..570K explanation, postulating
a large semitransparent
totally eclipsing mass, with the non-selective
opacity due to scattering off free electrons,
is now universally abandoned in favour of the
1953AJ.....58..219K and 1965ApJ...141..976H
hypothesis of an almost edge-on (2010ApJ...714..549H)
cool opaque gas-dust low-mass
disk or disk-like entity (spiral
arm? cf. 2013PASP..125..775G)
(rotating while orbiting, and several au in diameter,
presenting a
temperature gradient ~550 K to ~1150 K (representing
the portions respectively
farthest from and closest to the primary star),
and in terms of its vertical
development not a (thick) ice-hockey puck
but a (thin) wafer, of much larger
radius
of much larger radius (~8 AU?) than the
(already prodigiously bloated,
with R* ~150 solar radii, post MS)
primary star; 2013PASJ...65L...1S gives
evidence for clumping in the disk;
2015ApJS..220...14K raises the
possibility that the disk is slightly tilted out of the
binary-system orbital plane, with consequent precession),
shrouding a B-type
star (B5V?) or star pair (the more dramatic
hypothesis of a shrouded black hole is not now
generally favoured: 2010AJ....140..595W, e.g. reports
null result from X-ray search), with the disk geometry
making the eclipses of the primary star,
as observed from Earth, only partial;
the disk may have been formed
by mass transfer from the primary star,
and indeed 2013PASP..125..775G
and 2018MNRAS.479.2161G
report putative spectroscopic
detection of narrow mass-transfer stream;

the former paper stresses that the detection of rare-earth elements within the putative stream spectrum (an indication that the primary is highly evolved?) now poses a fresh puzzle, in a system traditionally classed as puzzling

¶ 2012ApJ...748L..28H and 2012MNRAS.423.2075M discuss the question of gas-to-dust ratio in the disk; 2015ApJ...798...11P, 2012MNRAS.423.2075M, and 2010ApJ...714..549H suggest not-very-small values in the distribution of dust-particle diameters, with the first two of these three papers suggesting carbonaceous chemistry; additionally, 2011AJ....142..174S spectroscopy finds CO absorption bands, symptomatic of sublimation, with indications that large particles dominate

¶ 2013ARep...57..991P and 2013PASP..125..775G document indications that the structure of the disk does not greatly change from one eclipse to the next

¶ the brightening around mid-eclipse has in the post-1970 papers repeatedly been attributed to a central opening in the postulated disk: however, (*a*) dissenter 2011A&A...530A.146C has instead suggested intrinsic variability in the primary (primary indeed has various quasi-periods or periods, with 67 d and 123 d prominent, with also variations in radial velocity, and (unblended) spectral line width, and other periodic or quasi-periodic behaviour, including possible orbitally excited non-radial pulsation; there seems as yet, however, to be no extensive asteroseismology), and (*b*) dissenter 2011A&A...532L..12B has instead suggested forward scattering by disk dust (a line of thought now supported by the key imaging-and-modelling paper 2015ApJS..220...14K)

¶ *HIPPARCOS* yields π possibly < 2 mas, distance ~2000 ly; we now, however, choose to relinquish the *HIPPARCOS* determination, made at the limit of *HIPPARCOS* capabilities, in favour of 2019IBVS.6258....1P, which deduces from *Gaia* DR2 $\pi = 2.4144 \pm 0.5119$ mas, and goes on to deduce from this, via supplementary (not straightforward , Bailer-Jones et al. 2018AJ....156...58B) considerations what we express here as "~1450 ly"

¶ section 1 of 2012A&A...546A.123G and section 1 of 2012A&A...544A..91M summarize past controversies regarding mass of primary (low or high?), stemming from the difficulty in determining distance (2012A&A...546A.123G assigns a high distance, ~4900 ly, and consequently favours a high mass value, ~20 $M_\odot$; however, several post-2009 papers instead assign a modest mass to the primary, suggesting various values within the range ~2 $M_\odot$ – ~6 $M_\odot$: 2014MNRAS.445.2884M, e.g. suggests 2.5 $M_\odot$ for primary, 5.4 $M_\odot$ for secondary (and suggests disk diameter 8.9 au)): evolutionary status of the primary has been correspondingly controverted (post-AGB star, now of modest mass, with much past shedding of mass, and consequent accumulation of the low-mass opaque disk around the secondary (a view taken by various papers, including recently 2019IBVS.6258....1P) or, rather, an evolutionally earlier supergiant (cf 2012JAVSO..40..647K), even perhaps of high mass? – but it is clear that the primary is at any rate sufficiently evolved to have left the MS, and there are indications that it is pulsating and a wind source;

													angular diameter is 2.1 mas) ¶ most recent photometric eclipse started 2009 Aug. 12, ended 2011 Aug. 23 ±15 d; next secondary (shallow, for the casual observer elusive) eclipse is possibly 2025 Dec. 20 through 2028 Mar. 29; next (deep, easy observable) primary photometric eclipse starts in 2036; monitoring even outside both the primary eclipse and the secondary eclipse is useful, in part because of intrinsic variations in the primary star (cf 2012JAVSO..40..647K); in part because the postulated dense disk has an extended "atmosphere" yielding (e.g.) Hα absorption even outside photometric eclipse (2011A&A...530A.146C), with spectral premonitions starting ~3 y before the onset of the photometric eclipse; and in part because the opaque primary-star-eclipsing disk is potentially liable to thermal changes, visible in mid-infrared outside primary and secondary eclipse (2011AJ....142..174S) ¶ the Kloppenborg et al. CHARA interferometric imaging of the eclipsing disk is perhaps the single largest 21st-century advance in ε Aur studies: 2010Natur.464..842G supplies journalistic background, including a recapitulation of 2010ApJ...714..549H modelling; 2010Natur.464..870K is the formal Kloppenborg et al. discovery paper (with the first spatially resolved image for any eclipsing binary during eclipse); and 2015ApJS..220...14K is a Kloppenborg-et-al update, with additional interferometry, now including also PTI and NPOI (and supplying also an overall history of ε Aur studies) ¶ news sources include mysite.du.edu/~rstencel/epsaur.htm (Prof. R. Stencel, Univ of Denver, on the Kloppenborg-2010 team) and twitter.com/epsilon_Aurigae; 2012JAVSO..40..618S summarizes the 2009–2011 campaign from an AAVSO perspective; an 18-paper archive, of NSF-supported ~2009-through~2011 AAVSO eclipse campaign, is at www.aavso.org/citizen-sky-epsilon-aurigae-papers; coverage in the popular press includes a *Los Angeles Times* feature of 2011 Jan. 20 by reporter Thomas Curwen, describing a night's interferometry at the CHARA beam-combining facility on Mount Wilson; this feature is retrievable through (e.g.) a Google search on the string thomas curwen centuries-old mystery in the stars ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.210 mas ± 0.5%, in 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ since the eclipsing companion of ε Aur A has not yet been resolved, even in interferometry, WDS is not as yet (at any rate as of 2024 Dec. 07) able to write "ε Aur Aa," "ε Aur Ab"; WDS does, on the other hand, catalogue celestial-sphere neighbours B,C,D,E,F,G,H,I,J,K; all of these are fainter than mag. 10, except for ε Aur E (at the wide angular separation of 207″ (2013) from ε Aur A, and at mag. 9.6 just barely clearing our mag.-10 threshold for comment-worthiness of a bright-star neighbour on celestial sphere)
ε	Lep	5 06.6	−22 20	3.17†	1.47	K4 III	15	−0.9	210	0.076	164	+1	possible slightly var. (3.12−3.20 in V passband?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 06: status flag = suspected variable;

													32 AAVSO observations found; no variability classification symbol assigned) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ evolutionary status is uncertain: RGB or AGB?	
η	Aur	5 08.4	+41 16	3.17†	−0.18	B3 V†	13	−1.2	240	0.075	155	+7 V?	slight var.: (rotating ellipsoid?) 3.16–3.18 in V, 2.6 d further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 06: status flag = confirmed variability; 64 AAVSO observations found; variability classification symbol = "**ELL:**") ¶ it has been suggested that variations are present also in spectroscopy ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (0.453 mas ± 2%, with limb-darkening correction, in the visible-light R passband, from the PAVO beam-combining facility at CHARA) ¶ weak magnetic field detected, ~2× strength of Earth's dipole field	Haedus
β	Eri A	5 09.2	−5 03	2.78†	0.13	A3 IVn	36	0.6	89	0.112	228	−9	poss. slight var.: type unknown (2.72−2.80 in V?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April: status flag = suspected variable; 61 AAVSO observations found; no variability classification symbol assigned); unexplained brightening episode, over 2 h, by ~3 mag, in 1985 (recalling the 1972 unexplained brightening of ε Peg) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	Cursa
μ	Lep	5 14.1	−16 11	3.29†	−0.11	B9p IV: (HgMn)†	18	−0.5	190	0.050	109	+28	elusive slight var., 0.001 in V, period 3.0113 d (*TESS*), of α CVn A ("α^2 CVn") type; en.wikipedia.org/wiki/Mu_Leporis has a light curve, from *TESS* data (AAVSO(VSX) assessment as of 2024 April 06: status flag = confirmed variability; 166 AAVSO observations found; variability classification symbol = "**ACV**") ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ among the brightest of the Hg-Mn stars ¶ Astron. Alm. (epoch 2021.5) assigns MK temperature type B9p HgMn (and does not assign an MK luminosity class) ¶ X-ray emission noted from putative companion, at angular distance 0.93″	
β	Ori A†	5 15.8	−8 10	0.14v†	−0.03	B8 Ia	4	−6.9	900	0.001	69	+21 SB	B: 6.8, B5 V, 9.4″ (2023); C: 7.6; BC: 0.1″ (2005) A−BC orbit ≥ 25,000 y, BC orbit ~400 y ¶ m_v, B−V values are for β Ori ABC combined light ¶ the β Ori system presents variability in the α Cyg class, range 0.08–0.20 in V (AAVSO(VSX) assessment as of 2024 April 06: status flag = confirmed variability; 89 AAVSO observations found; variability classification symbol = "**ACYG**") ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.606 mas ± 3%, in passband 550-850 nm, from the PAVO beam-combining facility at CHARA ¶ E(B–V) =+0.00	Rigel
α	Aur Aa,Ab†	5 18.7	+46 01	0.07v†	0.80	K0 III + G1 III	76	−0.5	43	0.433	170	+30 SB2	interferom. binary: ~79 mas min, ~109 mas max ¶ m_v, B−V values are for α Aur Aa,Ab combined light; Aa,Ab are resp. mags. ~0.08, ~0.18 in V passband ¶ under IAU rules, "Capella" designates Aa, not Ab ¶ we now base the MK classification, K0 III + G1 III, for the α Aur Aa,Ab composite spectrum on 1990A&A...230..389S; Astron. Alm. (epoch 2022.5), on the other hand, assigns G6 III + G2 III; in this composite spectrum, it is sharp-lined α Aur Aa	**Capella**

												that dominates, because α Aur Ab, being a rapid rotator, suffers line broadening ¶ orbit of the Aa, Ab SB is 104.02 d, with physical orbit circular or very nearly circular, Aa-to-Ab distance ~0.74 au (but the apparent orbit is foreshortened, because the orbital plane is inclined to the sky plane); Aa,Ab is the first binary with orbit studied interferometrically (1920ApJ....51..263A: 1981AJ.....86..795M, on the other hand, recapitulates all interferometric work to date, obtains for the first time a purely interferometric orbit without assistance from spectroscopy, and presents the foreshortened apparent-orbit-of-best-fit in its Fig. 1): the binary is informally known as “The Interferometrist’s Friend”, as being bright, and moreover as having components of nearly equal magnitude; full system appears to be α Aur Aa+Ab+H+L, where H and L are red dwarfs, of respective mags. 9.99 and 13.5, sharing the proper motion of Aa+Ab and perhaps possessing further gravitationally bound companions (with α Aur B,C,D,E,F,G,I,J,K being mere line-of-sight coincidences; of these 9 celestial-sphere neighbours of “The Interferometrist’s Friend” which is the Aa,Ab SB, only G, at wide angular separation of 522″ from Aa,Ab, is brighter than mag. 10 (at mag. 8.10); additionally, WDS documents the celestial-sphere neighbours M,N,O,P, of which only the sparsely observed M and N are brighter than mag. 10 (at mag. 6.29 and mag. 9.84, respectively); the crowding, surely with abundant line-of-sight coincidences, in this region of the celestial celestial sphere is perhaps to be expected, given the celestial-sphere adjacency of α Aur to the Milky Way) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter (there is no limb-darkening corrrection), published in 1991, is 6.09 mas ± 4% at 2200 nm for α Aur Ab, from a Michelson beam-combining facility at the Calern station of what is now France's Observatoire de la Côte d’Azur; although JMDC reports no recent diameter measurements for α Aur Aa, and although the JMDC reported 1977 interferometric work on α Aur Aa cannot now be taken as reliable, astrophysical theory implies for α Aur Aa a diameter ~1.4 times the diameter of α Aur Ab ¶ α Aur Ab is in rapid evolutionary transition, currently crossing the Hertzsprung Gap ¶ AAVSO(VSX) assessment as of 2024 April 06: status flag = confirmed variability (had been flagged in 2022 merely as a suspected variable, without variable classification symbol); 97 AAVSO observations found; variability classification symbol = “**RS**” ¶ α Aur system is among the brightest of X-ray sources
η	Ori Aa†	5 25.8	−2 22	3.36v†−0.17†	B0.5 Ve†	3	−4.0	1000	~0.004?	n.a.+20	SB2	ecl.: 3.31–3.60 in V, 8.0 d; A: 3.6; B: 4.9, 1.8″ (2022) η Ori Aa is unresolved SB2, strictly 7.989268 d, eclipsing (β Per type), to be informally thought of as “the Aa1, Aa2 binary” (but since the SB2 is not as yet resolved, even in interferometry, WDS is not, at any rate as of 2024 Dec. 07, able to formally catalogue the stars as η Ori Aa1, η Ori Aa2, and uses the informal terminology only in a note); Ab experiences “Aa1,” “Aa2” as essentially a point mass; the Ab-with- “Aa1,Aa2” period is 9.44 y, spectroscopically SB but not SB2 (with at least one orbital solution published); in a very slow orbit with the three-star “Aa1,Aa2 binary”-plus-Ab system, and so in turn experiencing that triple as essentially a point mass, is η Ori B (mag. 4.9; AB astrometry is 0.9″→1.8″, PA 87°→77°, 1848→2022, with orbit ≥ 2000 y) ¶ one or other of “Aa1,” “Aa2” is a pulsator, with period 8 h (possible β Cep variability? but

one or other of the Aa components is an instance
of the “Be phenomenon,” and additionally a shell
spectrum has been observed from one or other
of “Aa1,” “Aa2”); as of 2024 April 06,
AAVSO(VSX) assessment is as follows:
status flag = confirmed variability;
1188 AAVSO observations found;
variability classification symbol = “**EA+BCEP:**”
¶ the JMDC 2021 Sep. 13-or-14 edition does not report
any direct measurement of angular diameter
(whether through interferometry
or by any other direct means)
¶ m_v, B−V values are for η Ori Aa,Ab combined light
¶ Astron. Alm. (epoch 2021.5) assigns MK type B1 IV
¶ BSC5: “expanding circumstellar shell”

γ	Ori A	5 26.6	+6 22	1.64†	−0.22	B2 III†	13	−2.8	250	0.015	212	+18 SB?	poss. slight var.: type unknown (1.59−1.64 V?) **Bellatrix**

possible variability in γ Ori system noted ~1988
(the system was previously believed
constant, and was used in a defining
of the UBV photometric scheme);
further photometric study advisable?
(AAVSO(VSX) assessment as of 2024 April 06:
status flag = suspected variable;
18 AAVSO observations found (there had been
only one as of 2022 July 29);
no variability classification symbol assigned)
¶ the JMDC (2021 Sep. 13-or-14 edition)
most recent reported interferometric measurement
of angular diameter with limb-darkening corrrection
is 0.785 mas ± 0.9%, in the visible-light R passband,
from the VEGA beam-combining facility at CHARA
¶ BSC5: “expanding circumstellar shell”

β	Tau	5 28.0	+28 38	1.65	−0.13	B7 III†	24	−1.4	130	0.175	173	+9 V SB	**Elnath**

BSC5: “expanding circumstellar shell”
¶ lunar occultations possible as far N as
southern California: we use simply the
designation “β Tau,” even though WDS
has “β Tau Aa”; there are now 2 observations
of “β Tau B,” (33.40″ in 1898, 33.80″ in 2021,
with non magnitude given in either case),
and additionally a single observation of an
alleged “β Tau Ab,” of mag. 2.40, at angular
separation just 0.10″, possibly an occultation
observation, from 1930; this sparse observational
material suggests to us that a lunar-occultation
campaign (for observers at suitable latitudes,
such as in southern California) might be worth
undertaking, conceivably to yield a positive result
corroborating the 1898-and-2021 suggestions
of multiplicity, and rebutting the 1930 suggestion
of multiplicity)
¶ often, but not invariably, classified as
Hg–Mn star: Mn 25× solar (and Ca, Mg only
~0.12× solar: radiative lofting,
gravitational settling)
¶ AAVSO situation as of 2024 April 06:
no status flag (so not confirmed variable,
not suspected variable, not confirmed non-variable),
a fortiori no variability symbol assigned
¶ the JMDC (2021 Sep. 13-or-14 edition)
most recent reported interferometric measurement
of angular diameter with limb-darkening corrrection
is 1.09 mas ± 7%, in the near-infared H band,
from the CLIMB beam-combining facility at CHARA;
CHARA has achieved imaging
¶ E(B–V)=0.00

β	Lep A†	5 29.4	−20 44	2.84†	0.82†	G5 II	~20.3	−0.6	160	0.086	183	−14 V?	B: 7.5, 2.7″, PA 268°→12°, 1875→2021 Nihal

¶ although β Lep B has been held to be
possibly variable, AAVSO(VSX),
as viewed 2024 April 06, has no entry
(no status flag, so not confirmed variable,
not suspected variable, not confirmed non-variable;
a fortiori no variability symbol assigned)
¶ the JMDC 2021 Sep. 13-or-14 edition does not report
any direct measurement of angular diameter
(whether through interferometry
or by any other direct means)
¶ m_v, B−V values are for β Lep AB combined light

													¶ duplicity now suspected also in β Lep A, through 2002 adaptive-optics observation at Haleakala: separation 2.58″	
δ	Ori Aa†	5 33.4	−0 17	2.23v†	−0.22†	O9.5 II	5	−4.4	700	0.001	137	+16 SB	a good marker of celestial equator ¶ Aa is an Algol-type eclipsing binary, not as yet resolved (so WDS is not as yet, at any rate as of 2024 Dec. 07, able to write "δ Ori Aa1," "δ Ori Aa2") with period 5.73249 d, yielding a combined-light variation reported at AAVSO(VSX) (for the entire Aa,Ab system? or just for the unresolved Aa SB?) over the mag. range 2.20−2.32 (in the V band); (AAVSO(VSX) assessment as of 2024 April 06: status flag = confirmed variability; 2156 AAVSO observations found; variability classification symbol = "**EA**") ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ WDS assigns to the unresolved Aa SB the MK type O9.5 II, and to the single Ab star (mag. 3.76) the MK type (with luminosity class tentative) "O9.7 III:"; angular separation of the unresolved Aa pair and the single star Ab has increased over recent decades (0.2″→0.3″, 1978→2022); at least one orbital solution has been published for Aa,Ab; there is also a bright celestial-sphere neighbour, δ Ori C, at mag. 6.8 (AC astrometry 50″→52″, PA 0°→0°, 1777→2023) ¶ m_v, B−V values are for δ Ori Aa,Ab combined light ¶ yielded first detection of ISM (Hartmann, 1904, through non-moving Ca line in the SB) ¶ E(B–V)=+0.07	Mintaka
β	Dor	5 33.9	−62 28	3.52v†	0.66	F7–G2 Ib	3.2	−3.7	1000	0.013	4	+7 V	Cepheid var.: 3.41–4.08 in V passband, 9.84 d period not quite constant; evolutionary status uncertain (AAVSO(VSX) assessment as of 2024 April 06: status flag = confirmed variability; 9529 AAVSO observations found; variability classification symbol = "**DCEP**") ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one campaign of interferometric measurements for angular diameter of this pulsating (Cepheid) star, a timeseries published in 2016 (1.6022 mas, 1.6857 mas, 1.7098 mas, 1.7584 mas, 1.7939 mas, 1.8160 mas, with uncertainty ±0.7%, without limb-darkening correction, in the near-infared H band, from the PIONIER beam-combining facility at VLTI) ¶ observed by *FUSE*, *XMM-Newton* missions **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
α	Lep A	5 33.9	−17 48	2.58†	0.21	F0 Ib†	1.5	−6.6	2000	0.004	72	+24	poss. slight var.: type unknown (2.56−2.62 in V?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 06: status flag = suspected variable; only one AAVSO observation found; no variability classification symbol assigned) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (1.77 mas ± 5%, with limb-darkening correction, at 740 nm, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ) ¶ evolutionary status uncertain (has helium fusion already started in core?); helium-fusion past yields present abundances N 5× solar, Na 2× solar	Arneb
λ	Ori A†	5 36.6	+9 57	3.39†	−0.18†	O8 IIIf	3	−4.2	~1100	0.004	216	+34	B: 5.45, B0 V, 4.1″, PA 45°→43°, 1779→2021 WDS, citing 1985A&AS...60..183L, remarks that B may be a mere line-of-sight coincidence; WDS also gives, in addition to two faint celestial-sphere neighbours, neighbours λ Ori D (mag. 9.6; AD angular separation was 78″ in 2012) and λ Ori E (mag. 9.2; AE angular separation	Meissa

														was 151″ in 2012) ¶ mv, B−V values are for λ Ori AB combined light ¶ the most prominent member of the "λ Ori Cluster," a.k.a. Collinder 69 ¶ within Sharpless 264 (i.e. Sh2-264), a.k.a. the "λ Ori Ring," a.k.a. the "Angelfish Nebula," a gas ring 150 ly in diameter (possibly, but not certainly, remnant from a Type II supernova) ¶ as of 2024 April 06, AAVSO(VSX) flags λ Ori assemblage as harbouring confirmed variability (had been flagged merely as suspected var. when VSX was viewed 2022 July 29), notes the availability of 140 AAVSO observations (the same count as on 2022 July 29), and assigns range 3.39−3.40 in V passband (2022 July 29 suggested range had been 3.38−3.54 in V passband); AAVSO(VSX) as of 2024 April 06 assigns variability classification symbol "**BCEP:**", for possible-yet-not-certain β Cep type (no symbol had been assigned as of 2022 July 29); further photometric study advisable? ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (0.226 mas ± 7%, with limb-darkening correction, at 800 nm, from the PAVO beam-combining facility at CHARA) ¶ **E(B–V)**=+0.12	
ι	Ori Aa†	5 36.7	−5 54	2.77†	−0.24†	O9 III	~1.4	−6.5	2000	0.001	108	+22	SB2	Aa,Ab 0.2″ (2023), mags. 3.0, 6.3 B: 7.7, B7 IIIp (He wk), 11.2″, PA 134°→141°, 1779→2023, orbit ≥ 700,000 y; there is additionally a celestial-sphere neighbour ι Ori C, at mag. 9.8, with AC angular separation 49″ in 2023; ι Ori Aa is SB, not as yet resolved (so WDS is not as yet, at any rate as of 2024 Dec.. 07, able to write "ι Ori Aa1," "ι Ori Aa2"), with published orbital solutions (29.134 d, *e*=0.76, 0.11 au min, 0.8 au max): the elongated orbit, and a disparity in ages, suggest duplicity through many-body interaction-with-expulsion, rather than through the cogenesis that is usual for a binary; the ι Ori Aa, ι Ori Ab pairing does not for its part possess published orbital solutions ¶ colliding winds make ι Ori A a strong X-ray source ¶ m_V, B−V values seem unavailable in GCPD; we take values from 2002yCat.2237….0D (but we are uncertain whether these values are meant for ι Ori Aa,Ab combined light or for ι Ori Aa,Ab,B combined light) ¶ ι Ori Aa,Ab system presents a slight variability, 2.76−2.79 in V, of an AAVSO(VSX) (but not GCVS) ellipsoid-photospheres type; additionally, and independently of this HB phenomenon, ι Ori B is variable (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; seems no AAVSO observations found; variability classification symbol = "**HB**") ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening corrrection is 0.660 mas ± 3%, at the very short wavelength of 443 nm, from an innovative application of the VERITAS beam-combining facility (normally used in gamma-ray-Cherenkov studies) at Fred Lawrence Whipple Observatory ¶ brightest member of Sword asterism ¶ E(B–V)=+0.07	Hatysa
ε	Ori A	5 37.6	−1 11	1.69v†	−0.18	B0 Ia	2	−7.2	2000	0.002	118	+26	SB	var.: α Cyg type, 1.64−1.74 in V passband supergiant, non-radially pulsating (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 635 AAVSO observations found; variability classification symbol = "**ACYG**") ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter	**Alnilam**

													(whether through interferometry or by any other direct means) ¶ luminosity (etc) controverted: Crowther (2006) 275,000 $L_{\odot}$, Searle (2008) 537,00 $L_{\odot}$, Puebla (2015) 832,000 $L_{\odot}$ ¶ E(B–V)=+0.08	
ζ	Tau	5 39.2	+21 09	2.92v†	−0.20	B2 IIIpe (shell)†	7	−2.7	400	0.020	175	+20 SB†	var. (ecl..? and γ Cas?): 2.80–3.17 in V, 133.0 d although eclipse-generated variability is asserted at AAVSO(VSX), with period 132.9735 d (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 751 AAVSO observations found; variability classification symbol = "**E/GS+GCAS**"), the occurrence of eclipses has been disputed (cf en.wikipedia.org/wiki/Zeta_Tauri); γ Cas variability would be consistent with the observed Be-phenomenon-cum-shell, and is accepted by AAVSO(VSX), although not accepted throughout the literature ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ m_v, B−V values are for the combined light of the ζ Tau SB ¶ the primary in the SB pairing is one of the best-known "Be phenomenon" stars, and is possibly one of the keys to the solution of currently unsolved Be-phenomenon problems; consistently with the shell-spectrum history, the disk is just 5° away from being seen edge-on (2013A&ARv..21...69R, p. 58n); although the disk gases move in Keplerian orbits, their orbits are not circular, and consequently the material has some nonzero radial velocity even at the midpoint of transit; a further consequence of this kinematics is that the orbiting gas is less dense at apastron than at periastron; shell spectrum underwent three full cycles of V/R variation from 1997 to 2010, with these cycles generally taken as making the precession, under gravitational influence of the elusive SB companion, of a one-armed density wave within the Be disk (for geometry and time variations of disk, cf Fig. 7 of 2010AJ....140.1838S, Fig. 8 of 2015A&A...576A.112E); however, in more recent years, the V/R cycling has been absent; precession notwithstanding, the disk has been observed to be stable, and therefore must be being fed by decretion from the host-star photosphere at a nearly constant rate; as a step toward the eventual discovery of the excitation structure of some conveniently observable Be-phenomenon disk, 2012ApJ...744...19K reports spectro-interferometry from two different ζ Tau primary-star radii, in hydrogen Brackett γ and in a set of hydrogen Pfund lines (while drawing also on hydrogen Balmer α data from previous literature); the emission is found to originate at roughly the same disk radius for hydrogen Balmer α and hydrogen Brackett γ, and at a smaller radius for the hydrogen Pfund lines; the 2012ApJ...744...19K ζ Tau study provides some observational support for the viscous decretion-disk, Keplerian-rotation model prevalent in recent Be-phenomenon theorizing, and additionally supports the density-wave-in-disk hypothesis for the observed V/R cycles; modelling efforts are ongoing, with 2015A&A...576A.112E serving as a progress report ¶ its rapid rotation and Be-phenomenon and shell-spectrum histories notwithstanding, the ζ Tau primary has already evolved some distance off the MS, to "giant" stage (in general, giants are not expected to be rapid rotators); 2012ApJ...744...19K assumes an equatorial radius of 7.7 $R_{\odot}$ ¶ the nature of the elusive low-flux? ~1 $M_{\odot}$ SB companion, of period 133.0 d, is unknown (could even be a neutron star); separation (with orbit nearly circular) is ~1.17 au; since interferometry seems so far to have failed to resolve the companion, WDS, at any rate as of 2024 Dec. 07,	Tianguan

													is unable to write catalogue entries for “ζ Tau A” and “ζ Tau B”; the elusive companion may be producing a truncation in the Be-phenomenon disk, in the sense of a radical change in the dependence of disk density on radius (2013A&ARv..21...69R) ¶ under IAU rules, the name “Tianguan” applies only to the primary, not to the entire SB system	
α	Col A	5 40.6	−34 04	2.65†	−0.12	B7 IVe†	12	−1.9	260	0.025	176	+35 V?	possible slight var. (γ Cas type? 2.62−2.66 in V?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 09: status flag = suspected variable; no AAVSO observations found; variability classification symbol = “**GCAS:**”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ rapid rotator, with mass loss to disk, and so an instance of the “Be phenomenon”; Hα is variable, and Hβ profile varies rapidly; nevertheless, the Be disk is stable (unlike, e.g. the Be disk of γ Cas), indicating that the process of decretion-from-photosphere is in this case proceeding at a constant rate ¶ E(B−V) =0.00	Phact
ζ	Ori Aa	5 42.1	−1 56	1.76†	−0.21†	O9.5 Ib	4	−5.0	960	0.005	58+18	SB2†	B: 3.7, B0 III, 2.5″, PA 152°→167°, 1822→2022 orbit ≥ 1500 y; B is a very rapid rotator, and also is possibly a β Cep variable, with departures from the classic rotational-broadening spectral profile (2013A&A...554A..52H is first presentation of high-quality spectroscopy for ζ Ori B; for the overall ζ Ori system, AAVSO(VSX) as of 2024 April 09 notes the availability of 1183 AAVSO observations, and gives the V-passband range 1.74−1.77, and assigns simply the variability classification symbol “**VAR**” (further photometric study advisable?) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.556 mas ±5%, at 800 nm, from the PAVO beam-combining facility at CHARA ¶ there is additionally a celestial-sphere neighbour ζ Ori C, of mag. 9.6 (AC astrometry: 56″→58″, PA 8°→10°, 1839→2023), said by WDS to be possibly a physical companion; ζ Ori Aa,Ab now possesses an orbital solution from a combination of high-resolution spectroscopy (Aa,Ab is now found to be SB2, not merely SB) with full-period NPOI interferometry campaign (2013A&A...554A..52H; period is 7.3 y); since minimum distance of the O-star ζ Ori Aa from the B1 IV star ζ Ori Ab is 9.5 au, this system is a good candidate for mass determinations (helpfully for the determinations, the distance, even at periastron, precludes a significant mass-transfer stream linking Aa with Ab; and in fact ζ Ori Aa is not only the brightest of the O-type stars in our visual sky, but is the first O-giant to have been assigned a mass via orbital computation); although there is no mass transfer between ζ Ori Aa and ζ Ori Ab, nevertheless Aa does eject mass vigorously, consistently with its membership in MK type O; at least one orbital solution has also been published for Aa,Ab-with-B (where ζ Ori B experiences the Aa,Ab binary as essentially a point mass) ¶ m_V, B−V values are for ζ Ori Aa,Ab,B combined light ¶ we here take the distance D from the Solar System (in our notation, and writing here to just 2 significant figures) 960 ly suggested in 2013A&A...554A..52H on the basis of orbital solution (the suggestion is made	Alnitak

														with 7% uncertainty, and additionally with the caveat that ζ Ori B photometry would indicate a larger D, in our notation ~1300 ly); from this D we deduce the corresponding value of π, as 4 mas; *HIPPARCOS* 2007 stated instead a different D (in our notation, and to just one significant figure, D = 700 ly) ¶ 2013A&A...554A..52H suggests age of ~7 My (but elsewhere a still lower age, below 4 My, has been suggested) ¶ E(B–V) =+0.09	
ζ	Lep	5 48.2	−14 49	3.54	0.10	A2 Vann†	~46.3	1.9	~70.5	0.015	266	+20	SB?	rapid rotator (period ~0.2 d or ~0.3 d) ¶ has debris disk, has first known extrasolar asteroid belt ¶ Astron. Alm. (epoch 2021.5) assigns MK type A2 Van ¶ approached to within ~4 ly or ~5 ly of Sun ~1 My ago ¶ AAVSO(VSX) situation as of 2024 April 09: no status flag (so not a confirmed variable, not a suspected variable, not a confirmed non-variable; a fortiori no variability classification symbol) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.670 mas ±21%, in the 800 nm - 1300 nm mid-infrared passband, from the KIN beam-combining facility at the W.M.Keck Observatory **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
κ	Ori	5 49.0	−9 40	2.06†	−0.18	B0.5 Ia†	5	−4.4	600	0.002	131	+21	V?	slight var. of α Cyg type, 2.04−2.09 in V passband (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 70 AAVSO observations found; variability classification symbol = "**ACYG**") ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (0.44 mas ± 7%, without limb-darkening correction, at the very short wavelength of 443 nm), from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia ¶ evolutionary status unclear, high mass-loss rate ¶ carbon-deficient (with metallicity otherwise unremarkable) ¶ E(B–V) =+0.07	Saiph
β	Col	5 51.9	−35 46	3.11	1.16	K1.5 III†	37.4	1.0	87	0.408†	8	+89†	V	although high space velocity indicates that β Col is an interloper from outside galactic thin disk, nevertheless this star is richer than Sun in the elements beyond He ¶ AAVSO(VSX) situation as of 2024 April 09: no status flag (so not a confirmed variable, not a suspected variable, not a confirmed non-variable); a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	Wazn
α	Ori Aa†	5 56.6	+7 25	0.48v†	1.86	M2 Iab†	7†	−5.5	500†	0.030†	68	+21†	SB	semireg., late-type supergiant var.: ~0–1.7 in V variability was discovered by J. Herschel in 1839; the latest deep minimum, early in 2020, at ~1.7 in V, sank below even the minima of 1927 and 1941 (each ~1.2); journalism on this 2020 event includes www.sciencenews.org/article/betel geuse-star-dim-supernova-death-what-happened; three currently offered explanations are dust cloud from mass ejection, (gigantic) starspot, and fortuitous coincidence of minima from three separate cyclical variations; recovery began 2020 Feb. 22, with a rise to ~0.3 in V by 2020 late April; AAVSO reports mag. 0.65 in V on 2021 Jan. 11, 0.60 in V on 2022 Feb. 4; recent AAVSO reports (all thee of them from the same observer) are 2024 Feb. 14, 0.656 in V; 2024 March 16, 0.758 in V; 2024 March 25, 0.738 in V;	**Betelgeuse**

2018A&A...615A.116M suggests on
basis of magnetic variations
a scenario on which evolution of giant
photospheric convective cells, generating
magnetism through local
dynamos, is responsible for the
observed long secondary ~2100-day photometric period;
there are additionally ~200- ~400-day photometric
periodicities, plus a stochastic variation
ascribed to photospheric granulation
(AAVSO(VSX) assessment as of 2024 May 14:
status flag = confirmed variability;
49835 AAVSO observtions found;
variability classification symbol = “SRC”)
¶ Astron. Alm. (epoch 2021.5) assigns MK type
M1–M2 Ia–Iab
¶ brightest star in IR sky, also brightest in bolometric sky
¶ nearest RSG (contrast with o Cet, as AGB);
greatest angular diameter of almost any star other than Sun
(near-IR limb-darkened disk ~42 mas;
but R Dor, having approx 1/3 radius
of α Ori, is less distant, and
so attains still greater angular diameter);
en.wikipedia.org/wiki/List_of_largest_stars
supplies context, giving radii for many supergiants;
reduction of α Ori angular diameter
over period 1993/2009 has been asserted;
the pioneering study is Michelson's and Pease's
unsteady-white-light-fringes, human-eye-at-
eyepiece, interferometer measurement of 47 mas ± 10%,
reported in 1921ApJ....53..249M;
the JMDC (2021 Sep. 13-or-14 edition) most recent
reported interferometric measurement of angular
diameter with limb-darkening correction
is 43.15 mas ± 1%, in the near-infrared H band,
from the PIONIER beam-combining facility at VLTI
¶ 2017AJ....154...11H reviews the
longstanding α Ori
distance problem: parallaxes, including *HIPPARCOS*,
labour under the difficulty of
accurately determining photocentre of visually
extended object, awkwardly harbouring
even plumes and hotspots;
we now give in our table these authors’ values for π
(rounding from their 4.51 mas) and
by implication for D (strictly 717 ly ± 20%)
¶ very slow rotator (true period difficult;
8.4 y has been suggested)
¶ 2019A&A...628A.101H, using aperture-masking
interferometry in polarimetric mode, announces
dust halo with inner radius 1.5 R*;
2016A&A...585A..28K locates 3 R* as the interface between
hot-gas and more outlying dust envelopes
¶ CO shells inner 50 R* to 150 R*, outer as far as 250 R*
¶ runaway star, exceeding local
speed-of-sound in ISM: bow shock 6′−7′,
from stellar wind meeting ISM,
plus linear bar at 9′ (it has been suggested that the
bar is a relic of collapsing wind from a previous BSG phase,
and it also has been suggested that the bar is a feature
intrinsic to the embedding ISM, unconnected with
any α Ori Aa wind)
¶ although RSG
stars pose a more serious mass-loss problem for astrophysics
than do the AGB stars,
since it is not immediately clear
what mechanism is lifting RSG
stellar material above the photospheres
(convection? pulsation? magnetics?), there is now a possible
partial resolution in this particular case:
2018A&A...609A..67K, using ALMA,
finds α Ori anisotropic mass loss, with plume of ejecta;
the authors suggest that plume is associated with strong
“rogue” convection cell, observable as photospheric hot spot
(in contrast with the cool spots encountered on
such MS stars as the Sun)
¶ progenitor mass possibly ~20 $M_\odot$ (making
α Ori Aa very massive),

													age since arrival on ZAMS possibly 8.0-8.5 My (making α Ori Aa very young) ¶ present evolutionary status of α Ori Aa uncertain: has this RSG previously been a BSG? (and 2017MNRAS.465.2654W suggests history may have been complicated by a stellar merger) ¶ α Ori Aa is SN Type II-P progenitor, the core collapse being due within, (perhaps much within) 1 My: although SN will plateau for several months, yielding a star visible even in daytime, with the brilliance of a quarter Moon or full Moon, the SN radiation from so distant a source will not constitute a terrestrial biohazard ¶ *Sky & Telescope.* feature article 2019-05 on α Ori can usefully be supplemented with Fig. 13 from 2018A&A...609A..67K (multi-wavelength composite, showing ejecta plume condensing to dust at a few R*, and showing also two areas of local photospheric magnetic activity): AAVSO has backgrounder at www.aavso.org/vsots_alphaori ¶ WDS documents the putative detection, from a small amount of work in speckle interferometry, of two close companions (and is therefore compelled to write “α Ori Aa,” “α Ori Ab,” and “α Ori Ac”; since we reproduce WDS designations, we are in turn obliged to refer to Betelgeuse not as α Ori A but as α Ori Aa); however, since the WDS-documented speckle interferometry observations are from no later than 1983, and since current interferometry detects no close companions, it is now likely that Betelgeuse is unperturbed by any other star (the very faint WDS-catalogued stars α Ori B,C,D, E,F,G,H;I,J all lie on the celestial sphere at large angular separations from Betelgeuse, with the smallest angular separation, between A and B, measured as a quite wide 38″ in 2023; of these faint celestial-sphere neighbours, even the brightest, α Ori E, shines at a mere mag. 11) ¶ perhaps the most thoroughly studied supergiant (but note also, as a visually prominent, and much-studied, supergiant, α Sco (Antares))	
β	Aur Aa,Ab	6 01.5	+44 57	1.90†	0.03†	A1 IV + A1 IV	~40.2	−0.1	81	0.056	269	−18 SB2	slight ecl.: 1.89–1.98 in V, 3.96 d (mags. equal) eclipsing system is of β Per type (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 4 AAVSO observations found; variability classification symbol = “**EA/DM**”, period 3.960036 d) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ orbit is found in the published orbital solutions to be either circular or nearly circular (possibly e=2.8e−06); β Aur Aa,Ab was spectroscopically identified as a binary in 1890 (and is said to be only the third binary ever to be spectroscopically identified); orbit has been studied interferometrically since 1990s ¶ likely a "stream" member of the UMa moving group (i.e. remnant of stellar association) whose most prominent "nucleus" members are β, γ, δ, ε, and ζ UMa ¶ m_v, B−V values are for β Aur Aa,Ab combined light ¶ under IAU naming rules, “Menkalinan” denotes Aa, not Ab	Menkalinan
θ	Aur A	6 01.5	+37 13	2.64†	−0.08†	A0p II: (Si)†	~19.7	−0.9	166	~0.086	~149	+30 SB	B: 7.2, G2 V, 3.7″, PA 7°→302°, 1871→2022 orbit ≥ 1200 y, with AB distance ≥ 185 au ¶ at least one of the components in the SB that is θ Aur A is magnetic, and an oblique rotator; there are abundant anomalies in photosphere patches, with Si and Cr 10× and 100× solar, respectively; consistently with rotation, the θ Aur A SB pairing presents	Mahasim

													weak variability (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 3 AAVSO observations found; variability classification symbol = “**ACV**”; range = 2.63−2.66 in V; period = 3.618664 d (a period of 1.37 d has been asserted elsewhere)); although AAVSO(VSX) asserts “α^2 CVn-” (α CVn A-) type variability, 2007A&A...464.1089S finds that observed variations in Hα, Hβ, and Hγ profiles cannot be modelled with photosphere inhomogeneities (this is the α CVn A (“α^2 CVn”) variability scenario), and instead proposes changes in atmospheric pressure structure, as ions moving in the star’s magnetic field undergo Lorenz-force deflections ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ m_v, B−V values are for θ Aur AB combined light	
η	Gem A†	6 16.5	+22 30	3.28v†	1.59†	M3 III	8	−2.0	400	~0.064	~259	+19 SB	var.: 3.1−3.7 in V, 2979 d; B: 6.2, 1.9″ (2021) (AB astrometry in detail: 1.1″→1.9″, PA 300°→256°, 1881→2021); a potentially confusing blend of two variabilities: the unresolved single-line SB which is η Gem A is an Algol- type eclipsing system, with each eclipse lasting 17 weeks, system range possibly 3.1−3.8 in V, period 2969 d (most recent minimum around 2020 Oct. 22, with mag 3.766 in V band reported at AAVSO; next eclipse may therefore be expected to begin late in 2028); additionally, however, one or the other component of this SB presents semiregular instability of a type more or less analogous to o Cet, with one or more periods, average period 234 d (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 33259 AAVSO observations found; variability classification symbol = “**EA/GS+SRA**”) ¶ m_v, B−V values are for η Gem AB combined light ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 11.789 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ liable to lunar, and also to very rare planetary, occultations (making η Gem A not only an SB, but also an occultation binary)	Propus
ζ	CMa Aa,Ab	6 21.3	−30 05	3.02†	−0.20†	B2.5 V	9.0	−2.2	360	0.008	61	+32 SB†	possible var. (max light in V passband 3.02?) SB is recently resolved, as ζ CMa Aa, ζ CMa Ab, with just 11 observations (from 2019 through 2023) documented in WDS as of 2024 Dec. 07 (Aa,Ab angular separation surely much less than 1″; analysis involves some speckle interferometry); SB period is 675 d; WDS asserts mags. 3.6, 3.8; the pairing with ζ CMa B (mag. 7.8) is wide (167″→170″, PA 338°→340°, 1833→2016) ¶ m_v, B−V values are for ζ CMa Aa,Ab combined light ¶ variability has been claimed somewhere in what is now resolved as the ζ CMa Aa,Ab pair (possibly of the β Cep type: as of 2024 April 09, AAVSO(VSX) notes the existence of an NSV entry, but finds no record of AAVSO observations, and is able to state V-passband range only as “3.02−?”, and assigns the conjectural variability classification symbol “**BCEP:**”; further photometric study advisable?) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	Furud

β	CMa A	6 23.9	−17 58	1.98†	−0.24	B1 II–III	7	−3.9	~490	0.003	256	+34 SB	slight var., β Cep type, 1.97–2.00 in V, 0.25 d (AAVSO(VSX) assessment as of 2024 May 15: status flag = confirmed variability; 6 AAVSO observations found; variability classification symbol = “**BCEP**”; period = 6.031 h); the brightest of the β Cep pulsators; has multiple modes, with beat period 50 d; it is not known why ε CMa, while physically similar, is not a pulsator ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.542 mas ± 3%, at the very short wavelength of 420 nm, from an innovative application of the VERITAS beam-combining facility (normally used in gamma-ray-Cherenkov studies) at Fred Lawrence Whipple Observatory ¶ near the boundary of the “Local Bubble” ISM cavity ¶ E(B–V) =+0.01	Mirzam
α	Car	6 24.5	−52 43	−0.72	0.16†	A9 Ib†	11	−5.5	~310	0.031	41	+21	visible both in X-ray (magnetically heated corona; also rapid rotator, strongly convective) and in radio ¶ evolutionary status not fully clear, and colour unusual in its luminosity class ¶ AAVSO(VSX) situation as of 2024 April 09: no status flag (so not a confirmed variable, not a suspected variable, not a confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 6.920 mas ± 0.02%, at 2300 nm, from the AMBER beam-combining facility at VLTI ¶ Astron. Alm. (epoch 2021.5) assigns MK type A9 II	**Canopus**
μ	Gem A	6 24.6	+22 30	2.87v†	1.64	M3 IIIab	14	−1.4	230	0.124	153	+55 V?	semiregular var.: 2.75–3.02 in V passband (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 1960 AAVSO observations found; variability classification symbol = “**SR**”) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 15.118 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ on AGB ¶ good marker of the ecliptic; subject to lunar occultations	Tejat
ν	Pup	6 38.6	−43 13	3.17†	−0.11	B8 IIIn†	9	−2.1	370	0.004	186	+28 SB	slight var., 3.16−3.20 in V possibly an instance of “Be phenom.” AAVSO(VSX) asserts λ Eri-type variability; shell spectrum has been suggested, with “central quasi-emission peak” (cf 1999A&A...348..831R) (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 7 AAVSO observations found; variability classification symbol = “**LERI**”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ rapid rotator, with period < 1.7 d ¶ distance was ~27 ly 3.6 My ago ¶ the IAU-official “Pipit” is originally a (Dayak) name for ν Pup in an indigenous tradition of Borneo	Pipit
γ	Gem Aa	6 39.2	+16 22	1.93	0.00†	A1 IVs	30	−0.7	110	0.057	166	−13 SB†	γ Gem Aa,Ab is SB system in highly elongated orbit, known historically as an occultation binary (the brightest ever to be observed in an asteroid occultation: 381 Myrrha, in 1991) and as SB, but also reported in 2014 as resolved with adaptive optics at the USA military facility “Starfire Optical Range,” thereby facilitating study of component masses (2014AJ....147...65D, Fig. 6: that author finds period 12.634 y, e=0.89, in good agreement with period and eccentricity from other published orbital solutions for γ Gem Aa,Ab);	Alhena

													average Aa,Ab distance is ~8.5 au; Ab is mag. ~7.5 ¶ AAVSO(VSX) situation as of 2024 April 09: no status flag (so not a confirmed variable, not a suspected variable, not a confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (1.39 mas ± 6%, with limb-darkening correction, at the very short wavelength of 443 nm), from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia ¶ E(B–V) =+0.03	
ε	Gem A	6 45.6	+25 06	2.99†	1.40†	G8 Ib	4	−4.0	800	0.014	204	+10 SB	slight irreg. var.: 2.97−3.05 in V passband (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 1029 AAVSO observations found; variability classification symbol = "**LC**") ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening corrrection is 4.677 mas ± 0.3%, in the 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ unusually yellow in the general population of supergiants; mv, B−V values are for ε Gem A alone (not for ε Gem AB combined light) ¶ among the few supergiants liable to lunar and planetary occultations ¶ celestial-sphere neighbour ε Gem B (112″→110″, PA 93°→95°, 1825→2017) is mag. ~9.6	Mebsuta
α	CMa A†	6 46.3	−16 45	−1.45†	0.00†	A0mA1 Va†	~379	1.5	8.6	~1.339	~204	−8 SB	B: 8.4, WDA; 11.3″ (2022); orbit 50.1 y separation 8.2 au min (3″), 31.5 au max (11.3″, in 2019; greatest observational separation, still to three significant figures 11.3″, was in 2022 or 2023); although α CMa AB, now among the more celebrated visual binaries, was first resolved in 1862 (Alvan G. Clark, using 18.5-inch refractor), binarity was conjectured as early as 1834 (by Bessel, on the grounds of variability in proper motion); cdsarc.u-strasbg.fr/viz-bin/getCa tFile_Redirect/?-plus=-%2b&B/wds/./notes.dat, as notes for "WDS 06451-1643," has vivid and extended discussion of 19th-century struggles with obtaining accurate angular-separation and PA measurements for the α CMa AB system; as of 2024 Dec. 07, WDS reports the existence of 2063 measurements, for the timespan 1862→2022 (in contrast with the more difficult, and less well observed, α CMi AB system, where the secondary is again a WD, and the primary is again an intrinsically luminous (~7 Suns; Sirius radiates with the power of ~25 Suns) and nearby and notably hot star, but where smaller angular separation and greater magnitude difference pose a greater challenge: as of 2024 Dec. 07, WDS reports the availability of just 99 α CMi AB measurements, with the most recent of these from 2014); α CMa B is the brightest WD in the visual sky (its nearest competitors being o^2 Eri B, at mag. 9.5, and α CMi B, at mag. 10.8); www.atnf.csiro.au\outreach\education/senior/astrophysics/ binary_types.html compares and contrasts a visual-wavelengths image of the α CMa AB pair (with A much brighter than B) and a CHANDRA X-ray image of this same pair (with B much brighter than A; A is said to appear in the image largely through reflecting UV emitted by the much hotter B) ¶ mv, B−V values are for α CMa A (which, however, can differ only minimally from α CMa AB combined light, since the α CMa B contribution is minuscule) ¶ AAVSO(VSX) situation as of 2024 April 09: no status flag (so not a confirmed variable, not a suspected variable, not a confirmed non-variable),	**Sirius**

													and a fortiori no variability classification symbol (but in 2022 classified as confirmed non-variable?) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 5.993 mas ± 2%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ IRAS detected IR excess, a signature of dust (rather unexpected in a binary) ¶ Fe abundance of α CMa is ~2× or ~3× solar ¶ α CMa B is unusually massive for a WD (1.02 $M_{\odot}$; Chandrasekhar Limit is, however, 1.4 $M_{\odot}$; spectral type of α CMa B is DA (= hydrogen-only)) ¶ E(B–V) =-0.03	
ξ	Gem	6 46.8	+12 52	3.35†	0.44	F5 IV	56	2.1	58.7	0.223	211	+25 V? †	previous assertion of variability is now discounted AAVSO(VSX) asserts constant light ¶ possibly SB, with components of ~equal mass ¶ rapid rotator (but just barely over the internal-structure transition, or "F5 rotation break," that causes some stars to rotate rapidly, others to experience braking through magnetics and winds) ¶ AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed non-variability; variability classification symbol = "**CST**") ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (1.401 mas ± 0.6%, with limb-darkening correction, in near-infared K band, from the CLASSIC beam-combining facility at CHARA) ¶ X-ray source (suggesting significant corona)	Alzirr
α	Pic	6 48.5	−61 58	3.26	0.22	A6 Vn kA6†	~34	0.9	100	0.252	345	+21	rapid rotator; shell, with time-varying spectral absorption features ¶ X-ray emission suggests a companion, otherwise undetected ¶ AAVSO(VSX) assessment as of 2024 April 09: no status flag (so not a confirmed variable, not a suspected variable, not a confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
τ	Pup	6 50.6	−50 39	2.93	1.20	K1 III	18	−0.8	180	0.077	154	+36 SB†	SB period 1066.0 d, separation ~3 au, orbit of low eccentricity; since the SB is not as yet resolved, even in interferometry, WDS is not as yet able to write "τ Pup A" and "τ Pup B" ¶ AAVSO(VSX) assessment as of 2024 April 09 (in 2022, no assessment offered): flagged as confirmed variability; no AAVSO observations found; (very small) range stated as "2.94 V (0.006)", from *TESS* photometry; variability classification symbol = "**ORG**") ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
κ	CMa	6 50.8	−32 32	3.88v†	−0.21	B1.5 IVne†	4.9	−3.0	700	0.010	293	+14	var. of γ Cas type, 3.40–3.97 in V passband (was at faint end of its range before 1963; AAVSO reports visually ~3.3 in 2021 January, ~3.6 in Mar. 2022, and additionally ~3.7 and ~3.9 (both from same observer) in 2024 February; an instance of the "Be phenomenon" (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 473 AAVSO observations found; variability classification symbol = "**GCAS**") ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
ε	CMa A†	6 59.7	−29 01	1.50†	−0.21†	B2 II	8.0	−4.0	410	0.004	68	+27	B: mag.7.5 (7.9″, PA 161°→162°, 1850→2008) AB distance 900 au, period at least 7500 y	**Adhara**

													¶ brightest known source of extreme UV (~75 nm) in Earth's night sky; hydrogen Lyman α (121.6 nm) observed by NASA OAO-3 ¶ mv, B−V values are for ε CMa AB combined light ¶ AAVSO(VSX) situation as of 2024 April 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.80 mas ± 6%, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia ¶ E(B–V) =+0.02	
σ	CMa A	7 02.8	−27 58	3.47v†	1.73†	K7 Ib†	3	−4.2	1100	0.008	308	+22	irregular var.: 3.41–3.51 in V passband (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 24 AAVSO observations found; variability classification symbol = "**LC**") ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ authorities are in some disagreement on MK type (possibly M, rather than K) [THIS STAR **ONLY IN ONLINE VERSION OF TABLE]**	Unurgunite
o^2	CMa	7 04.1	−23 52	3.02†	−0.08†	B3 Ia	1	−6.6	3000	0.004	329	+48 SB	slight var.: α Cyg type, 2.98–3.04 in Hp band, 24.44 d (AAVSO(VSX) assessment as of 2024 April 09: : status flag = confirmed variability (but only one AAVSO observation found), variability classification symbol = "**ACYG**") ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ mv, B−V values seem unavailable in GCPD; we take these values from 2002yCat.2237….0D ¶ E(B–V) =+0.03	
δ	CMa	7 09.5	−26 26	1.84†	0.68	F8 Ia†	2	−6.6	2000	0.005	317	+34 SB	poss. slight var.: type unknown (range 0.004 V?) ¶ further photometric studies advisale? (as of 2024 April 09, AAVSO(VSX) notes slight variability suspected, of unassigned type, range 0.004 mag. in V passband, with just one AAVSO observation available) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (3.60 mas ± 13%), with limb-darkening correction, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia ¶ mv, B−V values seem unavailable in GCPD; we take these values from 2002yCat.2237….0D ¶ slow rotator (possibly ~1 y); N 2× solar, Na 6× solar	Wezen
L_2	Pup A+1P†	7 14.3	−44 41	4.73v†	1.54	M5 IIIe	16	0.4	210	0.342	18	+53 V?	semireg. late-type var.: 2.6–8.0 in V, 140.6 d fainter since 1995, with typical 2-mag. 140-day V-band variation now between 6 and 8 (AAVSO(VSX) assessment as of 2024 April 09: status flag = confirmed variability; 30760 AAVSO observations found; variability classification symbol = "**SRB**"); for 2024 Feb. and 2024 March, the AAVSO principal database lacks V-band photometry, but has visual estimates in the range [7.0, 8.0]: further photometric studies now advisable, from observers equipped with electronic detector and Johnson V passband? ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ shedding mass, possibly on AGB; 2015Msngr.162...46O remarks that L_2 Pup interferometry is potentially a key to understanding of mass loss (and in particular of dust formation), and	HR2748

													presents an image, from a combination of speckle interferometry and VLTI/AMBER aperture synthesis, of L_2 Pup A circumstellar dust disk ¶ exoplanet possible but not certain (could be mere cloud of gas and dust)	
π	Pup Aa	7 18.1	−37 09	2.71†	1.62	K3 Ib	4	−4.3	800	0.012	303	+16	B: 7.9, 69″, PA 214°→213°, 1826→2015 as of 2024 Dec. 07, WDS records just 4 observations of the Aa,Ab system; the most recent, from 2023, gives separation 0.7″, with Ab at mag. ~6.5 ¶ as of 2024 April 09, AAVSO(VSX) states range as “2.8−2.87” in Hp passband, and finds no record of AAVSO observations, and assigns variability classification symbol = “**SRD:**”; further photometric study advisable? ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
δ	Gem A	7 21.7	+21 56	3.53	0.34	F0 IV†	54	2.2	60	0.018	237	+4 SB†	B: 8.2, K3 V, 5.5″, PA 198°→229°, 1822→2018 orbit 1200 y ¶ m_v, B−V values are for δ Gem AB combined light ¶ AAVSO situation as of 2024 April 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable; and a fortiori no variability classification symbol) ¶ a good marker of the ecliptic; lunar occultations possible; planetary occultations possible-yet-rare: since the SB which is δ Gem A is not as yet resolved (even interferometrically) with astrometry, WDS is not as yet (at any rate as of 2024 Dec. 07) able to write “δ Gem Aa,” “δ Gem Ab”; SB period is 6.129y; a companion (the secondary component in the SB?) has, however, been noted through occultation ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ in evolutionary transition, having completed stable core-hydrogen fusion ¶ Astron. Alm. (epoch 2021.5) assigns MK type F0 V+ **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	Wasat
η	CMa A	7 25.1	−29 21	2.45v†	−0.08†	B5 Ia	2	−6.5	2000	0.007	325	+41 V	B: 6.8, 177″ (2020) is mere optical companion ¶ variable in α Cyg class of non-radial pulsators; AAVSO(VSX), as viewed 2021 Jan. 28, 2022 July 09, and 2024 April 09, gives range 2.36–2.50 in V, period 4.70433 d (with just one AAVSO observation found as of 2024 April 09) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (0.75 mas ± 8%, with limb-darkening correction, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia ¶ mv, B−V values seem unavailable in GCPD; we take these values from 2002yCat.2237….0D ¶ strong wind; ejected circumstellar mass inferred from IR excess ¶ E(B–V) =+0.02	Aludra
β	CMi A	7 28.6	+8 14	2.89†	−0.10	B8 Ve†	~20.2	−0.6	~162	0.064	234	+22	slight var.: rapid rotn. Be, 2.89–2.90 in V band rapid rotator, possibly ~1 d, with modest variability in the hydrogen Balmer emission; disk of ejected matter has diameter ~4× diameter of β CMi itself (BSC5: “rotationally unstable”); an instance of the “Be phenomenon”; although GCVS assertion of γ Cas-type variability has not been corroborated, 2007ApJ...654..544S reports, using *MOST*, millimagnitude “slowly pulsating B-type” variability; AAVSO(VSX) as viewed 2021 Jan. 16 gives V-mag. range 2.84–2.92, but as viewed 2022 March 03 and 2022 July 09 and 2024 May 15	Gomeisa

													the narrower range 2.89–2.90; (AAVSO(VSX) assessment as of 2024 May 15: status flag = confirmed variability; 138 AAVSO observations found; variability classification symbol = “**SPBe**”; period = 7.37 h); in contrast with e.g. the Be-phenomenon star γ Cas A, the Be disk is in this case considered very stable (2013A&ARv..21...69R), indicating constancy in the process of decretion from the host-star photosphere; 2012ApJ...744...19K reports confirmation, using interferometry, of Keplerian rotation in the Be disk (an important follow-on to the discovery of Keplerian rotation in Be-phenomenon star α Ara A); 2019ApJ...875...13H finds that, contrary to an earlier claim that β CMi A is SB with period 170.4 d, there is so far no convincing evidence of SB status; the question is significant for overall Be theory, in that duplicity has been suggested as a possible mechanism generating the “Be phenomenon” in at least some stars ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter of star (whether through interferometry or by any other direct means)	
σ	Pup A	7 30.1	−43 21	3.25†	1.52†	K5 III	17	−0.6	190	0.198	342	+88 SB†	B: 8.8, G5: V, 22.1″, PA 90°→74°, 1826→2016 orbit ≥ 27,000 y, A-to-B distance ≥ 1300 au; SB is possibly eclipsing, of β Lyr type, with orbit 257.8 d, with very modest alternating primary (0.04 mag) and secondary (0.03 mag) minima (but a contrary view is expressed at AAVSO(SVX), which classifies the σ Pup system as rotating-ellipsoid variable without eclipsing, giving the range 3.23−3.27 in V passband: AAVSO(VSX) assessment as of 2024 April 10 has status flag = confirmed variability (although only 2 AAVSO observations found), variability classification symbol = “**ELL+LB**”); additionally, the SB primary component shows slow irregular variability ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ mv, B−V values are for σ Pup A; the corresponding values for σ Pup B are 8.82, 0.70 ¶ system has high space velocity	
α	Gem Aa,Ab†	7 36.3	+31 50	1.93†	0.03†	A1mA2 Va	63	0.9	52	~0.254	~234	+6 SB	AB orbit 445 y; max = 6.5″, in 1880;	
α	Gem Ba,Bb†	7 36.3	+31 50	2.97†	0.03†	A2mA5 V:	63	2.0	52	~0.254	~234	−1 SB	min = 1.8″, in 1965; 5.4″ (2023); separation 71 au min, 138 au max; C mag. 9.8; AC 70″, PA 162°→164°, 1822→2023, orbit ≥ 14,000 y; orbital solutions have been published both for the binary α Gem AB and for the much wider binary involving C (with C experiencing AB as a point mass); C has variable-star name YY Gem (an eclipsing binary, and additionally a variable of the BY Dra type, with flaring); not only C, but also each of A, B is itself SB, making ABC a hierarchical 6-star system (Kaler at stars.astro.illinois.edu/sow/castor.html writes, “certainly the sky’s ranking sextuple”); en.wikipedia.org/wiki/Castor_(star) has a diagram summarizing this sextuple hierarchy, on the basis of 2012MNRAS.423..493H; as of 2024 Dec. 07, WDS shows 16 observations for the Aa,Ab pair (2007→2021) and 12 observations for the Ba,Bb pair (all from 2021) ¶ GCPD gives mv, B−V values of 1.58, 0.03 for α Gem AB combined light (and additionally gives 9.07, 1.49 for α Gem C); the B−V value of 0.03 likely applies also to each of α Gem A, α Gem B individually, since these two stars are spectrally similar; our individual respective	Castor

													mv values of 1.93, 2.97 for α Gem A, α Gem B match the values given by WDS ¶ AAVSO(VSX) situation as of 2024 April 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means), either for α Gem A or for α Gem A ¶ Castor-Pollux comparison is a helpful test of naked-eye night colour response	
α	CMi A†	7 40.7	+5 09	0.37†	0.42†	F5 IV–V	285	2.7	11.5	~1.259	~215	−3 SB	B: mag. 10.8, WD; 3.8″ (2014); orbit 40.84 y (PA 286° in 2014; this is the most recent astrometry available in WDS as of 2024 Dec. 7) with e=0.4; 2015ApJ...813..106B gives α CMi AB periastron distance as 9.1 au; α CMi B is visually the third-brightest WD in the sky (overtaken by o2 Eri B, at mag. 9.5, and by α CMa B, at mag. 8.5); 2015ApJ...813..106B is a recent study of masses, with orbital solution, drawing on observations beginning in the 19th century and including 1995−2014 HST data (Fig. 4 makes the problem of orbit-fitting, from good recent data and less good historical data, vivid), and discussing also the possible evolutionary history of the system (past mass transfer may be a complicating factor) ¶ α CMi A radiates with the power of ~7 Suns (and so is not dramatically unlike α CMa A, which radiates as ~25 Suns) ¶ mv, B−V values are for α CMi A (which, however, can differ only minimally from α CMi AB combined light, since the α CMi B contribution is minuscule) ¶ asteroseismology of α CMi A is somewhat uncertain (MOST mission 2004 did not find pulsations, and yet *WIRE* mission 1999 and 2000 did); at the level of tens of millimags., or coarser, the previous claim of variability is now discounted (AAVSO(VSX) assessment as of 2024 April 10: status flag = confirmed non-variability; 6 AAVSO observations found; variability classification symbol = "**CST**") ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 5.448 mas ± 0.9%, in the near-infared K band, from the VINCI beam-combining facility at VLTI ¶ the WD α CMi B is physically unlike the WD α CMa B, attaining only ~0.2 of the density of α CMa B, and being of a rare spectral type DQZ6.5 (elusive in ground-based spectroscopy: but at long last *(a)* helium-not-hydrogen character of spectrum was noted at HST through filter photometry in a set of bands running from 1600 Å to 7828 Å, and *(b)* detailed spectroscopy was performed at HST through STIS camera, over the range 1800 Å to 10000 Å; in this spectral type, H features are absent and C, Mg, and Fe features are present) ¶ from an astrometrist's perspective, the α CMi AB system contrasts with the less difficult, and consequently better measured, α CMa AB system, in which the secondary is again a WD, and the primary is again an intrinsically luminous and nearby and notably hot star, with the magnitude difference less severe and the typical angular separation greater: as of 2024 Dec. 7, WDS reports the existence of just 99 α CMi AB astrometry measurements,(with the most recent from 2014), as against the much larger tally of 2063 α CMa AB measurements (with the most recent from 2022); Bond et al. write, in **2015ApJ...813..106B**, "Charles Worley, double-star observer at the USNO,	Procyon

													asserted to two of us, more than two decades ago, that he was the only living astronomer who had seen Procyon B with his own eye" ¶ WDS documents, for the α CMi AB system, celestial- sphere neighbours α CMi C,D,E,F,G,H; of these, only E and G are brighter than mag. 10, at mags. 9.2 and 8.8 respectively (at the large respective angular separations, from α CMi A, of 467″ (2009) and 356″ (2012))
β	Gem A+1P†	7 46.9	+27 58	1.14†	1.00†	K0 IIIb	97	1.1	33.8	0.628	266	+3 V	poss. slight var.: unkown type (1.14−1.15 in V?) Pollux further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 10: flagged as suspected variable; 35 AAVSO observations found; classification symbol = "**VAR:**") ¶ the nearest of the giants; unusual in being a giant known to harbour an exoplanet (and the brightest known exoplanet host in Earth's sky); as of 2015, exoplanet is IAU-named "Thestias" ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 8.134 mas ± 0.2%, in the 550 nm –850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ mv, B−V values are for β Gem AB combined light ¶ subject to rare lunar occultations, for observers S of Earth's equator ¶ Castor-Pollux comparison is a helpful test of naked-eye night colour response
ξ	Pup A†	7 50.4	−24 56	3.33†	1.24†	G6 Iab–Ib†	3	−4.5	1200	0.005	260	+3 SB†	slight semireg. var.: 3.31−3.35 in V band, 31.2 d Azmidi full system comprises an unresolved tight binary (an SB) and widely separated ξ Pup B, with B experiencing the unresolved SB which is ξ Pup A as essentially a point mass (with the AB system sparsely observed: B is mag. 13; 4.6″→5.1″, PA 189°→191°, 1899→1964; orbit ≥ 26,000 y?) ¶ SB primary has high metallicity, with exact evolutionary status uncertain ¶ SB primary is near, but is a little too cool to lie within, the HR diagram IS ¶ mv, B−V values are for ξ Pup AB combined light ¶ possible slight variability in the ξ Pup assemblage: as of 2024 April 10, AAVSO(VSX) seems to have no record of AAVSO observations, but does indicate range 3.31−3.35 in V passband and period 31.15265 d, and assigns classification symbol "**SRD:**" ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)
χ	Car	7 57.5	−53 03	3.46†	−0.18	B3 IV(p?)†	7	−2.3	500	0.035	304	+19 V	slight var.: β Cep type, range 0.015 in V passband, 2.4 h Si II anomalous strength now discounted ¶ the assertion, in en.wikipedia.org/wiki/Chi_Carinae as viewed 2022 Jul. 29, that χ Car is free of variability seems to us at the *Handbook* to be based on an erroneous reading of 2011MNRAS.410..190T; we instead favour AAVSO(VSX), which as viewed 2024 April 10 asserts slight β Cep-type variability (although, admittedly, without available AAVSO observations), asserting range 0.015 in V, period 2.4 h, with variability classification symbol "**BCEP**" ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ the MK luminosity class "IV" (phenomenologically "giant") notwithstanding, χ Car is in astrophysical terms in the last part of its stable core-hydrogen-fusion phase; Astron. Alm. (epoch 2021.5) assigns MK temperature type

														B3p Si without assigning an MK luminosity class	
ζ	Pup	8 04.5	−40 05	2.25†	−0.27†	O5 Iafn†	3.0†	−5.4	1080†	0.034†	299	−24†	V?	blue supergiant ¶ rapid rotator (1.78 d), despite ~2300 km/s stellar wind (in which spiral structure was announced in 2017 by *BRITE* mission team), with mass loss rate > 1e-6 MΘ /y ¶ high space velocity (impelled by past nearby supernova? or, rather, impelled by multibody gravitational interactions in its stellar birth family?); possibly ejected from Trumpler 10 OB association ¶ distance has been controverted ¶ He, N overabundant ¶ further photometric study advisable? has been suspected of being a variable of the α Cyg type; however, as of 2024 April 10, AAVSO(VSX), while confident of variability (although no AAVSO observations are available), and while giving V-passband range 2.24−2.26, period 1.78 d, classifies this star as possibly (not certainly) spotted-and-rotating, under classification symbol “**ROT:**” ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.42 mas ± 7%, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia ¶ E(B–V) =+0.04	Naos
ρ	Pup A	8 08.7	−24 23	2.80v†	0.42	F2mF5 II: (var)†	51.3	1.4	64	0.095	299	+46	SB	var.: (δ Sct type?) 2.68–2.87 in V passband, ~3 h prototype of the “ρ Pup stars” (but in the AAVSO taxonomy, a δ Sct-type variable: AAVSO(VSX) assessment as of 2024 April 10 has status flag = confirmed variability, 965 AAVSO observations found, period (i.e. main period) = 0.1408809 d, variability classification symbol = “**DSCT**”); photosphere temperature is notably low in the overall population of stars presenting δ Sct variability ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ Astron. Alm. (epoch 2021.5) assigns MK type F5 (Ib–II)p ¶ IR excess (circumstellar ring, at separation 50 au?)	Tureis
γ	Vel Aa†	8 10.4	−47 25	1.79†	−0.24	O7.5 III-I†	3†	−5.9	~1100†	0.012	330	+35	SB2†	eruptive WR var.:1.81−1.87 in V; Aa is a.k.a. γ^2 Vel AAVSO(VSX) as of 2024 April 10 reports availability of 66 AAVSO observations, gives period 78.53 d, assigns variability classification symbol “**WR**” ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.44 mas ± 11%, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia ¶ Aa is a double-lined SB not as yet resolved, even in interferometry (so WDS is not, at any rate as of 2024 Dec. 7, able to write “γ Vel Aa1,” “γ Vel Aa2”), but with published orbital solutions (period 78.5 d, e=0.4 or 0.5); faint Ab (mag. 13.4) is poorly known, with just one astrometry result, from 1997 (Aa,Ab angular separation 4.7″); distance between components of the unresolved γ Vel Aa SB is 0.8(?) au min, 1.6 au max); γ Vel B, a.k.a. γ^1 Vel, is itself a resolved SB pair (so in WDS γ Vel Ba, γ Vel Bb: period is 1.48 d); AB astrometry is 43″→41″, PA 222°→221°, 1826→2017 ¶ the (carbon-rich) WR component in the unresolved SB which is γ Vel Aa is of spectral type WC8, and is the nearest and visually brightest of all WR stars (presenting “a unique opportunity to spatially resolve	

a WR wind by means of interferometry"
(2007A&A...464..107M)), and is an exceptionally
massive WR (9.0 MΘ; but at birth, > 30 MΘ);
this SB is the best studied of all O-WR binaries:
in the SB pair it is the WR component, rather
than the O component, that dominates spectrally
(although we assign an O type, and Astron. Alm.
(epoch 2021.5) rather similarly assigns
the uncertainty-flagged MK type
"O9 I:," since the V-passband light is overwhelmingly
from the more massive (18.5 MΘ) O-type
component), making the γ Aa SB the "Spectral
Gem of the Southern Skies," and a notable sight within
broader "Vela complex" (dominated by the
Gum Nebula, within which lie the Vela SNR, the
IRAS Vela shell, and the Vela pulsar; some literature,
including 2011A&A...525A.154S, indeed proposes
intersection between the Vela SNR and a γ Vel
SWB, taking the IRAS Vela shell as marking the meeting
of SNR and SWB)
¶ mv, B−V values are for γ Vel Aa,Ab combined light
¶ like η Car (bright to mag. ~0 for several years after
1837, but now too faint, and now too lacking in firm
future-outburst prognoses, to qualify for the RASC
Handbook "Brightest Stars" list), the unresolved
γ Vel Aa SB is a colliding-wind pair
(2017MNRAS.468.2655L Fig. 1 sketches the collision
geometry), and in consequence is a UV and X-ray source
(and in consequence may also possibly resemble η Car
in being a γ-ray source
(cf 2017ApJ...847...40R; as of
at any rate 2017, it seems that
no other colliding-winds-binary
stellar γ-ray sources are known));
it is the wind from the (WR) secondary
that dominates, with mass-loss
rate at least 100× greater than for the (O-type) primary;
the WR wind may feature some clumping,
but is to a good approximation
spherically symmetric until it
encounters the O-star wind;
orbital motion of the two SB components
around their centre of mass
yields a spiral structure in the wind-collision area,
particularly salient at periastron
¶ 2017ApJ...847...40R summarizes recent observations
of the γ Vel Aa SB, in radio and IR
and optical, including interferometry,
noting inter alia discrepancies in the available
determinations
of mass-loss rates from the WR star (a copious 3e-6 MΘ /y?
or a still more copious 8e-5 MΘ /y?)
¶ notable among recent observational studies are
2017MNRAS.468.2655L (VLTI/AMBER
near-IR spectro-interferometry,
with also 3-D hydrodynamic modelling)
and 2012MNRAS.427..581R
¶ likely destiny of γ Vel Aa
(WR) secondary is as (exotic) stripped-core
SN (same prognosis as for η Car; this
contrasts with α Ori, which
will for its part instead explode as a (not exotic)
hydrogen-spectrum SN)
¶ dust emission is absent (even though
formation of circumstellar dust is common
in stars that, like the γ Vel Aa (WR) secondary, undergo
copious mass outflow)
¶ distance ~1200 ly, in contrast with our
~1100 ly, has also been recently asserted,
on basis of VLTI/AMBER
¶ we take MK type for γ Vel Aa from
1999A&A...345..163D (as what
must be considered an emendation
of our (slightly cooler)
Garrison-approved MK type
from earlier editions of this table;
admittedly, MK determination of γ Vel Aa is still
difficult, because the raw spectrum

													is a composite comprising not only the O and WR stars, but also emission from the wind-collision zone) ¶ Ba,Bb appear in combined light as mag. 4.1; there are additionally wide celestial-sphere neighbours C (mag. 7.3; AC separation was 62″ in 2015) and D (mag. 9.2; AD separation was 94″ in 2000) ¶ neither the traditional Suhail al-Muhlif nor the modern Regor (devised within NASA, to commemorate 1967 fire victim Roger Chaffee) is presently IAU-approved name for any of the five stars γ Vel Aa primary, γ Vel Aa secondary, Ab, Ba, Bb	
β	Cnc A+1P	8 18.0	+9 06	3.52†	1.48	K4 III†	11	−1.3	300	0.068	224	+22 V?	slight var: type unknown, range 0.005 in V passband “barium star,” with Ba abundance ~6× solar, presumably as contamination from defunct companion (but no companion remnant has been found) ¶ GCPD offers not only the mv value of 3.52, but also, as an alternative possibility supported by a smaller number of authorities, 3.54 ¶ AAVSO(VSX) assessment as of 2024 April 10: status flag = confirmed variability (but it seems that no AAVSO observations are available), variability classification symbol = simply “**VAR**”, period 6.00565 d) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 5.167 mas ± 0.7%, in the 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ Astron. Alm. (epoch 2021.5) assigns MK type K4 III Ba 0.5 [THIS **STAR ONLY IN ONLINE VERSION OF TABLE**]	Tarf
ε	Car A	8 23.1	−59 36	1.86v†	1.27	K3:III	5	−4.5	600	0.034	311	+2	B is possibly ecl., with AB mag. 1.82−1.94 in V (AAVSO(VSX) as of 2024 April 10 notes existence of NSV entry, seems to have no record of AAVSO observations, assigns variability classification symbol “**E:**”) further photometric study advisable? − cf also 2004AJ....127.2915P, Table 5, which treats B as an unresolved binary (or is it that the eclipses (if real at all), involve not an unresolved “ε Car B primary,” “ε Car B secondary” pair, but more straightforwardly the ε Car A, ε Car B pair?); full WDS-catalogued system is ε Car A (mag. 2.2) and ε Car B (mag. 3.9), with ε Car B not further resolved, and with the ε Car AB pairing reported by WDS as very tight, the angular separation being just 0.4″ in 2023; the AB system is sparsely observed (as of 2024 Dec. 7, WDS documents just 8 satisfactory astrometry measurements, 1991→2023); the 1959AJ.....64..127G report of variability notwithstanding; Kaler comments at stars.astro.illinois.edu/sow/avior.html, with reference to the overall paucity of observations, that “if there is a stellar category of ‘bright stars getting no respect’, [ε Car A] probably holds the record” ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ B is of MK type (uncertainty-flagged) “B2: V” ¶ the IAU-official name “Avior” for ε Car A is of uncertain etymology, and yet its origins are known: here, as also with α Pav A (IAU-officially “Peacock”), the name stems from the 1930s RAF Air Almanac project, which directed HM Nautical Almanac Office that no air-navigation star was to be left nameless	**Avior**
o	UMa A+1P	8 32.5	+60 38	~3.37†	0.85	G5 III	~18.2	−0.3	~179	0.172†	231	+20†	poss. slight var.: type unkn. (3.30–3.36 in V?) further photometric study advisable? (AAVSO(VSX) as of 2024 April 10 applies suspected-variable flag, notes availability of 176 AAVSO observations, assigns no variability classification symbol)	Muscida

		RA	Dec	m_V	B−V	MK type							Notes	
													¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ mv, B−V values are for o UMa AB combined light (where, however, the contribution of o UMa B, shining at mag. ~15, is minuscule) ¶ o UMa A is currently in rapid evolutionary transition, crossing the Hertzsprung Gap ¶ despite high space velocity, a member of the galaxy thin disk	
δ	Vel Aa†	8 45.4	−54 48	1.96v†	0.04†	A1 Va	40	0.0	81	~0.107	~164	+ 2 V?	Aa,Ab brightest known ecl. binary (1.95−2.43, V) orbital period 45.15023 d, primary (resp. secondary) eclipse duration 0.587 d (resp. 0.91 d), with eclipse indicated by photometry to be total; system is β Per type, with average Aa,Ab distance 90.61 au, resolved both interferometrically and with VLT adaptive optics; 2007A&A...469..633K offers orbital solution (0.23≤e≤0.37, with orbit inclination to plane of sky near one or other of the two extremes 87.5°, 92.5°), discusses masses, finds unexpectedly large stellar diameters (so both stars are evolved?); B experiences Aa,Ab as essentially a point mass, the Aa,Ab-with-B orbital period being 142 y (at least one orbital solution has been published); B is mag. 5.6, 2.2″→1.1″ (min. angular separation was in 2000), PA 177°→185°, 1894→2023 ¶ AAVSO(VSX) assessment as of 2024 April 10: status flag = confirmed variability; 13 AAVSO observations found; variability classification symbol = “**EA**” ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ WDS as at 2024 Dec. 7 documents faint celestial-sphere neighbours C,D,E, and also a sparsely observed close brighter celestial-sphere neighbour F (mag. 5.8, with just 4 observations 1991→2016) ¶ mv, B−V values are for δ Vel Aa,Ab,B combined light	Alsephina
ε	Hya A†	8 48.2	+6 19	3.38†	0.68†	G5:III	25	0.4	130	~0.232	259	+36 SB†	slight var.: (BY Dra type?) 3.35−3.39 in V band composite A: 3.5; B: 5.6, 0.2″ (2023); C: 6.7, 2.7″ (2022); B is of poorly known MK type “A:”; orbital solutions have been published both for AB (15.09 y) and for the much wider AB+C system (C experiences AB as essentially a point mass; period is 590 y) ¶ C is unresolved (WDS as of 2024 Dec. 7) SB, with orbital period 9.9 d ¶ m_V, B−V values are for ε Hya ABC combined light ¶ our π, D are from 2018 *Gaia* parallax, which is known to ±2% (since π is stated as 20.7182 ±0.3925 mas), and which we take to supersede 2007 *HIPPARCOS* ¶ the ε Hya system presents slight variability (with further photometric study advisable?): AAVSO(VSX), as of 2024 April 10, notes the availability of 52 AAVSO observations, assigns variability classification symbol “**BY:**” ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	Ashlesha
ζ	Hya	8 56.8	+5 51	3.10	1.00	G9 II–III	~21†	−0.4	~157	0.101	279	+23	 ¶ Astron. Alm. (epoch 2021.5) assigns MK type G9 IIIa ¶ AAVSO situation as of 2024 April 10: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter (and the only one with limb-darkening correction) is 3.196 mas ± 0.5%, in the 550 nm–850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ	

ι	UMa A†	9 01.0	+47 56	3.14†	0.20	A7 IVn	~68.9	2.3	47.3	~0.491	~244	+9 SB†	A+BC 2.4″, PA 349°→90°, 1831→2017 A+BC orbit 818 y; BC 0.9″, period ~39 y; the A+BC binary system (in which A experiences the ι UMa B, ι UMa C binary as essentially a point mass) possess published orbital solution which is in a sense problematic (WDS, as at 2024 Dec. 7, calls the solution “premature”); A is itself SB, orbit 4028 d, making this a quadruple system; the system is not, as in many cases of multiplicity, hierarchical and stable, but kinematically unstable (disruption in ~0.1 My?); B is mag. 9.9 M1 V and C is mag. 10.1 M1 V; since the A SB has not yet been resolved, even interferometrically, WDS as of 2024 Dec. 7 is not yet able to write “ι UMa Aa,” “ι UMa Ab” ¶ further photometric study advisable? (AAVSO(VSX) as of 2024 April 10 applies suspected-variability flag, notes the availability of 42 AAVSO observations, suggests a V-passband range of 3.12−3.18, and treats the system as a possible, underexamined, case of slight and rapid variability, assigning variability classification symbol “**S**” (but is this symbol perhaps a misprint for “**S:**”?) − WDS indicates a possible line of research by by indicating, in a note, that the ι UMa A SB pairing presents δ Sct variability) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	Talitha
λ	Vel A	9 09.0	−43 32	2.20v†	1.66	K4 Ib–IIa†	6.0	−3.9	540	0.028	299	+18	irregular variability: 2.12–2.32 in V passband (AAVSO(VSX) assessment as of 2024 April 10: status flag = confirmed variability; 69 AAVSO observations found; variability classification symbol = “**LC**”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ probably on or approaching AGB, but could still be on RGB ¶ Astron. Alm. (epoch 2021.5) assigns MK type K4.5 Ib ¶ has slow wind, whose origins are said to be poorly understood	**Suhail**
a†	Car	9 11.7	−59 05	3.43†	−0.20	B2 IV–V	7	−2.3	500	0.022	312	+23 SB2†	slight var: (Be type?) 3.41–3.44 in V passband further photometric and further spectroscopic study advisable? (AAVSO(VSX), as of 2024 April 10, notes availability of a single AAVO observation, and classifies this tentatively (not with certainty) as Be-star variability without the γ Cas variability common in cases of the “Be phenomenon” (noting that in many such cases the variability is found to be of the λ Eri type; AAVSO(VSX) assessment has variability classification symbol = “**BE:**”)) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ orbit 6.74 d, with light curve indicating tidal distortion; since the SB is as yet unresolved, even in interferometry, WDS is not yet able to write “a Car A,” “a Car B” ¶ there is some uncertainty whether observable light is solely from primary, or whether primary and secondary make approximately equal contributions ¶ not to be confused with α Car	HR 3659
β	Car	9 13.5	−69 50	1.67	0.00	A1 III	28.8†	−1.0	113	0.191	305	−5 V?	rapid rotator (< 2.1 d), despite having finished stable core hydrogen fusion ¶ quasi-periodic variation, ~0.5 h,	**Miaplacidus**

													in hydrogen Balmer lines ¶ AAVSO(VSX) situation as of 2024 April 10: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (1.59 mas ± 4%, with limb-darkening correction, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia	
ι†	Car	9 17.8	−59 23	2.25†	0.18	A7 Ib	4.3	−4.6	800	0.022	302	+13	poss. slight var.: unkn. type (2.23–2.28 in V?) further photometric study advisable? (AAVSO(VSX) as of 2024 April 10 applies suspected-variability flag, assigns no variability classification symbol) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ despite being slow rotator, has magnetic activity (as inferred from X-rays) ¶ not to be confused with l (letter el) Car	Aspidiske
α	Lyn A	9 22.7	+34 17	3.14†	1.55	K7 IIIab	16	−0.8	~203	0.224	274	+38	B: 8.8, 223″, PA 33°→42°, 1823→2017 suspected var., mag. 3.12–3.17 (beginning to evolve into a Mira? further photometric study advisable?); AAVSO(VSX) as of 2024 April 10 notes the unavailability of any AAVO observations, cites “Pannekoek” as a discoverer, assigns no variability-type symbol ¶ the JMDC (2021 Sep. 13-or-14 edition) reports several interferometric measurements lacking limb-darkening correction, as 7.71, 8.4, 7.2, 6.92, and 4.01 mas, and one measurement with limb-darkening correction: the latter is 7.538 mas ± 1%, from the Mark III beam-combining facility at Mount Wilson	
κ	Vel	9 22.9	−55 07	2.49	−0.19	B2 IV–V	6	−3.8	600	0.016	315	+22 SB†	IAU name “Markeb” is not to be confused with “Markab” (the IAU name for α Per A) ¶ orbit 116.65 d, average separation possibly ~1.1 au; since the SB has not yet been resolved (even interferometrically), WDS, at any rate as of 2024 Dec. 7, is not yet able to write “κ Vel A” and “κ Vel B” ¶ mass loss rate ~1e–9 M☉/y ¶ system is X-ray source ¶ AAVSO(VSX) situation as of 2024 April 10: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ ISM absorption has varied over the years (ISM cloud in transit?)	Markeb†
α	Hya A†	9 28.9	−8 46	1.98†	1.44	K3 II–III†	18	−1.7	180	0.038	336	−4 V?	poss. slight var.: type unknown (1.93−2.01 in V?) further photometric study advisable? (AAVSO(VSX), as of 2024 April 11, applies suspected-variability flag, finds only one AAVSO observation, does not assign a conjectured variability type symbol) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 9.36 mas ± 0.06%, at 2300 nm, from the AMBER beam-combining facility at VLTI ¶ slow rotator (possibly 2.4 y), with Ba mildly overabundant ¶ asteroseismology has been studied ¶ α Hya B (mag. 9.7; 284″, PA 155°→155°, 1833→2015) might be a true binary component (with orbit ≥ 870,000 y, separation ≥ 15,700 au)	Alphard
N	Vel	9 32.0	−57 09	3.14†	1.55	K5 III	13.6	−1.2	240	0.033	280	−14	slight semiregular var.: 3.12–3.18 in V, 82.0 d (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 2315 AAVSO observations found;	HR 3803

													variability classification symbol = “**SR**”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ evolutionary status uncertain (helium core fusion impending, or already ended?)	
θ	UMa A	9 34.7	+51 34	3.18†	0.46	F6 IV†	74.2	2.5	44.0	1.088	241	+15 SB†	possible slight variability now discounted (V-passband range 3.16–3.20 had been suspected, it appears as recently as 2022: AAVSO(VSX), as of 2024 April 11, however, although noting the unavailability of AAVSO observations, applies non-variability status flag, assigns variability classification symbol “**CST**”) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.662 mas ± 0.8%, in the 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ luminosity class, and also SB status, have been controverted, with postulated SB companion remaining undetected in speckle interferometry ¶ mv, B−V values are for θ UMa AB combined light (where, however, the contribution of θ UMa B, at mag. ~14, is minuscule)	
o	Leo Aa†	9 42.6	+9 46	3.52	0.49	F9 III + A5m	24.2	0.5	135	0.148	255	+27 SB2†	IAU name “Subra” applies only to o Leo Aa; Aa,Ab is a tight binary, with angular separation ~4 mas, but nevertheless now interferometrically resolved (2001AJ....121.1623H; from this paper we take MK type, and also our π-cum-D (as a distance derived from comparing seen angular size of orbit with orbit physical size, yielding a result in good agreement with the 2007 *HIPPARCOS* trigonometric parallax, and yet with smaller uncertainty); period is 14.498 d, with orbit nearly circular, distance between the two stars 0.165 au; our assertion of eclipsing in some earlier edition(s) of the *Handbook* was erroneous, although it is true that the orbit is seen rather close to edge-on; lunar occultation as reported in 1978AJ.....83.1100A failed to split Aa,Ab ¶ WDS (as at 2024 Dec. 7) additionally documents a single observation, from 1997, of “o Leo Ac”, noting that some subsequent work on the Aa,Ab has not corroborated this observation ¶ mv, B−V values are for o Leo Aa,Ab combined light ¶ AAVSO(VSX) situation as of 2024 April 11: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability type symbol ¶ Henry Draper catalogue (HD) numbers are needed in some work with bright stars, notably for lookups in JMDC; when the relevant portion of HD was published in 1919, as vol. 94 from *Annals of the Astronomical Observatory of Harvard College*, o Leo A was known as an (as yet unresolved) spectroscopic binary, and accordingly received the pair of catalogue numbers HD 83808, HD 83809, with a note saying simply "The spectrum is composite. This star is a spectroscopic binary.";since o Leo A is now resolved, WDS, whose star designations this *Handbook* article follows, is now able to write o Leo Aa (for HD 83808) and o Leo Ab (for HD 83809): for the giant which is o Leo Aa (= HD 83808), the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (1.347 mas ± 6%, with limb-darkening correction, in the 8000 nm - 13000 nm mid-infrared passband, from the KIN beam-combining facility at the W.M. Keck Observatory); for the dwarf which is o Leo Ab (= HD 83809), the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry	Subra

													or by any other direct means) ¶ o Leo Aa is a rare instance of a star that has ended core hydrogen fusion, and yet in which the convection typical of an evolved star has not removed the chemical peculiarities possible in a core-hydrogen fuser (where the still-quiet atmosphere facilitates radiative lofting and gravitational settling) **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
l†	Car	9 46.0	−62 38	3.36v†	1.02	F9–G5 Ib	2	−4.7	2000	0.015	302	+3 V	Cepheid variable: 3.32–4.12 in V band, 35.6 d (AAVSO(VSX) assessment as of 2024 May 15: status flag = confirmed variability; 33155 AAVSO observations found; variability classification symbol = “**DCEP**”; period = 35.561 d (AAVSO(VSX) as viewed both 2021 Jan. 18 2022 Jul. 13 gave the shorter period 35.551609 d)); an exceptionally luminous, and consequently exceptionally slow, Cepheid (compare both the visual brightness and the intrinsic luminosity with less dramatic δ Cep A (in this table), η Aql A (Okab; in this table), and ζ Gem Aa (Mekbuda; almost, but not quite, bright enough for inclusion in this table): Kaler remarks that “if Carina had been in the northern hemisphere, the collection of these variables might well have been called the ‘Carinids’”) ¶ the JMDC 2021 Sep. 13-or-14 edition reports two interferometric campaigns for the (pulsation-varying) angular diameter, both published in 2016, both presented as a time series, both using the PIONIER beam-combining facility at VLTI, both in the near-infrared H band, one without limb-darkening correction and the other with limb-darkening correction; the latter time series consists of 16 measurements, of which the smallest is 2.6905 mas ± 0.01% and the largest is 3.2726 mas ± 0.009% (illustrating the extraordinary difference, in a Cepheid, between maximum compression and maximum dilation); the authors call attention to the variations among cycles, such as variations in angular-diameter maxima ¶ circumstellar envelope of ejected matter, radius 10 au–100 au ¶ lower-case ell Car; not to be confused with i (lower-case i) Car (HR 3663), ι Car (HR 3699), L Car (HR 4089), I (upper-case i) Car (HR 4102) (and note additionally that Bayer nomenclature does not use the label “λ Car”) **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	HR 3884
ε	Leo	9 47.4	+23 39	2.98†	0.81	G1 II	13.2	−1.4	250	0.047	259	+4 V?	poss. slight var.: type unknown (2.95−3.04 in V band?) further photometric study advisable? (AAVSO(VSX), as at 2024 April 11, applies suspected-variability flag, notes the availability of 3 AAVSO observations, and does not assign a conjectured variability-type symbol); some photometric work is possibly reported in 1998AN....319..239A (pulsation as in Cepheids?) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.587 mas ± 1%, in the 550 nm–850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ slow rotator, period possibly as long as 200 d ¶ currently residing in the Hertzsprung Gap? ¶ the Arabic or quasi-Arabic name Algenubi (more classically, al Ras al Asad al Janubiyyah et al.) is not presently IAU-official	
υ	Car A	9 47.8	−65 12	2.96	0.27	A6 II	2.3†	−5.3	~1400†	0.028	307	+14	A: 3.00; B: 6.0, B7 III, 5.1″, PA126°→128°, 1836→2016 orbit ≥ 19,500 y, separation ~2000 au ¶ m_V, B−V values are for υ Car AB combined light ¶ AAVSO(VSX) situation as of 2024 April 11: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability type symbol	

													¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ the duplicity causes parallax to be poorly known
φ	Vel A	9 57.8	−54 42	3.53†	−0.09	B5 Ib	2.0	−4.9	1600	0.014	285	+14	¶ m_V, B−V values are for φ Vel A alone (however, the contribution of B, at mag. ~12, to the φ Vel AB combined light is minuscule) ¶ AAVSO(VSX) situation as of 2024 April 11: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability type symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)
η	Leo A	10 08.8	+16 38	3.49†	−0.03†	A0 Ib†	3	−4.5	1300	~0.003	n.a.	+3 V	**[THIS STAR ONLY IN ONLINE VERSION OF TABLE]** B: 8.4, 0.4″, PA 84°→239°, 1937→2015 ¶ variable of α Cyg type, 3.49−3.53 in V passband: AAVSO(VSX), as of 2024 April 11, applies variability flag (while, however, noting that no AAVSO observations are available), assigns variability-type symbol "**ACYG**" (as of 2022 July 30, AAVSO(VSX) had flagged this as merely a suspected variable) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ mv, B−V values are for η Leo AB combined light ¶ mass-loss rate ~5e-8 MΘ/y (> 10,000× solar mass-loss rate); BSC5: "chromospheric shell" ¶ we follow WDS in asserting duplicity (with WDS indicating that the A,B pair has been split both through lunar occultation and in speckle interferometry, and documenting 7 observations 1937→2015; the assertion is, admittedly, questioned by Kaler at stars.astro.illinois.edu/sow/etaleo.html)
α	Leo A†	10 09.8	+11 50	1.36†	−0.11†	B8 IVn†	41	−0.6	79	0.249	271	+6 SB†	poss. slight var.: type unkown (1.33−1.40 V?) **Regulus** α Leo A is SB orbit 40.11 d, with the secondary in the pair that is α Leo A now detected (2011IBVS.5987....1R reports null photometry result from *MOST*, at the high precision of ~0.5 millimag., but a spectroscopic detection is reported in 2020ApJ...902...25G; since the secondary is not yet resolved, even interferometrically, WDS is not yet able, at any rate as of 2024 Dec. 18, to write "α Leo Aa" and "α Leo Ab"); at the level of coarse photometry (further photometric study advisable?), slight variability has been asserted: AAVSO(VSX) as of 2024 April 11 applies suspected-variable flag (while finding no AAVSO observations), shows possible range 1.33−1.40 in V passband, does not assign a conjectural variability classification symbol) ¶ mv, B−V values are for the combined light of the α Leo A SB two-star system ¶ the primary in α Leo A is an exceptionally rapid rotator (15.9 h), making the star an oblate spheroid (Rpol is only about 75% as large as Req) and rendering the photosphere equator ~3000 K cooler than the photosphere poles (and possibly inducing meridional flow in the envelope); this is the first rotating star not in an eclipsing binary system to have its gravitational low-latitudes darkening detected, and the first to have its inclination angle and low-latitudes darkening measured through a direct application of spectroscopy-constrained interferometry (inaugural science run of CHARA, 2005ApJ...628..439M); in contrast with pole-on rapid rotators such as α Lyr A, the α Leo A primary is seen nearly equator-on; in 2011ApJ...732...68C, Fig. 5 presents an image as fitted to CHARA interferometry (the luminosity contours display the perturbing effect of limb darkening upon the rotation-induced gravity darkening; since the poles

are near the limb, the brightest regions, as viewed from Earth, do not quite coincide with the poles);
the aperture-synthesis imaging of
2017NatAs...1..690C Fig. 5 displays the
photosphere temperature variation
(a joint consequence of limb darkening and oblateness),
along with oblateness and axis orientation;
according to 2017NatAs...1..690C,
the α Leo A primary *(i)* has attained 96.5%
of its breakup speed (earlier literature
had suggested 86%), and *(ii)* is the first rapid rotator found
to exhibit Chandrasekhar rotation-induced
stellar limb polarization
(the related phenomenon of eclipse-induced stellar limb
polarization was admittedly
detected earlier, with β Per, as reported in
1983ApJ...273L..85K)
¶ the JMDC (2021 Sep. 13-or-14 edition)
most recent reported interferometric measurement
of angular diameter with limb-darkening correction
is 1.664 mas ± 2% (we presume this is the maximum,
not the minimum, width of the plane-of-sky projection
of the α Leo A oblate spheroid), in the
550 nm–850 nm passband,
from the NPOI beam-combining facility,
US Naval Observatory station at Flagstaff, AZ
¶ despite the large rotation-induced latitude variation
in photospheric effective temperature, at all latitudes
the envelope is radiative (since the photospheric
effective temperature, even at the equator, never falls
so low as to approach the ~8300 K radiation-to-convection
transition value); rotation-induced meridional circulation,
on the other hand, disturbs the usual radiative-equilibrium
picture of a radiative envelope
(2011ApJ...732...68C, p. 11a); since meridional
circulation transfers angular momentum, the envelope
cannot be presumed to be in solid-body rotation
¶ the rapid rotation, the membership in MK type B,
and the near-MS evolutionary status notwithstanding,
the question of Be-phenomenon behaviour
is answered in the negative by 2005ApJ...628..439M;
the authors do, however, remark on p. 446 that the
historical record contains a lone report of marginal
hydrogen Balmer-α emission, from February 1981
(might amateur-spectroscopist monitoring now be
advisable?)
¶ 2011ApJ...732...68C revises
the mass of the primary upward,
offering 4.15 MΘ in place of
the 2005ApJ...628..439M determination of ~3.5 MΘ
¶ A+BC almost unchanged since 1779
(176″; PA 307°→308°, 1779→2023);
AB is nevertheless known to be a true binary
pairing, rather than a mere line-of-sight coincidence;
AB distance ≥ 4200 au, orbit ≥ 125,000 y;
BC combined-light mv, B−V are 8.13, 0.88;
BC is no longer underobserved (PA: 89°→94°,
4.0″→2.1″, 1867→2021, with orbit ≥ 880 y)
¶ a puzzling discrepancy between the ages of
the α Leo SB primary and α Leo B (surely
condensed from the same ISM cloud, at the
same time) is perhaps to be explained by the
peculiarities in the evolution of rapid rotators
¶ we adopt here the MK classification
of 2003AJ....126.2048G, while
recalling that earlier editions
of our RASC brightest-stars table
used instead B7 Vn, essentially in accordance with
1953ApJ...117..313J; Astron. Alm. (epoch 2021.5)
likewise assigns MK type B7 Vn
¶ the α Leo system
is occasionally occulted by Mercury, Venus
(e.g. 1959 Jul. 07, 2044 Oct. 01),
Moon (e.g. 2017 Sep. 18;
1972JBAA...82..431K describes the 18.6-year
1940-through-2050 cycle of possibilities),
and asteroids (e.g. 166 Rhodope 2005 Oct. 19
(2008mgm..conf.2594S reports GTR

												effect of light bending, not only from general solar gravitational field but also from Rhodope field), 163 Erigone 2014 Mar. 20 (cloud-defeated 2014 Erigone campaign is documented at occultations.org/regulus2014) ¶ E(B–V) =+0.01	
ω	Car	10 14.4 −70 10	3.31†	−0.09	B8 IIIn†	9.5	−1.8	340	0.037	281	+7 V	or “IIIne”, shell star; slight var. (3.30−3.32 in V band) ¶ rapid rotator (< 1.2 d, ~85% of breakup speed); instance of “Be phenomenon”; AAVSO(VSX), following GCVS, on the one hand asserts slight variability (3.30−3.32 in V), as would be consistent with λ Ori-type variability, and on the other hand implicitly denies the γ Cas-type outburst variability that often accompanies the “Be phenomenon” (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability (although no AAVSO observations found), variability classification symbol = “**BE**”); further photometric study advisable? ¶ on the side of spectroscopy, as distinct from photometry, BSC5 reports variable hydrogen Balmer-α ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
q	Car A	10 18.0 −61 28	3.36v†	1.54	K3 IIa†	5.0	−3.1	660	0.026	286	+8	irregular variable, 3.34–3.44 in V (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 13 AAVSO observations found; variability classification symbol = “**LC**”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ metallicity is uncertain ¶ evolutionary state is uncertain (has core already started He fusion?) ¶ Astron. Alm. (epoch 2021.5) assigns MK type K2.5 II	HR 4050
ζ	Leo A	10 18.2 +23 17	3.44†	0.31	F0 IIIa†	12	−1.2	270	0.020	110	−16 SB	B is mere optical companion (6.0, 335″ , PA 337°) (since A,B parallax discrepancy is large, 12 mas for ζ Leo A, but 33 mas for the decidedly less distant ζ Leo B; fuller astrometry particulars for the (spurious) AB pairing: 314″→335″, PA 343°→ 347°, 1836→2016) ¶ further photometric study advisable? (AAVSO(VSX), as of 2024 April 11, has no record of available AAVSO observations, offers possible range 3.42−3.46 in V passband, does not assign a conjectural variability-type symbol) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means ¶ Astron. Alm. (epoch 2021.5) assigns MK type F0 III ¶ in rapid evolutionary transition, currently residing in Hertzsprung Gap	Adhafera
λ	UMa	10 18.7 +42 47	3.45	0.03	A1 IV†	24	0.3	140	0.186	256	+18 V	despite MK luminosity class “IV,” has not yet finished core hydrogen fusion ¶ mildly metallic, but insufficiently metallic to warrant MK “Am” ¶ AAVSO(VSX) situation as of 2024 April 11: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification flag ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (0.757 mas ± 0.9%, with limb-darkening correction, in near-infrared I passband, from the VEGA beam-combining facility at CHARA) ¶ seems mild IR excess (indicating circumstellar debris)	Tania Borealis
γ	Leo A +1P†	10 21.4 +19 42	2.29†	1.20†	K1 IIIb Fe–0.5†	26	−0.3	130	~0.333†	~118	−37† SB	4.7″ (2022), PA 99°→127°, 1820→2022 (510.3 y);	Algieba
γ	Leo B	10 21.4 +19 42	3.46†	0.92†	G7 III Fe–1†	26	0.2	130	~0.346†	~118	−36† V	max = ~5″, around 2100 separation ≥ 170 au, orbital parameters	

											not yet well known ¶ A, B are of mildly unequal masses, and therefore are of mildly disparate evolutionary stage (Kaler stars.astro.illinois.edu/sow/algieba.html: “best understood as being in different stages of gianthood”; cf this same source for further discussion of the uncertainties in various γ Leo parameters, including the respective magnitudes of A and B) ¶ we take mv, B−V values (following normal procedure in this *Handbook* table) from GCPD, but correcting here what we believe to be a clerical error in GCPD, leading to “AB” being stated as of 2022 Aug. 05 where in our view “B” was meant: additionally, GCPD gives, as directly measured mv, B−V values for γ Leo AB combined light, 1.98, 1.14 ¶ γ Leo A, or γ Leo B, or both, harbour variability of RS CVn type (spotted star in binary, with differential rotation): AAVSO(VSX), as of 2024 April 11, applies confirmed-variability flag, notes availability of 180 AAVSO observations, offers V-passband range 1.98−2.02 in V, assigns variability type symbol “**RS**”, presumably for AB combined light ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of γ Leo A angular diameter (7.7 mas ± 4%, without limb-darkening correction, at the near-infrared wavelength of 2200 nm, from the IOTA beam-combining facility at the Fred Lawrence Whipple Observatory); the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter for γ Leo B (whether through interferometry or by any other direct means) ¶ γ Leo A “+ 1P” is an exception to the tendency for exoplanets to be found around the more metallic stars (but the “+1P” could be modelled as a brown dwarf); and indeed even “+2P” is now considered possible ¶ high space velocity of the γ Leo AB pair, plus their low metallicity, suggests system is interloper from more remote galactic region ¶ WDS documents celestial-sphere neighbours γ Leo Ca, Cb, D,E,F, of which all but Ca and Cb are fainter than mag. 10; Ca and Cb, a tight pair first split in 1981, shine with a combined light of mag. 9.64, the contribution coming almost entirely from Ca (the faint Cb has been detected only at 750 nm), and are widely separated from A (341″, at PA 288°, in 2016); the AC pairing is found through analysis of the respective proper motions to be a mere line-of-sight coincidence (211″→341″, PA 294°→288°, 1851→2016) ¶ γ Leo AB, and indeed also the next “Sickle” star ζ Leo, serve to mark the radiant of the Leonids meteor shower
μ	UMa	10 23.9+41 22	3.05†	1.58	M0 IIIp†	14	−1.2	230	0.089	293	−21 SB†	slight var.: 3.03–3.10 in V, irreg. (& ecl.?)Tania Australis AAVSO(SVX) considers the system to present slow irregular evolved-star variability, and additionally to possibly present β Lyr-type eclipses (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 164 AAVSO observations found; variability classification symbol = “**EB:+LB**”) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 8.538 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ SB period 230 d; since the SB is not yet resolved, even interferometrically, WDS cannot, at any rate as of 2024 Dec. 18, write “μ UMa A” and “μ UMa B”; ¶ Ca II emission ¶ Astron. Alm. (epoch 2021.5) assigns MK type M0 III ¶ Kaler (stars.astro.illinois.edu-sow-taniaas.html)

												terms this “a rare ‘hybrid star’” (in the sense of blowing both a fast-and-thin wind and a slower-and-dense wind), and additionally notes the puzzle posed by X-ray emission in the presence of cool photosphere	
p	Car	10 33.0−61 49	3.31v†	−0.10	B4 Vne†	7	−2.6	500	0.021	304	+26	var.: γ Cas type, 3.22–3.55 in V passband an instance of the “Be phenomenon” (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 4 AAVSO observations found; variability classification symbol = “**GCAS**”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ fast rotator; BSC5: shell; variable hydrogen Balmer-line profiles	HR 4140
θ	Car	10 43.9−64 32	2.74†	−0.22†	B0.5 Vp	7	−3.0	460	0.022	303	+24 SB†	slight var.: ellipsoidal (*TESS* mission), range 0.003 in V chemically anomalous; of three published orbital solutions for this unresolved SB, the two that seem most reliable (from 1995, 1988) assert periods of 2.20 d, 2.13 d respectively (with e values 0.0, 0.24 respectively); the short SB period, even given the low *e*-values (i.e. the lack of severely close periastron passages) suggests mass transfer could be the culprit in the anomalies ¶ since the SB is not as yet resolved, even interferometrically, WDS is not yet able, at any rate as of 2024 Dec. 18, to write “θ Car A,” “θ Car B” ¶ mv, B−V values seem unavailable in GCPD; we take these values from 2002yCat.2237….0D ¶ AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability (although seems no AAVSO observations available); variability classification symbol = “**HB**”, period 2.2026 d ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ the primary is the brightest of the “blue stragglers”; at stars.astro.illinois.edu/sow/thetacar.html, Kaler discusses difficulties in determination of the primary’s temperature and of its (short) rotation period ¶ E(B–V) =+0.06	
μ	Vel A†	10 47.9−49 34	2.68†	0.90†	G5 III†	28	−0.1	~117	0.083	131	+6 SB	A: 2.8; B: 5.6, 2.3″, PA 55°→59°, 1880→2023 period variously given as 116.24 y (Hoffleit) and 138 y (Heintz); A-to-B distance possibly 8 au min, 93 au max, 51 au average ¶ A is itself an SB, not as yet resolved, even in interferometry (so WDS is not yet, at any rate as of 2024 Dec. 18, able to write “μ Vel Aa,” “μ Vel Ab”) ¶ m_v, B−V values are for μ Vel AB combined light ¶ AAVSO(VSX) situation as of 2024 April 11: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ μ Vel B is of uncertainty-flagged MK type “F8: V” ¶ one or the other component of the SB that is μ Vel A is in rapid evolutionary transition, having recently finished core hydrogen fusion ¶ one or other component of the SB that is μ Vel A is magnetic, and an X-ray emitter, with hot corona, and with violent 2-day X-ray flare detected in 1998 by IUE	
ν	Hya	10 50.9−16 20	3.12	1.24	K2 III†	23	−0.1	144	0.220†	25	−1†	 slow rotator (but ≤ 619 d) ¶ low metallicity and high space velocity suggest interloper, born outside Sun’s neighbourhood ¶ Astron. Alm. (epoch 2021.5) assigns MK type K1.5 IIIb Hδ–0.5 ¶ AAVSO(VSX) situation as of 2024 April 11:	

												no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
β	UMa	11 03.4+56 14	2.37†	−0.02	A0mA1 IV–V	~40.9	0.4	80	0.088	68	−12 SB	poss. slight var.: type unknown (2.35−2.40 in V?) (AAVSO(VSX), as of 2024 April 11, applies suspected-variability flag, finds 77 AAVSO observations, does not assign a conjectured variability-type symbol); further photometric study advisable? ¶ one of the nucleus members of the “UMa moving group” (a group of stars condensed from the same molecular cloud at the same time, but not gravitationally bound: visually salient members of the 15-star “nucleus” include also the β, γ, δ, ε UMa, and ζ UMa stars or star systems; of the ~47 “stream” group members, on the other hand, particularly salient are β Aur system and α CrB); [2015ApJ…813…58J]() uses various observations, including CHARA interferometry (for determining oblateness) to assign a mass to this star and several others in the moving group, and then through evolutionary-model isochrone fitting, with due accounting for gravity darkening for those stars found to be significantly oblate, to assign a notably precise age to the entire (coeval) group (as 414 Myr ± 6%) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.078 mas ± 6%, in the mid-infrared 8000 nm–13000 nm passband, from the KIN beam-combining facility at the W.M. Keck Observatory ¶ debris disk first detected via IR excess, now marginally resolved by Herschel Space Observatory (2010A&A...518L.135M)	Merak
α	UMa A†	11 05.3+61 36	1.86†	1.07†	K0 IIIa	27	−1.1	120	0.139	255	−9 SB	A: 2.0; B: 5.0, A8 V, 0.8″ (2017), PA 342° orbit 44 y ¶ m_v, B−V values are for α UMa AB combined light ¶ the α UMa AB system has also a widely separated, not very faint, celestial-sphere neighbour α UMa C, at mag. 7.19: 384.0″→384.5″, PA 205°→206°, 1800→2020 ¶ the first cool star found to have multimodal oscillations (*WIRE* camera; 2000ApJ...532L.133B suggests fundamental mode 6.35 d); nevertheless, the NSV entry notwithstanding, the α UMa system is non-variable at the level of ordinary ground-based photometry (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed non-variability; variability classification symbol = “**CST**”) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 6.419 mas ± 0.6%, in the 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ the most distant of the seven Big Dipper stars (and, like η UMa at the other extreme of the Big Dipper, not a member of the same-age association that is the UMa Moving Group)	**Dubhe**
ψ	UMa+2P?	11 11.1+44 21	3.01	1.14	K1 III	22.6	−0.2	145	0.068	246	−4 V?	slow rotator (but ≤ 2.6 y) ¶ AAVSO(VSX) situation as of 2024 April 11: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 4.131 mas ± 0.2%, in the 550 nm−850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ	
δ	Leo A	11 15.5+20 23	2.56†	0.13	A4 IV	56	1.3	58	0.193	132	−20 V	poss. slight var.: type unknown (2.54−2.57 in V?)	Zosma

												AAVSO(VSX), as of 2022 Jul. 30, notes existence of NSV entry, fails to find record of AAVSO observations (AAVSO(VSX) assessment as of 2024 April 11: status flag = suspected variable (but seems no AAVSO observations found), no conjectural variability classification symbol assigned); further photometric study advisable? ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.328 mas ± 0.6%, in the near-infrared L band, from the CLASSIC beam-combining facility at CHARA ¶ rapid rotator (< 0.5 d)	
θ	Leo	11 15.6+15 17	3.34[†]	−0.01	A2 IV[†]	~19.8	−0.2	165	0.099	217	+8 V	poss. var.: type unknown (3.29−3.40 in V?) (AAVSO(VSX) assessment as of 2024 April 11: status flag = suspected variable (but seems no AAVSO observations found); no conjectural variability classification system assigned) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.769 mas ± 1%, in the visible-light R band, from the VEGA beam-combining facility at CHARA ¶ rotation rather slow for MK type A (but < 9 d); quiet atmosphere renders Ca, Sc underabundant, and Fe, Sr, Ba overabundant; Ca II K-line is variable ¶ IR excess (debris disk?)	Chertan
ν	UMa A	11 19.9+32 57	3.48[†]	1.40	K3 III Ba0.3[†]	~8.2	−1.9	400	0.039	317	−9 SB	B: 10.1, 7.0″, PA 145°→147°, 1827→2020 orbit ≥ 12,000 y; AB distance ≥ 950 au; in addition to celestial-sphere neighbour ν UMa B and the very faint celestial-sphere neighbour ν UMa C, WDS lists the not-very-faint, but widely separated, celestial-sphere neighbour ν UMa D (mag. 8.88; angular separation from A was 281″ in 2020, at PA 269°) ¶ m_V, B−V values are for ν UMa A combined light ¶ further photometric study advisable? (AAVSO(VSX), as of 2024 April 11, seems to find no AAVSO observations, writes “3.51−?” for possible V-passband range, does not assign a conjectural variability-type symbol) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 4.561 mas ± 0.4%, in the 550 nm−850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ Astron. Alm. (epoch 2021.5) assigns MK type $K3^-$ III **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	Alula Borealis
ξ	Hya Aa	11 34.3−32 00	3.54[†]	0.95	G7 III	~25.2	0.5	130	0.214	259	−5 V	poss. slight var.: type unknown (3.69−3.71 in Hp passband?) further photometric study advisable? (AAVSO(VSX), as of 2024 April 11, applies suspected-variability flag, seems to find no record of AAVSO observations, does not assign a conjectural variability-type symbol) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (2.394 mas ± 1%, with limb-darkening correction, at 2178 nm, from the VINCI beam-combining facility at VLTI) ¶ we give mag. value for ξ Hya Aa, Ab combined light in V passband; ξ Hya Aa is of mag. 3.7, and ξ Hya Ab of mag. 5.8; WDS as of 2025 March 11, 2025 documents just 2 astrometry measurements for this tight pair, from 2001 and 2023 (with angular separation 0.1″ on both occasions) ¶ the CORALIE spectrograph on the 1.2 m Euler telescope at La Silla (ESO) in 2002 demonstrated for the first time the feasibility of asteroseismology for a highly evolved star: ξ Hya Aa has left the theoretical MS, being now near the theoretical SGB-RGB transition, and yet CORALIE was able to find solar-like oscillations (with periods, however, of 2.0 h to 5.5 h, in contrast with the “five-minute oscillations” in the Sun; ξ Hya Aa, being evolved, is larger than the Sun, and so its starquakes face	

												larger propagation distances; correspondingly, where the solar “five-minute oscillations” involve speeds of ~15 cm/s or ~20 cm/s, in the case of ξ Hya Aa the observed speeds attain values only a little below 2 m/s (such a refined stellar radial-velocity measurement is now possible as a kind of spinoff from advances in exoplanet-search spectrograph engineering); both radial and non-radial oscillations are found in ξ Hya Aa; the pertinent ESO press release is at www.eso.org/public/news/eso0215/, and the modern ξ Hya Aa asteroseismology literature in the journals starts with the “Letter” which is 2002A&A…394L…5F **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
λ	Cen Aa†	11 37.0−63 10	3.12†	−0.04†	B9.5 IIn†	8	−2.4	400	0.034	258	−1 V	despite possible fast rotation (< 2.7 d?), Fe is overabundant, with Si and C mildly underabundant ¶ at stars.astro.illinois.edu/sow/lambdacen.html, Kaler discusses questions of visual binarity (λ Cen Aa, Ab, B: but WDS as of 2025 March 11 documents only a single observation of λ Cen Ab, from the year 2000, and just 3 observations of the faint λ Cen B, over the period 1937→2015) ¶ mv, B−V values are for λ Cen Aa,Ab combined light ¶ AAVSO(VSX) situation as of 2024 April 11: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
β	Leo A	11 50.4+14 25	2.14†	0.09	A3 Va	91	1.9	36	0.511	257	0 V	slight var.: δ Sct type, range 0.025 in V band (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 1157 AAVSO observations found; variability classification symbol = “**DSCTC**”) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.339 mas ± 6%, in the 8000 nm–13000 nm mid-infrared passband, from the KIN beam-combining facility at the W.M. Keck Observatory ¶ rapid rotator (< 0.65 d) ¶ debris disk resolved by Herschel Space Observatory (2010A&A...518L.135M), disk structures differentiated with ground-based interferometry (2010ApJ...724.1238S) ¶ WDS as of 2025 March 11 documents very faint celestial-sphere neighbours β Leo B,C, and additionally the not-so-faint D (mag. 8.5; AD astrometry is 298″→236″, PA 204°→194°, 1833→2022), and has now deleted its mention, in recent past years, of the putative tight (0.5″) pair Ea,Eb (in recent past years: mags. 6.5 and 6.6; separated by 2″ from A; for the “AE” pairing WDS in recent years had just a single measurement, from 2009, and likewise for the Ea,Eb pairing WDS in recent years had just a single measurement, again from 2009)	**Denebola**
γ	UMa A	11 55.2+53 33	2.44†	0.00	A0 Van†	39	0.4	83	0.108	84	−13	slight var.: Be&“UV Cet”, 2.41−2.45 in V band rapid rotator: although in MK temperature class A, nevertheless an instance of the “Be phenomenon” (the term “Ae star” is sometimes used for this rare category); following GCVS, AAVSO(VSX) asserts slight variability for the γ UMa system, while refraining from asserting the eruptive γ Cas-type variability often found with the “Be phenomenon” (could this also be an instance of λ Eri-type variability?); additionally, AAVSO(VSX) asserts eruptive UV Ceti-type variability in the γ UMa system (AAVSO(VSX) assessment as of 2024 April 11:	Phecda

												status flag = confirmed variability (although no AAVSO observations found); variability classification symbol = “**BE+UV**”) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (0.922 mas ± 12%, with limb-darkening correction, in the near-infrared K passband, from the CLASSIC and CLIMB beam-combining facilities at CHARA); as can be seen from Fig. 2 in the underlying primary publication, 2015ApJ...813...58J, γ UMa, despite being rotationally flattened, is observed not too far from pole-on, making this flattened star appear not unlike a disk; on the modelling of 2015ApJ...813...58J, the equatorial physical radius is 3.435 Rsolar ± 4%, and the polar physical radius just 2.233 Rsolar ± 3% ¶ one of the nucleus members of the “UMa moving group” (a group of stars condensed from the same molecular cloud at the same time, but not gravitationally bound: visually salient members of the 15-star “nucleus” include also the β, δ, ε UMa, and ζ UMa stars or star systems; of the ~47 “stream” group members, on the other hand, particularly salient are β Aur system and α CrB); 2015ApJ…813…58J uses various observations, including CHARA interferometry (for determining oblateness) to assign a mass to this star and several others in the moving group, and then through evolutionary-model isochrone fitting, with due accounting for gravity darkening for those stars found to be significantly oblate, to assign a notably precise age to the entire (coeval) group (as 414 Myr ± 6%) ¶ γ UMa is said in en.wikipedia.org/wiki/Gamma_Ursae_Majoris to be an astrometric binary, of period 20.5 y (γ UMa A with an invisible companion? or is this, rather, the sparsely observed pairing of γ UMa A with (visible, mag. 8.2) γ UMa B? and we are also not fully certain on the SB situation: although we have in the past applied the flag “SB” (is γ UMa A a binary with companion unresolved?), we now withdraw the flag, on the strength of 2010NewA...15..324G (which proposes an astrometric binary-system orbit for γ UMa AB, but additionally writes, “Spectroscopic duplicity of this star mentioned in some catalogues seems to be a mistake: it [sc the alleged duplicity] could not have been detected because of a large rotational velocity [with rotational broadening, therefore, of the spectrum lines]”]))
												¶ E(B–V) =0.00
δ	Cen Aa†	12 09.7−50 52	2.58v†	−0.13	B2 IVne†	8	−2.9	400	0.050	262	+11 V	variability: γ Cas type, 2.51–2.65 in V passband (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 10 AAVSO observations found; variability classification symbol = “**GCAS**”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ rapid rotator (< 1.3 d), with shell spectrum; 2008A&A...488L..67M summarizes recent research, and as part of a wider VLTI investigation into the “Be phenomenon” not only discusses the circumstellar ejecta, but also reports discovery of binarity (Ab at angular distance 68.7 mas); WDS as of 2025 March 11, 2025 documents not only δ Cen Aa,Ab (mags. 2.5, 5.4, still only one observation) but also celestial-sphere neighbours δ Cen B, δ Cen C; δ Cen B (a Be star) is mag. 4.4, with astrometry 269.0″→269.1″, PA 325° →325°, 1861→2016; δ Cen C is mag. 6.4, with astrometry 217.6″→216.8″, PA 227°→227°, 1847→2016
ε	Crv+2P?	12 11.5−22 46	3.00†	1.33	K2 III†	~10.3	−1.9	320	0.072	278	+5	poss. slight var.: type unknown (2.98−3-06 in V passband?)

												further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 11: status flag = suspected variable; 22 AAVSO observations found; no variability classification symbol) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ slow rotator (but ≤ 3.9 y) ¶ metals somewhat overabundant ¶ evolutionary status uncertain (core-helium fusion starting, in progress, or finished?) ¶ Astron. Alm. (epoch 2021.5) assigns MK type K2.5 IIIa ¶ the etymologically Arab name “Minkar” is of merely modern origin, and is not currently IAU-official	
δ	Cru	12 16.6−58 54	2.79†	−0.24	B2 IV†	9.4	−2.3	350	0.037	254	+22 V?	slight var.: β Cep type, 2.78–2.80 in V band, 3.62 h (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 2 AAVSO observations found; variability classification symbol = “**BCEP**”; period = 3.6249 h) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ rapid rotator (<1.3 d; BSC5: “expanding circumstellar shell”)	Imai
δ	UMa A	12 16.7+56 53	3.31†	0.08	A2 Van	40.5	1.4	81	0.104	86	−13 V	slight var.: type unknown, 3.30−3.31 in V band further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 2532 AAVSO observations found; variability classification symbol = “**VAR**” (so variability known only as a preliminary survey result); period = 11.435 h) ¶ one of the nucleus members of the “UMa moving group” (a group of stars condensed from the same molecular cloud at the same time, but not gravitationally bound: visually salient members of the 15-star “nucleus” include also the β, γ, ε, and ζ UMa stars or star systems; of the ~47 “stream” group members, on the other hand, particularly salient are β Aur system and α CrB); 2015ApJ…813…58J uses various observations, including CHARA interferometry (for determining oblateness) to assign a mass to this star and several others in the moving group, and then through evolutionary-model isochrone fitting, with due accounting for gravity darkening for those stars found to be significantly oblate, to assign a notably precise age to the entire (coeval) group (as 414 Myr ± 6%) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular "diameter" with limb-darkening correction is 0.804 mas ± 11%, in the near-infared H passband, from the CLIMB beam-combining facility at CHARA; as can be seen from Fig. 2 in the underlying primary publication, 2015ApJ...813...58J, δ UMa A not only is rotationally flattened but is seen very far from pole-on, making this flattened star appear very unlike a disk, with angular minimum width ~0.8 mas (corresponding, we presume, to the cited value angular "diameter" value of 0.805 mas ± 11%); on the modelling of 2015ApJ...813...58J, the equatorial physical radius is 2.512 Rsolar ± 3%, and the polar physical radius just 1.921 Rsolar ± 2% ¶ possesses debris disk, of unusually low radius (Wyatt et al 2007; Pointing-Robertson drag?)	Megrez
γ	Crv	12 17.2−17 41	2.58†	−0.11	B8 III†	21	−0.8	154	0.160	278	−4 SB	poss. slight var.: type unkn. (2.56−2.60 in V?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 11: status flag = suspected variable; 22 AAVSO observations found; no variability classification symbol assigned; “Ferrero” cited as discoverer) ¶ the JMDC 2021 Sep. 13-or-14 edition reports	**Gienah**

only one interferometric measurement
of angular diameter (0.75 mas ± 8%, at the very
short wavelength of 443 nm, from the pioneering
intensity interferometer at Narrabri Observatory
(now Paul Wild Observatory) in Australia
¶ rather rapid rotation notwithstanding
(BSC5: “expanding circumstellar shell”), Hg and Mn
are overabundant, with some other elements
underabundant (but rotational line broadening
makes abundance determinations difficult);
Astron. Alm. (epoch 2021.5) assigns MK temperature type
B8p Hg Mn, and does not assign an MK luminosity class

α	Cru A†	12 28.1−63 15	1.28†	−0.18†	B0.5 IV	10	−3.7	~320	0.037	251	−11 SB	5.4″→35″, PA 114°→111°, 1826→2020	**Acrux**
α	Cru B†	12 28.1−63 15	1.58†	−0.17†	B1 Vn	10	−3.3	~320	0.037?	251?	−1	orbit ≥ 1300 y, AB distance ~430 au	

(the WDS “U” flag for AB, indicating that the pairing
is a mere line-of-sight coincidence, does not seem
supported in the most obvious part of the secondary
literature (Kaler, *Wikipedia*)); A is SB pair
(not as yet resolved, even in interferometry, so WDS
cannot, at any rate as of 2025 March 11,
write “α Cru Aa,” “α Cru Ab”), with
period 75.78 d, distance between components
~0.5 au min, ~1.5 au max; C (itself an SB pair,
unresolved), at mag 4.8, has been said to be
imperfectly sharing AB proper motion
(AC astrometry 92″→89″, PA 216°→203°,
1750→2020), and so is possibly (not assuredly)
gravitationally bound with the putatively
gravitationally bound three-star AB system (if C
is bound, then period > 130,000 y, with distance
from AB ≥ 9,000 au); the other celestial-sphere
neighbours of the unresolved α Cru A SB pair
are fainter than mag. 10; the IAU-official name
“Acrux” applies to the “primary” (the more luminous,
and more massive) component of the unresolved
α Cru A pair; that unresolved pair has also been
called α^1 Cru, with α Cru B correspondingly
called α^2 Cru; it is a little puzzling that the WDS note
for this α Cru ABC putatively 5-star system is silent
on SB status of α Cru C, while suggesting instead
(on strength of 1967 Batten work at DAO)
possible SB status for α Cru B
¶ the AB duplicity makes the two individual
magnitude and colour determinations
“Aa-with-Ab-combined light,”
“B” somewhat controverted: we use
2002A&A...384..180F for these two
individual determinations; our normal authority,
GCPD, for its part does not give separate determinations,
but does give for α Cru Aa,Ab,B combined
light 0.76, −0.25
¶ AAVSO situation as of 2024 April 11:
no status flag (so not confirmed variable,
not suspected variable, not confirmed non-variable),
and a fortiori no variability symbol,
for either α Cru A or for α Cru B
¶ the JMDC 2021 Sep. 13-or-14 edition does not report
any direct measurement of angular diameter
for either α Cru A or α Cru B
(whether through interferometry
or by any other direct means)

δ	Crv A†	12 31.2−16 40	2.95†	−0.05†	B9.5 IVn	~37.6	0.8	87	0.252	237	+9 V	B:8.5, K2 V, 24″, PA 216°→216°, 1782→2020	Algorab

although A,B have common proper motion, disparity
in age estimates has caused binarity to be questioned;
Kaler, accepting binarity (he proposes period ≥ 9400 y)
suggests that the δ Crv AB system is young, and
that B (radiating less powerfully than A) is a
post-T-Tauri star (i.e. a star that, although
already stably burning core hydrogen, has
nevertheless not yet succeeded in clearing away its
surrounding dust)
¶ mv, B−V values are for δ Crv A; for δ Crv B,
GCPD gives 8.40, 0.87
¶ further photometric study advisable?
(AAVSO(VSX) assessment as of 2024 April 11:
status flag = suspected variable;
20 AAVSO observtions found;
possible V-passband range 2.91−2.96;

												no variability classification symbol assigned) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
γ	Cru A	12 32.7−57 16	1.62†	1.60	M3.5 III†	37	−0.6	89	0.267	174	+21	slight semireg. var.: 1.60–1.67 in V passband although classified by AAVSO(VSX) as semiregular var., at least 6 pulsation periods have been documented (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 363 AAVSO observations found; variability classification symbol = “**SR**”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ the nearest of the M giants, radius > 0.5 au; evolutionary status uncertain (is core He fusion now finished?) ¶ cause of the observed Ba overabundance is unknown (undetected evolved companion?) ¶ γ Cru B (celestial-sphere neighbour through mere line-of-sight coincidence) is mag. 6.4, with AB astrometry 93″→133″, PA 41°→24°, 1826→2018; γ Cru C is mag. 9.7, with AC astrometry 155″→168″, PA 86°→68°, 1879→2018	**Gacrux**
β	Crv	12 35.8−23 33	2.65†	0.90	G5 II†	22	−0.6	146	0.057	179	−8 V	poss. slight var.: type unknown (2.60−2.66 in V?) further photometric study advisable? (AASVO(VSX) assessment as of 2024 April 11: status flag = suspected variable; no variability classification symbol assigned) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ slow rotator (but ≤ 180 d) ¶ possibly in evolutionary transition (He core about to ignite?) ¶ assertion of weak Ba-star status is perhaps erroneous ¶ Astron. Alm. (epoch 2021.5) assigns MK type G5 IIb	Kraz
α	Mus Aa	12 38.8−69 17	2.69†	−0.22	B2 IV–V	10.3	−2.2	320	0.042	252	+13 V	slight var.: β Cep type, 2.68–2.73 in V passband, 2.17 h classification of the low-amplitude variability as β Cep, accepted by AAVSO(VSX), has been questioned elsewhere (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability (but no AAVSO observations found), variability classification symbol = “**BCEP**”, period = 2.17 h) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ rapid rotator (< 2 d) ¶ we give mag. for combined light of α Mus Aa and its very close, less luminous, companion α Mus Ab: the pair is sparsely observed, perhaps with nothing beyond the 2013MNRAS.436.1694R report that binarity has been discovered (Sydney interferometer: two 2020 observations, with angular separations ~10 mas, ~16 mas); individual mags. are 2.8, 5.5	
γ	Cen A†	12 43.0−49 06	2.82†	~−0.01†	A1 IV	25	−0.1	130	~0.194	~267	−6	orbit 84 y; 0.4″ (2010),	
γ	Cen B†	12 43.0−49 06	2.88†	~−0.01†	A0 IV	25	−0.2	130	~0.194	~267	−6	0.5″ (2021), 0.6″ (2023); max = 1.7″; PA in 2023 = 19°; AB distance 8 au min, 67 au max, 37 au average; γ Cen D (mag. 3.85), despite its large physical distance from, and large angular separation from, the γ Cen AB pair (1.72 ly, ~1°) is likely gravitationally bound to γ Cen AB, experiencing that binary as essentially a point mass; γ Cen D is a.k.a. τ Cen ¶ GCPD gives mv, B−V values only for γ Cen AB combined light (as 2.16, −0.01); we take individual γ Cen A, γ Cen B mv values from WDS, as viewed 2022 Aug. 05 ¶ γ Cen system presents slight variability, V-passband range 0.012 (*TESS* mission), period 2.401 d, considered by AAVSO(VSX)	

												as of 2024 April 11 (which, however, seems to find no AAVSO observations) to be possibly of type “α^2 CVn” (α CVn A), with Sebastian Otero credited as discoverer ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter for either γ Cen A or γ Cen B (whether through interferometry or by any other direct means) ¶ Arabic name Muhlifain, for γ Cen A, is not currently IAU-official	
γ	Vir AB†	12 43.0 −1 36	2.74†	0.36†	F1 V + F0mF2 V	85	2.4	39	~0.619	~276	−20	A: 3.48; B: 3.53; 3.4″ (2024) (was 3.2″ in 2022, but only 0.8″ in 2007; PA in 2024 was 352°; orbit 169 y; separation 5 au min (most recently 1836 and 2005), 81 au max, 43 au average, with plane of orbit inclined 31° to plane of sky; for discussion of orbit, with observations plot showing error bars (binary astrometry being now old enough to archive data for one full orbit), cf Kaler at stars.astro.illinois.edu/sow/porrima.html; the γ Vir AB pair has, in addition to some faint celestial-sphere neighbours, the widely separated, but not very faint, neighbours γ Vir E (mag. 8.9) and γ Vir F (mag. 9.5), neither of which is gravitationally bound to the AB pair; AE astrometry is 255″→260″, PA 186°→167°, 1851→2016, and AF astrometry is 482″→422″, PA 269°→267°, 1909→2015 ¶ m_v, B−V values are for γ Vir AB combined light; although GCPD does not give values for γ Vir A, GCPD does additionally give 2.80, 0.32 for γ Vir B ¶ AAVSO(VSX) reports Sebastian Otero as having rebutted the variability claim in **2000AcA....50..177P** (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed non-variability; variability classification symbol = “**CST**”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter for either γ Vir A or γ Vir B (whether through interferometry or by any other direct means) ¶ lunar occultations possible, planetary occultations possible-yet-rare	Porrima
β	Mus Aa	12 47.9−68 15	3.04†	−0.19†	B2 V†	~9.6	−2.1	340	~0.043†	~258	+42† V	A: 3.52; B: 3.98, 1.0″, PA 317°→58°, 1880→2019 orbit 194 y; average AB distance uncertain (101 au, or only ~80 au?); orbit map, showing error bars, given by Kaler at stars.astro.illinois.edu/sow/betamus.html, with Kaler’s accompanying discussion of orbit- modelling problems, underscores limitations in current β Mus AB knowledge; 2013MNRAS.436.1694R reports splitting β Mus A as tight binary system β Mus Aa, β Mus Ab, in two 2010 observations with Sydney interferometer: Ab is mag. 6.6, and Aa,Ab angular separation is < 50 mas ¶ m_v, B−V values are for β Mus Aa,Ab,B combined light ¶ AAVSO(VSX) situation as of 2024 April 11: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter for either β Mus Aa or β Mus Ab (whether through interferometry or by any other direct means) ¶ β Mus A is rapid rotator (< 1 d) ¶ β Mus B is of MK type B2.5 V ¶ a runaway system, in the sense of presenting a high velocity relative to the general galactic rotation	
β	Cru A	12 49.3−59 50	1.25†	−0.24	B0.5 III†	12	−3.4	300	0.046	249	+16 SB†	A is slight var.: β Cep type, 1.23–1.31 in V band although the photometry of β Cru A is dominated by a period of 5.68 h, this star is multiperiodic (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability;	Mimosa

												10 AAVSO observations found; variability classification symbol = “**BCEP**”; period = 5.67617 h) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.722 mas ± 3%, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia ¶ SB period 1828.0 d, e=0.38 (with distance between the SB components 5.4 au min, 12.0 au max); Kaler at stars.astro.illinois.edu/sow/mimosa.html discusses other possible companions, including an X-ray visible, and yet optically invisible, object interpreted as a pre-MS star; in gross optical-astronomy terms, the unresolved β Cru A SB has celestial-sphere neighbours B,C,D,E, of which only C is brighter than mag. 10; AC astrometry is 384″→373″, PA 23°→23°, 1826→2015 ¶ β Cru A is believed to be a rapid rotator (possibly ~3.6 d) ¶ β Cru A, its MK luminosity class “III” notwithstanding, is only about halfway through its career of stable-core hydrogen fusing	
ε	UMa A	12 55.2+55 49	1.76†	−0.02	A0p IV: (CrEu)	~39.5	−0.3	83	0.112	94	−9	SB? slight var.: α^2 CVn type, 1.75–1.78 in V, 5.09 d (AAVSO(VSX) assessment in 2022: status flag = confirmed variability; 2633 AAVSO observations found; variability classification symbol = “**ACV**”, period = 5.088631 d) ¶ the brightest of the Ap stars (in the specific case of ε UMa A, the magnetic-dipole axis is believed to be nearly perpendicular to rotation axis, yielding Cr bands nearly perpendicular to equator; dipole strength is unusually low) (but it has also been suggested that a substellar companion of mass ~14.7× Jupiter, at average inter-component distance 0.055 au, orbit 5.1 d, rather than a 5.1-d stellar rotation, is the source of the observed variability period); WDS, as of 2025 March 12, documents just 2 astrometry measurements for the ε UMa B companion of ε UMa A; the discovery of ε UMa B, via speckle interferometry, is announced in 1978MNRAS.183..701M; we at the *Handbook* do not know whether this discovery of ε UMa B constitutes a resolving of the putative SB ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of ε UMa A angular diameter (whether through interferometry or by any other direct means)	**Alioth**
δ	Vir A	12 56.9 +3 15	3.38†	1.57	M3 III†	16	−0.5	~198	0.473†	264	−18†	V? slight var.: semireg., 3.32−3.40 in V band (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability (but seems no AAVSO observations found); variability classification symbol = “**SR**”); multiperiod pulsator ¶ the JMDC 2021 Sep. 13-or-14 edition reports two interferometric measurements of angular diameter, one published in 1998 without limb-darkening correction, the other published in 2003, with limb-darkening correction (the latter is 10.709 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson); after this version of the catalogue was issued, [2022A&A...659A.192L](2022A&A...659A.192L) reported further interferometry of δ Vir A in the near-infrared L band from the MATISSE beam-combining facility at VLTI, yielding angular diameter, with limb-darkening correction, of 10.565 mas ± 0.3% ¶ high space velocity relative to galactic neighbours ¶ evolutionary status uncertain (helium fusion recently started, or already finished?) ¶ Astron. Alm. (epoch 2021.5) assigns MK type $M3^+$ III	Minelauva
α	CVn A†	12 57.3+38 11	2.89†	−0.12	A0 Vp (SiEu)	28	0.1	110	0.241	283	−3	V SB B:5.5, F0 V, 19″, PA 234°→229°, 1777→2023 orbit ≥ 8300 y (common proper motion indicates true binarity); separation ≥ 675 au; prototype for the	Cor Caroli

												α^2 CVn var. type; rotation period is 5.46939 d, with consequent spot-driven slight V-mag. range 2.86–2.93 (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 251 AAVSO observations found; variability classification symbol = “**ACV**”); the α CVn A SB is not as yet resolved, even in interferometry (so WDS, at any rate as of 2025 March 12, cannot write “α CVn Aa,” “α CVn Ab”), and also α CVn B is an as-yet-unresolved SB (so WDS cannot as yet write “α CVn Ba,” “α CVn Bb”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ two correct, potentially confusing, designations are α CVn A (signalling that this is the brighter of the binary pair) and α^2 CVn (signalling that α^1 crosses the local meridian before α^2, lying further W); the Latin “heart-of-Charles” designation, official at IAU as of 2016, honours the “martyr king” Charles I (although Charles II is sometimes cited in error)	
ε	Vir A	13 03.5+10 49	2.83†	0.93	G9 IIIab†	29.8	0.2	110	0.275	274	−14 V?	poss. var.: type unknown (2.65−2.84 in V?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 11: status flag = suspected variable; seems no AAVSO observations found; no conjectural variability classification symbol assigned; “Smyth” cited as discoverer) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 3.318 mas ± 0.4%, in the 550 nm–850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ one of the most notable X-ray sources in our table (X-ray luminosity, although far below α Aur, is nevertheless almost 300× solar) ¶ Astron. Alm. (epoch 2021.5) assigns MK type G8 IIIab	Vindemiatrix
γ	Hya A	13 20.4−23 19	2.99†	0.92	G8 IIIa	~24.4	−0.1	134	0.081	121	−5 V?	poss. slight var.: type unknown (2.94−3.02 in V passband?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 11: status flag = suspected variable; one single AAVSO observation found; no conjectural variability classification symbol assigned) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter, without limb-darkening correction, and with notably large uncertainty (3.71 mas ± 18%), in the near-infrared K passband, from the AMBER beam-combining facility at VLTI ¶ slow rotator (but ≤ 240 d) ¶ evolutionary state uncertain (core-helium fusion impending, or already in progress?)	
ι	Cen	13 22.1−36 51	2.75	0.04	A2 Va†	55	1.5	59	0.352	256	0	rapid rotator (< 2d) ¶ low metallicity ¶ debris disk (unusually luminous, given evolutionary state of ι Cen) ¶ AAVSO(VSX) situation as of 2024 April 11: no status symbol (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	Kulou
ζ	UMa Aa†	13 25.0+54 47	2.05†	0.03†	A1 Va†	40	0.1	90	0.123	100	−6 SB2†	B:3.9, A1mA7 IV–V, 14.4″; period >5000 y? (more precisely 13.9″→14.4″, PA 143°→153°, 1755→2022); Alcor, i.e. ζ UMa Ca, lies at an angular separation of about 12' from the naked-eye point of light which is the aggregate of ζ UMa Aa (Mizar), ζ UMa Ab, ζ UMa Ba, ζ UMa Bb: not only is ζ UMa AB a true binary; it is now additionally argued (controversy possibly continues) that the pair ζ UMa Ca (Alcor), Cb	Mizar

is gravitationally bound to the pair AB (Bob King, *Sky & Telescope* 2015 March 25); ζ UMa Aa, ζ UMa Ab are an interferometrically resolved SB2, seen nearly edge-on, with at least three orbital solutions published (20.5385 d or 20.5386 d, e=5.54 or 5.53, angle subtended by semimajor axis as projected onto plane of sky ≈10 mas (apod.nasa.gov/apod/ap970219.html, as NASA "Astronomy Picture of the Day" for 1997 Feb. 19, depicts an NPOI-derived ζ UMa Aa,Ab orbit), with 2010NewA...15..324G suggesting, on the basis of astrometry perturbations, a possible further unseen body); ζ UMa B is an unresolved SB, period 175.6 d, with highly elliptical orbit; although the old, widely repeated claim (cf Heard ApJ 1949) that ζ UMa C is binary is shown in www.leosondra.cz/en/mizar/ to be unfounded, binarity is now established (with WDS accordingly writing "ζ UMa Ca," "ζ UMa Cb," at mags. 4.0 and 8.0 respectively, typical angular separation 1″, with 5 satisfactory astrometry measurements over the period 2007→2009); Cb is a mid-M red dwarf, very notable as one of the few cases of a red dwarf detected as gravitationally bound to an A star (Ca is of MK type A5 Vn); the IAU-official name "Alcor" applies to ζ UMa Ca; www.leosondra.cz/en/mizar/ should be consulted also *(a)* for details on ζ UMa multiplicity-studies history, including Galileo and Michelson (Leoš Ondra, citing inter alia Fedele 1949, seems to establish that it was Galileo's pupil Castelli, rather than (as widely asserted) Riccioli, who discovered Mizar's visual duplicity) and *(b)* for a 15′ map documenting around 20 of the stars in the field, including mag. 7.6 "Stella Ludoviciana" ("Sidus Ludovicianum," in WDS ζ UMa D), a mere line-of-sight coincidence on the celestial sphere, too distant from ζ UMa ABC to be gravitationally bound to this 6-star system (Aa,Ab; B binary-as-yet-unresolved, Ca,Cb): WDS additionally documents, as gravitationally bound to the ζ UMa ABC 6-star system, E (mag. 6.9), F (mag. 9.9), G (mag. 8.2), and H (mag. 8.6)

¶ mv, B−V values are for ζ UMa Aa, Ab,B combined light; AAVSO(VSX), if we at the *Handbook* interpret this correctly, has 2.24 in V passband for Aa,Ab combined light

¶ Astron. Alm. (epoch 2021.5) assigns MK type "A1 Va+ (Si)"

¶ possible variability now discounted (AAVSO(VSX) overall "Mizar" situation, i.e. situation for ζ UMa AB system, as of 2024 April 11: status flag = confirmed non-variability (although no AAVSO observations found); no variability classification symbol assigned (but should not the ζ UMa AB system now be assigned the symbol "**CST**"?); AAVSO(VSX) overall situation for "Alcor", or ζ UMa C system, as of 2024 April 11: status flag = confirmed non-variability (although seems no AAVSO observations found), no variability classification system assigned (but should not the ζ UMa C system now be assigned the symbol "**CST**"?))

¶ the ζ UMa system is one of the nucleus members of the "UMa moving group" (a group of stars condensed from the same molecular cloud at the same time, but not gravitationally bound: visually salient members of the 15-star "nucleus" include also the β, γ, δ, and ε UMa stars or star systems; of the ~47 "stream" group members, on the other hand, particularly salient are β Aur system and α CrB); 2015ApJ…813…58J uses various observations, including CHARA interferometry (for determining oblateness) to assign a mass to ζ UMa Ca (Alcor) and several other stars in the moving group, and then

														through evolutionary-model isochrone fitting, with due accounting for gravity darkening for those stars found to be significantly oblate, to assign a notably precise age to the entire (coeval) group (as 414 Myr ± 6%) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter of any of the four stars ζ UMa Aa (Mizar), ζ UMa Ab, ζ UMa Ba, ζ UMa Bb (whether through interferometry or by any other direct means); on the other hand, this same authority does have a single direct measurement of angular diameter for ζ UMa Ca (Alcor), as 0.6845 mas ± 6%, with limb-darkening correction, in the near-infrared H band, from the CLIMB beam-combining facility at CHAARA (in the underlying primary publication, 2015ApJ...813...58J, Fig. 2 shows that Alcor is oriented almost exactly equator-on to Earth, and that there is significant rotational flattening: 2015ApJ...813...58J models the equatorial physical radius as 2.002 Rsolar ± 3%, and the polar physical radius as just 1.723 Rsolar ± 3%) ¶ in the mythology of the Mi'kmaq and the St Lawrence Seaway Iroquois, as presented at www.aavso.org/myths-uma, α, β, γ, and δ UMa are a bear at various seasons of the year passant, rampant, and expired (its four paws upward in death), pursued in the warm months by seven hunters, but once the nights are cold by a remaining above-horizon three, these persistent three being ε UMa, Mizar, and ζ UMa, with Alcor the middle hunter's cooking pot, awaiting bear-meat; www.aavso.org/myths-uma gives further detail, offering also a speculation about a possible bear mythology shared by Siberian and North American Paleolithic peoples, in the epoch of the Bering Strait land bridge	
α	Vir Aa†	13 26.6	−11 18	0.98†	−0.24	B1 V†	13	−3.4	250	0.052	234	+1	SB2†	slight ellipsoid var.: 0.96–1.00 in V passband, 4.0 d (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; variability classification symbol = "**ELL+BCEP**"; period = 4.0145 d); very tight (< 1″) system resolved interferometrically (and in occultation?) into α Vir Aa (mag. 1.3), α Vir Ab (mag. 4.5), α Vir Ac (mag. 7.5); as SB2 (primary-to-secondary distance 0.12 au; the geometry is close to achieving a grazing eclipse), the brightest of the rotating- ellipsoid variable systems; the Aa,Ab orbit is highly eccentric; Aa was measured in 1975 to lie 0.50″ from Ac ; although the Aa,Ab pair is at all times very close, an angular distance of 0. 1″ is reported from 1975; Aa (a rapid rotator, at ~0.3 breakup speed) is itself a pulsating variable of the β Cep type (0.1738 d; shortly after the ~1970 discovery of the β Cep variability, photometric and spectroscopic variations were present; the photospheric variations soon ceased, but the spectroscopic (radial-velocity, i.e. pulsational) variations continued; 2016MNRAS.458.1964T, incorporating precision *MOST* photometry, reports for Aa one radial and two non-radial pulsation modes, with one of the non-radial modes tidally induced) ¶ in an early application of intensity interferometry, 1971MNRAS.151..161H argues with the example of α Vir Aa,Ab that given supporting spectroscopy and photometry, orbit and distance of a double-lined SB can be deduced (the SB distance notably without recourse to trigonometric parallax,	**Spica**

													since distance can be deduced by comparing the angular and the physical dimensions of the ascertained orbit) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of α Vir Aa angular diameter (0.87 mas ± 5%, with limb-darkening correction), at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia; the measurement was published by the Hanbury Brown team about 3 years after this same team published the above-cited orbit study 1971MNRAS.151..161H ¶ the tidal-interactions studies 2016A&A...590A..54H and 2013A&A...556A..49P stress the importance of the α Vir Aa,Ab double-lined SB for critically testing the (astrophysically foundational) assumption that the individual components x, y of a binary, of determined masses, rotation periods, and chemical compositions, resemble in their photospheres, and even in their interiors, solitary stars x′, y′ possessing the same masses, rotation periods, and chemical compositions (could tidal effects, e.g. change internal temperature structure?); additionally, the tidal effects in the α Vir Aa,Ab SB are judged in 2009ApJ...704..813H to be responsible for large-scale shearing horizontal photospheric motions, spectroscopically observable as modifiers of line profiles (but 2016MNRAS.458.1964T questions the judgement) ¶ assignment of individual MK types to Aa, Ab is challenging: the rather-unevolved-B MK types (1971MNRAS.151..161H B1.5 IV-V + B3V, 2007AAS...211.6301A B0.5 III-IV + B2.5-B3V) are in any case consistent with rather high masses (10.9 $M_{\odot}$ + 6.8 $M_{\odot}$, 10.25 $M_{\odot}$ + 6.97 $M_{\odot}$, for these two respective papers) ¶ as is to be expected from the failure of Aa,Ab to be tidally locked, the system is young (with 2016MNRAS.458.1964T assigning as age 12.5 ± 1 My) ¶ the Aa,Ab binary is a polarimetric variable (ISM material entrained?), and a strong X-ray source (colliding winds?) ¶ α Vir Ab is one of the few stars known to exhibit Struve-Sahade variation (en.wikipedia.org/wiki/Struve%E2%80%93Sahade_effect) in its spectral line strengths ¶ 1972JBAA...82..431K describes the 18.6-year 1940-through-2050 cycle of lunar occultation possibilities ¶ E(B-V)=+0.03	
ζ	Vir A	13 36.1	−0 44	3.37†	0.11	A2 IV†	44	1.6	74	0.285	280	−13	a good marker of celestial equator (precession placed ζ Vir exactly onto equator in Feb. 1883) ¶ rapid rotator (< 0.5 d; this renders puzzling the possible evidence for chemical anomalies, which would presuppose a quiet atmosphere) ¶ slight variability, of δ Sct type, range 0.009 in V (*TESS* mission; AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; one single AAVSO observation found; variability classification symbol = "**DSCT**"; Jan Ovidiu Tercu, Gabriel Cristian Neagu cited as discoverers; period = 2.3307 h) ¶ the JMDC 2021 Sep. 13-or-14 edition reports	Heze

												only one interferometric measurement of angular diameter (0.852 mas ± 1%, with limb-darkening correction, in the near-infrared K band, from the CLASSIC beam-combining facility at CHARA) ¶ Astron. Alm. (epoch 2021.5) assigns MK type A2 IV– ¶ elusive red-dwarf companion ζ Vir B is mag. 10.0, with MK classification suggested as M4 V – M7 V; WDS as of 2025 March 12 documents just 9 ζ Vir AB measurements, 1.8″→1.8″, PA 145°→154°, 2004→2010; the discovery paper is 2010ApJ...712..421H, establishing inter alia shared proper motion, and proceeding from stellar coronagraphy on adaptive-optics platforms, both at Palomar and at Hawai'i-Haleakala (rather than, as is more usual with a difficult binary, from interferometry (with ζ Vir B directly imaged in Figs. 1 and 4)); 2010ApJ...712..421H, while remarking that orbital coverage is as yet too brief for an orbital solution to be attempted, nevertheless (assuming 2.04 MΘ for ζ Vir A, 0.168 MΘ for ζ Vir B) computes approximate lower bounds for semimajor axis, for *e*, and for period as, respectively, 24.9 au, 0.16, and 124 y; 2010ApJ...712..421H is a contribution to the important, and until recently unstudied, topic of low-mass companions for A stars (another contribution to this topic is, however, the circa-2010 discovery of an elusive M-type companion for the A5 Vn star that is Alcor); the topic in its turn is a building block in the overall theory of star and exoplanet genesis (could massive (e.g. A-type) stars acquire low-mass companion stars via condensation not directly from the parent molecular cloud, but rather from condensation in an unstable circumstellar disk?), the 2010ApJ...712..421H detection of red-dwarf ζ Vir B additionally affords an explanation for the puzzling ζ Vir X-ray emission observed by ROSAT (as a star of a spectral type lacking strong winds and lacking convection up to the photosphere, ζ Vir A would not itself be expected to emit X-rays: similar puzzles of X-ray emission from the putatively X-ray-dark A stars arise elsewhere also, and perhaps are similarly to be solved in terms of X-ray emission from (elusive) red-dwarf companions)
ε	Cen Aa	13 41.6−53 36	2.30†	−0.23	B1 III†	8	−3.3	400	0.019	233	+3	slight variability: β Cep type, 2.29−2.31 in V passband, 4.1 h multiperiodic (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability (although no AAVSO observations found); variability classification symbol = "**BCEP**"; salient period = 4.0706 h) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (0.48 mas ± 6%, with limb-darkening correction, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia ¶ rapid rotator (< 2.7 d) ¶ metals underabundant ¶ although we here assign MK luminosity class "III," Kaler at stars.astro.illinois.edu/sow/epscen.html discusses uncertainty ¶ we state mag. for combined light; WDS as of 2025 March 12 documents just one single measurement, from interferometry, for the elusive ε Cen Ab (mag 4.90, 0.2″ from Aa)
η	UMa	13 48.6+49 11	1.86†	−0.19†	B3 V†	31	−0.7	104	0.122	263	−11 SB?	slight var.: "slowly puls B", range 0.01 in V, 2.7 d **Alkaid** resembles α UMa, at the other extreme of the Big Dipper, in not belonging to UMa Moving Group; 1921LicOB..10..110T asserts membership in what was at that time called the "Pleiades Group" ¶ rapid rotator (< 21 h), with some line variability

												(circumstellar ejecta disk?) ¶ slight variability, 0.01 mag. in V (*TESS* mission), of the slowly pulsating B-star type, also known as the “53 Per type” (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 32 AAVSO observations found; variability classification symbol = “**SPB**”; period = 2.6755 d) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.834 mas ± 7%, in the near-infrared H band, from the CLIMB beam-combining facility at CHARA; CHARA has achieved imaging ¶ X-ray source ¶ colour and temperature are anomalous for the MK type ¶ unusually young in our Sample S (< 15 My) ¶ E(B–V)=+0.02
ν	Cen	13 51.1−41 49	3.41†	−0.23	B2 IV†	~7.5	−2.2	440	0.034	233	+9 SB†	slight var.: SB reflection effect, 3.40–3.42 in V, 2.62 d Heng SB period is 2.622 d; slight variable, not eclipsing, but varying photometrically through a so-called “reflection” (irradiation, re-radiation) effect (AAVSO(VSX) assessment as of 2024 April 11
:												status flag = confirmed variability; 2 AAVSO observations found; variability classification symbol = “**R**”; range in V passband = 3.40−3.42 in V; C. Waelkens, F. Rufener cited as discoverers; period = 2.6252541 d); additionally, the primary has been said, but not by AAVSO(VSX), to be a pulsator in the β Cep class ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ MK luminosity class “IV” notwithstanding, primary is still a stable fuser of core hydrogen ¶ possible weak instance of “Be phenomenon” (with the outbursts possibly temporary)
μ	Cen Aa	13 51.2−42 36	3.34v†	−0.17†	B2 IV–V pne†	~6.4	−2.5	510	0.031	232	+9 SB	variability: γ Cas type, 2.92–3.47 in V passband (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; 335 AAVSO observations found; variability classification symbol = “**GCAS**”); rapid rotator, and (consistently with the γ Cas behaviour) an instance of the “Be phenomenon”; additionally said to be a multiperiodic non-radial pulsator; BSC5: “line profiles of MgII 4481 change in period 0.505 d, about five times the period of weaker absorption”; variable Hα; “variable line profiles”; short-term photometric and polarimetric variability has also been reported (cf p. 46 of 2013A&ARv..21…69R, which notes a rapid rise, over just a few days, in photometric brightness or line-emission intensity, with a subsequent slower decline) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ WDS, as of 2025 March 12, documents just one single measurement for μ Cen Aa,Ab, via 2010 Sydney interferometry (as Aa mag. 3.50, Ab mag. 6.70, with angular separation 0.1″) ¶ mv, B−V values are for μ Cen Aa,Ab combined light ¶ Astron. Alm. (epoch 2021.5) assigns MK type “B2 IV–Vpne (shell)”
η	Boo A	13 55.9+18 16	2.68†	0.58	G0 IV†	88	2.4	37	0.361	190	0 SB	poss. var.: type unknown (0.1 in V passband?) Muphrid further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 11: status flag = suspected variable; seems no AAVSO observations found; no conjectured variability classification symbol assigned) ¶ unusually metal-rich ¶ an X-ray source (hot corona)

												¶ 2007ApJ…657.1058V discusses recent work (PTI interferometry, with one of the various available studies of angular diameter; *MOST* asteroseismology) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.134 mas ± 0.6%, in the 550 nm−850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ η Boo B is mag. 9.99; discrepant proper motions for the AB pair (126″→114″, PA 119°→85°, 1822→2023) establish that their pairing is a mere line-of-sight coincidence	
ζ	Cen	13 57.2−47 25	2.54†	−0.23	B2.5 IV†	8.5	−2.8	380	0.073	232	+7 SB2	slight var., 2.52−2.55 in V, 2.29 d further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 11: status flag = confirmed variability; no AAVSO observations found; variability classification symbol = simply “**VAR**”; period = 2.2903 d) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ primary is a rapid rotator (<1.5 d) (BSC5: “expanding circumstellar disk,” and yet not (as viewed 2022 March 3) catalogued as an instance of the “Be phenomenon” in Paris-Meudon BeSS database) ¶ MK luminosity class “IV” notwithstanding, primary is possibly only halfway through its core hydrogen fusing ¶ SB period 8.02 d; SB as yet unresolved, even by interferometry (so WDS not yet able to write “Cen A,” “Cen B”) ¶ E(B–V) =–0.02 ¶ the IAU-official “Leepwal” is originally a (Marshallese) name for ζ Cen in an indigenous tradition of the Marshall Islands; we at the Handbook suspect that IAU intends the name to apply only to the primary of this (unresolved) system, in contrast with its practice for the unresolved binary α Tuc (IAU-named Lang-Exster)	Leepwal
β	Cen Aa,Ab	14 05.7−60 30	0.61†	−0.24†	B1 III + B1 III	9.0†	−4.8	360†	0.041	235	+6 SB2†	B:3.95, A1mA7 IV–V, 0.2″ (2022) (more fully: 1.1″→0.2″, PA 257°→142°, 1935→2022); AB orbit is already constrained by the existing observations, with period 125−220 y, and 2016A&A...588A..55P indicates that it should be possible to compute the orbit by ~2025 or ~2030 or so); the β Cen A system (reported in 1999MNRAS.302..245R as resolved at AAT through spectrally dispersed aperture- masking interferometry) is β Cen Aa, β Cen Ab, comprising a pair of fast rotators of nearly equal mass, and with oddly disparate (high) rotation speeds (the slower rotator is known to be magnetic, so magnetic braking is possible) and with orbit so eccentric (how can the molecular- cloud ISM condensation have allowed this to happen?) as to make the periastron tight (at < 10 R*; so could there be tidal interaction between Aa, Ab at periastron, perturbing the variability that we discuss below?); Aa,Ab is additionally reported in 1999MNRAS.302..245R, on the strength of ESO spectra, to be not just SB, but SB2; since the masses are nearly equal, it becomes a delicate question which to take as the primary, i.e. to which to apply the label “Aa” and with it the IAU-official name “Hadar”; this question is answered by WDS in its usual terms, with “Aa” deemed to be the (very slightly) more luminous, more massive star (Aa mag. 1.29, Ab mag. 1.44), and yet the contrary decision has also been taken in the literature, since it is the less massive star that has the clearer, because the less severely (rotationally) broadened, spectrum; the observational challenges notwithstanding, the observational record for Aa,Ab is favourable, with WDS now	**Hadar**

documenting 56 measurements for 1995→2023
(not only aperture-masking interferometry, but
also speckle interferometry has been done);
the Aa,Ab orbit is 357 d, with e=0.8;
2002A&A...384..209A finds both β Cen Aa
and β Cen Ab to be β Cet variables
(AAVSO(VSX) assessment as of 2024 April 13:
status flag = confirmed variability
(although no AAVSO observtions found),
variability classification symbol = “**BCEP**”;
period (i.e. primary period) = 0.157 d = 3.8 h);
the Aa,Ab system is of astrophysical significance, as one
of the rare cases of β Cep variability amenable
to good-precision mass studies (and indeed
2016A&A...588A..55P, reporting precision two-filter
photometry with the BRITE constellation, discusses
prospects for future asteroseismology, noting also
that in addition to β Cep (“pressure-wave”)
pulsation, there is SPB-type (“gravity-wave,”
i.e. buoyancy-driven) pulsation (the question which
of Aa,Ab is presenting which of the 17 detected
pulsation modes is, however, difficult, and the
magnetic field of Ab is a further complication (with
the overall topic of asteroseismology for magnetic
β Cep variables only sparsely explored, at any
rate as of ~2016))
¶ the JMDC 2021 Sep. 13-or-14 edition does not report
any direct measurement of angular diameter
(whether through interferometry
or by any other direct means),
either for β Cen Aa or for β Cen Ab
¶ mv, B−V values are for β Cen Aa,Ab,B combined light
¶ we take π and D not from *HIPPARCOS* but from
2016A&A...588A..55P
¶ E(B–V) =+0.02
¶ the traditional (Latin-derived?) name “Agena”
is not IAU-official

π	Hya	14 07.9−26 48	3.27	1.12	K2 IIIb†	~32.3†	0.8	~101†	0.148†	163	+27† V

negative cyanide ion lines are anomalously weak
relative to metal lines, consistent with this star’s
anomalously high velocity relative to Sun (suggesting
interloper in our own galactic region; however,
π Hya is more metal-rich than the celebrated interloper
α Boo (Arcturus))
¶ Astron. Alm. (epoch 2021.5) assigns MK type
K2– III Fe–0.5
¶ in evolutionary terms, in “Red Clump” of core-He fusers
(but uncertain whether recent arrival
in clump or longtime denizen)
¶ AAVSO(VSX) situation as of 2024 April 13:
no status flag
(so not confirmed variable, not suspected variable,
not confirmed non-variable), and a fortiori
no variability classification symbol
¶ the JMDC 2021 Sep. 13-or-14 edition does not report
any direct measurement of angular diameter
(whether through interferometry
or by any other direct means)

θ	Cen A	14 08.3−36 30	2.06	1.01	K0 IIIb†	55	0.8	59	0.734†	225	+1†

Menkent

high velocity with respect to Sun suggests interloper status
(and yet metallicity is approximately solar)
¶ Astron. Alm. (epoch 2021.5) assigns MK type
K0– IIIb
¶ AAVSO(VSX) situation as of 2024 April 13:
no status flag
(so not confirmed variable, not suspected variable,
not confirmed non-variable), and a fortiori
no variability classification symbol
¶ the JMDC 2021 Sep. 13-or-14 edition reports
only one interferometric measurement
of angular diameter (5.305 mas ± 0.4%, without
limb-darkening correction, in the near-infrared K
band; however, the two facts that *(a)* the cited
underlying primary-literature source discusses
α Cen A and α Cen B, rather than θ Cen A,
and that *(b)* the presented measurement is very
large, suggests to us at the *Handbook* that
JMDC has made a clerical error

α	Boo A	14 16.9+19 03	−0.05†	1.23	K1.5 III Fe–0.5†	89	−0.3	37	2.279†	209	−5† V	high space velocity; slight var. (range 0.05 V) **Arcturus** a metal-poor interloper (from galactic thick disk? but galaxy-merger scenario has also been suggested), and member of Arcturus Moving Group (2009IAUS..254..139W) ¶ a magnetic cycle (< 14 y?) has been detected ¶ still ascending RGB, with He flash impending? (but a later evolutionary stage has also been suggested) ¶ publication of α Boo A line atlas 1968pmas.book…..G (R. Griffin) was a major event in postwar spectroscopy ¶ α Boo A has been studied in recent asteroseismology ¶ slight variability, of a slow-and-irregular type, range −0.07 to −0.02 in V (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability; 18 AAVSO observations found; variability classification symbol = “**LB**”) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 21.373 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ a single 1991 observation of a putative companion has constrained WDS to write “α Boo A,” “α Boo B”; however, 1990s assertion of multiplicity was retracted in 1998; independently of this pair of developments, there have been suggestions of a sub-stellar-mass companion at the margin of *HIPPARCOS* detectability
ι	Lup	14 21.1−46 11	3.54	−0.18	B2.5 IVn†	~9.6	−1.5	340	0.013	249	+22	slight var.: (β Cep type?) 3.54−3.55 in V passband further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability; seems no AAVSO observations found; conjectural variability classification symbol = “BCEP:”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ rapid rotator (possibly ~0.9 d), and yet no evidence of circumstellar disk, and in particular no Be-phenomenon spectral features ¶ the MK luminosity class “IV” notwithstanding, still performing stable core-hydrogen fusion **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**
γ	Boo Aa†	14 33.1+38 12	3.04†	0.19†	A7 IV+	37.6	0.9	87	0.190	323	−37 V	slight var.: (δ Sct type; 0.003 from *TESS*) Seginus (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability; 82 AAVSO observations found; variability classification symbol = “**DSCT**” (upgraded from “**DSCT:**” in 2022); V-passband range now considered to be just 0.003 (in 2022, AAVS(VSX) had offered range 3.02−3.07); period = 105.96 min (in 2022, AAVSO(VSX) had offered 6.97 h)) ¶ mv, B−V values are for γ Boo Aa,Ab combined light ¶ IR excess (from circumstellar debris, so far unexplained) ¶ Aa,Ab resolved in speckle interferometry, angular separation 70 mas ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter for γ Boo Aa (whether through interferometry or by any other direct means)
η	Cen	14 37.2−42 16	2.36v†	−0.22	B1.5 IV pne†	11	−2.5	310	0.048	227	0 SB	var.: γ Cas & λ Eri types (shell spectrum?), 2.29−2.47 in V multiperiod (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability; 46 AAVSO observations found; variability classification symbol = “**GCAS+LERI**”; salient period = 15.419 h); BSC5 says Hα variable, Hβ “sometimes bright, sometimes dark and double or multiple”; consistently with γ Cas variability, a rapid rotator (< 1 d) and an instance of “Be phenomenon”; again consistently with γ Cas variability, Astron. Alm. (epoch 2021.5)

												assigns MK type “B1.5 IVpne (shell)” ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
α	Cen A+1P?†	14 41.4−60 57	0.00†	0.65†	G2 V†	750	4.4	4.3	~3.710	~277	−22 SB	Ca (Proxima), 12.4, M5e, 2.2° SW of A still the closest known object in the population of stars and brown dwarfs, despite intense surveying of entire population over the past 20 or 30 years ¶ gravitational binding of AB+C was finally established with high probability in 2017A&A…598L…7K, and an orbit is considered to be known (~550,000 y: min > 4300 au, max 13,000 au) ¶ Ca is elusive, as one faint object in a sea of faint objects (detection was not achieved until the 1915 work of Innes, with blink comparator); nevertheless, violent flaring has been known to take Ca, briefly, up to the threshold of naked-eye visibility (2018ApJ...860L..30H reports peak V mag. 6.8 for a superflare of 2016 March 18, of duration ~1 h; the situation in UV and millimetre waves is also extreme, as reported in 2021ApJ...911L..25M) ¶ direct imaging in mid-IR suggests, without at present firmly establishing, that α Cen A hosts an object within its habitable zone, either exoplanet or material not yet aggregated into exoplanet ¶ 2016Natur.536..437A announces an approx. Earth-mass exoplanet, α Cen Cb, in the habitable zone of its host α Cen Ca; 2018ApJ...860L..30H analyzes the germicidal implications of flaring, finding that in a habitable-zone Earth-like exoplanet atmosphere the ozone UV shield would be destroyed; this paper, however, like some others, leaves open the possibility of life on Cb; breakthroughinitiatives.org/initiative/3 advocates nanocraft exploration, and en.wikipedia.org/wiki/2069_Alpha_Centauri_mission has footnote links to reports of small-scale discussions at NASA and in the USA Congress, envisaging the launch of some (nanocraft?) mission to celebrate the Apollo 11 centenary ¶ in 2020, a more distant exoplanet, either a super-Earth or a mini-Neptune, was suggested, as α Cen Ac (orbit 1930 d, whereas Ab has orbit 11 d; an unexpectedly bright detection with the VLT SPHERE instrument has been interpreted as the possible signature of rings around the putative Ac); an exoplanet Cd was announced in 2022 February ¶ GCPD gives not only m_v, B−V values directly measured for α Cen A, but additionally m_v, B−V values directly measured for α Cen AB combined light: −0.29, 0.72 ¶ further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 13: status flag = suspected variable; seems no AAVSO observations found; conjectural variability classification symbol = “**BY:**”; possible range stated as −0.3 to + 0.1 in V passband (but should this be −0.3 to −0.1 in V passband?)) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 8.502 mas ± 0.4%, in the near-infrared H band, from the PIONIER beam-combining facility at VLTI ¶ although the correct (IAU-official) star name is “Rigil Kentaurus”, the shortened form “Rigil Kent” is sometimes used	**Rigil Kentaurus**
α	Cen B†	14 41.4−60 57	1.36†	0.87†	K1 V†	750	5.7	4.3	~3.703	~283	−21 V?	AB 8.1″ (2023) orbit 79.9y min = 2″ (1955); max = 22″; PA in 2017 was 325°, in 2023 was 5°; A-to-B distance is 11.2 au min, 35.6 au max; Kaler at stars.astro.illinois.edu/sow/rigil-kent.html has map of apparent AB orbit (note further here that Kaler’s green, violet, and blue denote micrometry, photography, and interferometry, respectively: as Kaler’s error bars suggest, the α Cen AB	Toliman

												orbit is one of the most precisely known wide binary-system orbits in visual-binary astrometry); since plane of orbit is inclined at 79° to plane of sky, the apparent orbit is more severely elliptical than the true orbit (for which *e*=0.5); Kaler's map can accordingly be usefully supplemented with the apparent-versus-true-orbit diagram in en.wikipedia.org-wiki/Alpha_Centauri ¶ whereas magnetic activity of α Cen A is in steep decline since 2005 (analogue of Maunder Minimum? or, rather, mere regular cycle?), α Cen B shows more magnetic activity than α Cen A does, and its cycle is brief (8.2 y in spot numbers, 16.4 y in magnetics; this is not unlike the Sun, for which the corresponding pair of periods is ~11y, ~22 y); and 2005A&A...442…315R reports a flare on α Cen B ¶ GCPD gives not only mv, B−V values directly measured for α Cen B, but additionally mv, B−V values directly measured for α Cen AB combined light: −0.29, 0.72 ¶ AAVSO(VSX) situation as of 2024 April 11: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 5.999 mas ± 0.4%, in the near-infrared H band, from the PIONIER beam-combining facility at VLTI ¶ although 2012 α Cen B exoplanet claim is now discounted, an exoplanet is possible (2019 transit has been suggested; cf also 2015MNRAS.450.2043D) ¶ Einstein-ring event expected with 45% probability in 2028, early in May	
α	Lup A	14 43.7−47 30	2.30†	−0.21	B1.5 III	7	−3.5	460	0.032	221	+5 SB	slight var.: 2.29–2.34 in V passband, 6.24 h β Cep type multiperiodic (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability (although no AAVSO observations found); variability classification symbol = "**BCEP**"; salient period (unusually long for this type) = 6.23632 h) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	Uridim
α	Cir A†	14 44.7−65 05	3.18†	0.24†	A7 Vp (Sr)	60.4	2.1	54.1	0.303	220	+7 SB?	B: 8.5, K5 V, 15.7″, PA 263°→224°, 1826→2016 AB probably true binary, with orbit ≥ 2600 y ¶ Astron. Alm. (epoch 2021.5) assigns MK temperature type A7p Sr Eu and does not assign an MK luminosity class ¶ m_v, B−V values are for α Cir AB combined light ¶ slight variability of α CVn A ("α^2 CVn") type, and additionally the brightest (slight) variable of the "rapidly oscillating Ap" type (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability (although no AAVSO observations found); variability classification symbol = "**roAp+ACV**"; range in V passband = 3.17−3.19; period = 6.826 min); magnetically an oblique rotator, with field strength ~500× solar; 2009MNRAS.396.1189B discusses the rotation, two notably stable putative equatorial chemical-anomaly regions, and asteroseismology, with history and fresh *WIRE*+SAAO observations ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ the IAU-official name "Xami" is from a dialect of the South African Khoe language, ultimately deriving from an indigenous tradition on which Xami is a creature whose eyes are α Cen and β Cen (and whose face	Xami

												consequently incorporates α Cir)	
ε	Boo A+1P?	14 46.1+26 58	2.38†	0.97†	K0 II–III†	16†	−1.6	200†	0.044	288	−17 V	B:4.8, 2.7″, PA 318°→347°, 1822→2023 orbit well over 1000 y ¶ ε Boo B is of MK type A0 V, and is SB, with at least one component a rapid rotator ¶ m_V, B−V values are for ε Boo AB combined light; stars.astro.illinois.edu/sow/izar.html discusses difficulties in determination of the individual magnitudes and of the binary system's distance ¶ AAVSO(VSX) situation as of 2024 April 13: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means), either for ε Boo A or for ε Boo B ¶ F.G.W. von Struve, commenting in his Latin-language visual-binaries catalogue on the aesthetics of Boo AB: "pulcherrima" ("the loveliest")	Izar
β	UMi A+1P†	14 50.7+74 03	2.08†	1.47†	K4 III†	24.9	−0.9	131	0.035	289	+17 V	useful for aligning small equatorial mount (since NCP, although not quite coincident with α UMi, does lie near the great-circle arc linking β UMi with α UMi: conduct Google search under the term "arksky.org 730-clays-kochab-clock" ("arksky" for "Arkansas Sky"; not "darksky")) ¶ mv, B−V values are measured for β UMi A, rather than for β UMi AB combined light (however, greatly separated (~212″) β UMi B would, because shining faintly at a mere mag. ~13, make only a minuscule contribution to the β UMi AB combined light) ¶ further photometric study advisable? (AAVSO(VSX assessment as of 2024 April 13: status flag = suspected variable; no AAVSO observations found; possible V passband range 2.02−2.08) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 10.301 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ Fe underabundant, Ba possibly slightly overabundant ¶ 2008A&A...483L..43T suggests (via *CORIOLIS*-SMEI) two short-lived radial-pulsation mods ¶ 2014A&A...566A..67L announces exoplanet	**Kochab**
α	Lib Aa†	14 52.4−16 09	2.75†	0.15	A3 III–IV†	43	0.9	76	0.126	237	−10 SB†	B. 5.2, 231″ (2016) angular distance from α Lib B, which shares the proper motion of α Lib A, entails Aa,Ab–B distance ≥ 5500 au; if B and the A system are gravitationally bound, then their period is ≥ 200,000 y; alternative names for the α Lib Aa,Ab pairing and the single star α Lib B are α² Lib and α¹ Lib, respectively, with "1" signalling the fact that α¹ Lib, lying to W of α² Lib, although fainter than "2," is the earlier of the two in its crossing of the local meridian ¶ α Lib Aa, Ab are resp. mags. 3.30, 3.70; for this tight pairing (an SB as well as a resolved system, with Ab detected in speckle interferometry), WDS, as of 2025 March 12 documents just 5 measurements (4 from 2017, 1 from 2023), for angular separations perhaps < 0.1″ (distance between α Lib Aa and α Lib Ab may be a few tenths of 1 au); one of α Lib Aa,Ab is overabundant in some metals, perhaps due to the influence of its SB companion; α Lib B is likewise now resolved as α Lib Ba, α Lib Bb, at resp. mags. 4.8 and 9.4, with WDS as of 2025 March 12 noting 6 astrometry measurements (angular separation 0.4″ in 1999, 0.2″ in 2023); celestial-sphere neighbours α Lib C and α Lib E are faint; gravitationally bound neighbour D (at very small angular separation) is mag. 7.31 (only 4 astrometry measurements, 1991→2010)	**Zubenelgenubi**

												¶ lunar occultations are possible, planetary occultations possible yet rare ¶ AAVSO(VSX) situation as of 2024 April 13: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ; in 2022, AAVSO(VSX) had applied the suspected- variability status flag, without offering a conjectural variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
β	Lup	15 00.3−43 14	2.67†	−0.23	B2 IV†	9	−2.7	380	0.054	222	0 SB	β Cep-type variability is asserted, but is not well attested this star has been claimed to be slight (β Cep) var, salient period 0.232 d; however, AAVSO(VSX as of 2024 April 13 has no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori assigns no variability type symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ fast rotator (< 3.4 d) ¶ low metallicity	
κ	Cen Aa†	15 00.9−42 13	3.13†	−0.21†	B2 V	9	−2.2	400	0.029	218	+8 SB	strictly a triple system, Aa+Ab+B; B mag. 11.5; AB 4″, PA 84°→83°, 1926→2000, separation ≥ 470 au; ≥ 3000 y; Aa-to-Ab distance possibly ~10 au, period possibly ~10 y (stars.astro.illinois.edu/sow/kappacen.html discusses various physical uncertainties), with mags. resp. 3.34, 4.71, and with angular separation 0.1″→0.1″, 1991→2023; Aa,Ab orbit has been studied in speckle interferometry ¶ mv, B−V values are for κ Cen Aa,Ab,B combined light ¶ line profiles vary, making the Aa+Ab binary variability classification difficult (AAVSO(VSX) status as of 2024 April 13: status flag = confirmed variability (although seems no AAVSO observations found); variability classification symbol = “**BCEP**”; period = 2.2878 h) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of κ Cen Aa angular diameter (whether through interferometry or by any other direct means)	
β	Boo	15 03.0+40 17	3.50†	0.96	G8 IIIa†	14.5	−0.7	230	0.049	234	−20 V?	slight var.: unknown type, 3.47−3.50 in V band Ba 0.4, Fe −0.5 1995A&A...296..509H discusses the puzzling flare seen by *ROSAT* 1993 Aug. 08 (unusual for a lone M giant; it is possible, but seems unlikely, that flare came instead from an undetected M-dwarf companion; the mild Ba enhancement is, admittedly, consistent with presence of such a companion); slow rotator (~200 d) ¶ further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability; 53 AAVSO observations found; variability classification symbol = simply “VAR”) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.484 mas ± 0.3%, in the 550 nm–850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ	Nekkar
σ	Lib	15 05.6−25 23	3.30v†	1.68	M2.5 III	11	−1.5	290	0.083	239	−4	**[THIS STAR ONLY IN ONLINE VERSION OF TABLE]** semireg. var.: 3.2–3.46 in V, mean period 20 d there is also rapid microvariability (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability; variability classification symbol = “**SRB**”; salient period = 20 d) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (11.33 mas, with the very	Brachium

												small uncertainty ± 0.009%, with limb-darkening correction, at 2300 nm, from the AMBER beam-combining facility at VLTI) ¶ highly evolved (on AGB, with dead carbon-oxygen core)
ζ	Lup A[†]	15 14.2−52 12	3.40	0.92	G8 III	~27.8	0.6	117	0.133	238	−10	B: 6.74; 71.7″ (2020), PA 249°→249°, 1826→2020 A-to-B distance ≥ 2600 au; shared proper motion suggests true binarity (period possibly ≥ 68,000 y) ¶ ζ Lup A is in evolutionary terms on “Red Clump” (was Sun-like when still on MS, but helium flash now finished, core-helium fusion now underway) ¶ AAVSO(VSX) situation as of 2024 April 13: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)
δ	Boo A[†]	15 16.6+33 13	3.48[†]	0.95[†]	G8 III Fe–1[†]	~26.8	0.6	122	0.140	143	−12 SB	a very wide true binary: B is mag. 7.9, 105″ (2023) PA 84°→78°, 1780→2023, A-to-B distance ≥ 3800 au, period 120,000 y (with shared proper motion indicating true binarity); the SB that is δ Boo A is not as yet resolved, even in interferometry (so WDS cannot, at any rate as of 2025 March 13, write “δ Boo Aa,” “δ Boo Ab”) ¶ mv, B−V values are for δ Boo A, rather than for δ Boo AB combined light; for δ Boo B, GCPD gives mv, B−V values 7.84, 0.59 ¶ δ Boo A is CN weak; δ Boo B could be a subdwarf, consistently with the observed low metallicity of δ Boo A ¶ δ Boo A is in evolutionary terms a “Red Clump” star (core-helium fusion now underway) ¶ further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 13: status flag = suspected variable; 6 AAVSO observations found; variability classification symbol = “**CST:**” (i.e., conjectured to be constant, without certainty); range in V passband stated as “3.48−?”) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.764 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson
β	Lib	15 18.4 −9 29	2.61[†]	−0.11	B8 IIIn	~17.6	−1.2	190	0.100	259	−35 SB	slight var.: unkn. type, 2.60−2.62 in V Zubeneschamali further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability; 32 AAVSO observations found; variability classification symbol = simply “VAR”); the possibility of wide secular variations is suggested by the fact that Eratosthenes, resp. Ptolemy, asserted β Lib to be brighter than, resp. equal to, α Sco ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ rapid rotator ¶ E(B–V) =–0.02
γ	UMi	15 20.7+71 44	3.05[†]	0.06	A3 III[†]	6.7	−2.9	490	0.025	315	−4 V	slight var.: δ Sct type, range 0.05 in V, 3.43 h Pherkad a rapid rotator, and (despite being in MK type A, not B) said to be a variable shell star (cf [2000A&A...354..157H](2000A&A...354..157H); BSC5: “shell possibly variable,” H and CaII variable); however, AAVSO(VSX) gives the following assessment as of 2024 April 13: status flag = confirmed variability (although no AAVSO observations found); variability classification symbol = “**DSCTC**”; period = 3.4322 h ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)
γ	TrA	15 21.4−68 46	2.88[†]	0.01	A1 IIIn[†]	17.7	−0.9	184	0.074	244	−3 V	now confirmed as non-variable

												AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed non-variability (although seems no AAVSO observations found); no variability classification symbol assigned (but should the symbol "**CST**" be assigned?)) ¶ has been asserted to be chemically anomalous (Eu overabundance), and also, not quite consistently, has been classed as a rapid rotator (< 1.2 d) ¶ although we here give MK luminosity class III, class V has also been asserted; Astron. Alm. (epoch 2021.5) assigns MK type A1 III ¶ IR excess has been asserted (circumstellar disk?) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)
δ	Lup	15 23.1 −40 44	3.22†	−0.22	B1.5 IVn	4	−3.9	900	0.032	218	0 V?	slight var.: β Cep type, ~3.2–3.24 in V passband, 3.97 h rapid rotator (< 2.4 d) ¶ AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variable (although no AAVSO observations found); variability classification symbol = "BCEP"; period = 3.971 h (cf further 2007MNRAS.377..645S) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)
ε	Lup Aa†	15 24.5 −44 47	3.37†	−0.18†	B2 IV–V	6	−2.6	500	~0.030	~230	+8 SB2	A: 3.6; B: 5.0, 0.2″, PA 285°→6°, 1883→2023 orbit 737 y: in more detail, a (probable) hierarchical quadruple; although B experiences A as essentially a point mass, in fact A is SB, interferometrically resolved as ε Lup Aa, ε Lup Ab with a single 2010 measurement (mags. 3.60, 5.10, angular separation 0.1″), for which 2005A&A...440..249U gives SB period 4.55970 d (classifying the primary as a suspect β Cep variable and the secondary as a new β Cep variable); experiencing AB, on the other hand, as essentially a point mass is the (probably) gravitationally bound C (mag. 9.10; 19″→26″, PA 174°→168°, 1826→2020; AB-to-C distance ≥ 4100 au; if gravitationally bound, then period ≥ 60,000 y); in its stable kinematics, this putative hierarchical quadruple may be contrasted with the unstable, nonhierarchical θ Ori system, and in its detailed organization with the stable, hierarchical, but mere "double-double" ε Lyr system; AAVSO(VSX) indicates just slight variability for the ε Lup system, 3.36−3.38 in V, period seemingly same as the SB period (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability (although seems no AAVSO observations found); variability classification symbol = "**HB+SPB**"; period = 4.55964 d) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ m_v, B−V values are for ε Lup Aa,Ab,B combined light
ι	Dra A+2P†	15 25.5 +58 52	3.29†	1.17	K2 III†	32.2	0.8	101	0.019	334	−11	poss. slight var.: type unkn. (3.26−3.35 in V?) Edasich further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 13: status flag = suspected variable; seems no AAVSO observations found; no conjectural variability classification symbol assigned) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 3.559 mas ± 0.3%, in the 550 nm–850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ 2002ApJ...576..478F announces substellar-mass companion and discusses possibility of transits; this is the first discovery of a planet or

												brown dwarf (IAU name: Hypatia) orbiting a star that has finished stable core-hydrogen fusion; exoplanet.eu/catalog/HIP%2075458_b may from time to time have updates; its substellar companion notwithstanding, ι Dra has metallicity only slightly greater than solar ¶ since the ι Dra A substellar-mass companion is known through radial-velocity work, and has not yet been resolved (not even interferometrically), WDS is not, at any rate as of 2025 March 13 , able to write “ι Dra Aa,” “ι Dra Ab”; the widely separated celestial-sphere neighbour catalogued in WDS as ι Dra B (mag. 8.87, 255″→253″, PA 50°→49°, 1879→2023) is not gravitationally bound to the ι Dra A system	
α	CrB	15 35.8+26 38	2.23v†	−0.02	A0 IV (composite)†	43	0.4	75	0.150	127	+2 SB†	ecl.: 2.22–2.32 in V passband, 17 d this SB is a detached binary, of β Per type (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability; 1866 AAVSO observations found; variability classification symbol = “**EA/DM**”; period = 17.359892 d); distance between components 0.13 au min; as with β Per, so also with α CrB, instrumental photometry reveals both the primary and the secondary eclipse; components have not been interferometrically resolved (so WDS-conformant designation, at any rate as of 2025 March 13, is still “α CrB,” not “α CrB A” and “α CrB B”) ¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (1.202 mas ± 5%, with limb-darkening correction, in the 8000 nm–13000 nm passband, from the KIN beam-combining facility at the W.M. Keck Observatory ¶ individual MK types are difficult: primary possibly A0 V, secondary possibly G5 ¶ primary has IR excess (debris disk?) ¶ secondary is X-ray visible and is a rather rapid rotator (~9 d or ~7 d or less, so not tidally locked) ¶ likely a “stream” member of the UMa moving group (i.e. remnant of stellar association) whose most prominent “nucleus” members are β, γ, δ, ε, and ζ UMa ¶ non-IAU name Gemma denotes α CrB as “gem of the Northern Crown”	**Alphecca**
γ	Lup A†	15 36.9−41 15	2.78†	−0.21†	B2 IVn†	8	−2.8	400	~0.030	~212	+2 V	A: 3.4; B: 3.5; similar spectra 0.8″ (2023) PA 94°→275°, 1835→2023; maximum angular separation 1980, minimum angular separation 2075; orbit 190 y: γ Lup AB orbit is seen nearly edge-on; separation 41 au min, 128 au max, 84.5 au average; stars.astro.illinois.edu/sow/gammalup.html has an orbit map, showing that observational coverage is imperfect (green for micrometry (with large error bars), violet for photography, blue for interferometry); γ Lup A is itself SB (2.801 d, unresolved), making this a hierarchical triple system, with the primary in the γ Lup A pairing a fast rotator (< 1 d, so not tidally locked) ¶ BSC5 asserts expanding circumstellar shell, and (citing 1987 Vainu Bappu (India) spectra) notes emission peaks in Hα profiles, says possibly in transition from B to Be ¶ m_v, B−V values are for γ Lup AB combined light ¶ the γ Lup system harbours slight variability, range 2.77–2.79 in V, with AAVSO(VSX) giving a period perhaps equalling the period of the SB; light variations involve “reflection” (irradiation, causing re-radiation) (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability (although no AAVSO observations found); variability classification symbol = “**R**”;	

												period = 2.849769 d) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
α	Ser A	15 45.6 +6 21	2.64†	1.17	K2 IIIb CN1†	44	0.9	74	0.141	71	+3 V?	possible semireg. var. (range 0.2 in V?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 April 13: status flag = suspected variability; 60 AAVSO observations found; conjectural variability classification symbol = “SR:”) ¶ the JMDC (2021 Sep. 13-or-14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 4.77 mas ± 0.3%, in the 550 nm–850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ a “strong-lined giant” (although [Fe/H] metallicity is not very much above solar) ¶ a modest X-ray source ¶ has borne also the (not IAU-official) name Cor Serpentis (“Heart of the Serpent”), despite being the principal luminary of Serpens Caput (“Serpent Head”)	Unukalhai
μ	Ser A	15 51.0 −3 31	3.54	−0.04	A0 III	19	0.0	170	0.104	255	−9 SB†	binary resolved with speckle interferometry, and subsequently (2010NewA...15..324G) analyzed with astrometry: B is mag. 5.39, 0.2″→0.5″, 1991→2023; 2010NewA...15..324G offers an orbital solution, with period 36±2 y, *e*=0.4±0.3; these authors remark that the low precision of their orbit-based mass determinations leaves various possibilities open regarding the nature of μ Ser B (“A or F dwarf, subgiant, giant or even a pair of late-type dwarfs”) ¶ AAVSO situation as of 2024 April 13: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
β	TrA A	15 57.5−63 31	2.84†	0.30†	F0 IV†	~80.8	2.4	40.4	0.444	205	0	*Spitzer Space Telescope* finds IR excess (debris disk?) ¶ rapid rotator (slightly < 1 d), with detectable magnetic field ¶ metals vary widely (some overabundant, some underabundant) ¶ m_V, B−V values are for β TrA A (but these can differ only negligibly from the corresponding values for β TrA AB combined light, since β TrA B (widely separated, at ~172″), is faint, with GCPD giving m_V, B−V as 13.22, 0.83) ¶ AAVSO(VSX) situation as of 2024 April 13: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
π	Sco Aa	16 00.5−26 11	2.89†	−0.19†	B1 V†	6	−3.4	600	0.029	203	−3 SB2	Aa,Ab ecl.(?) SB; 1.57d; 2.88−2.91 in V passband (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability; 8 AAVSO observations found; variability classification symbol = “ELL”; period = 1.570103 d (a published orbital solution gives instead 1.5700925 d)); WDS asserts, and AAVSO(VSX) denies, that orbit is so close to edge-on as to be eclipsing; if not eclipsing, then the observed slight variability is the effect of ellipsoidally distorted stars presenting different surface areas to the photometer at different stages in their mutual orbit; orbit is circular or nearly circular (two published orbital solutions	Fang

												disagree slightly, asserting *e*=0, *e*=0.15), possibly with tidal locking, Aa-to-Ab distance possibly ~0.07 au; the binarity has been detected also via occultation; as of 2025 March 13, WDS documents just one Aa,Ab measurement (in the year 2000, with angular separation 2″); system has been said, but not at AAVSO(VSX), to be of β Lyr type; AAVSO observations archive, as viewed 2024 April 13, indicates a longstanding shortage of photometry (and Kaler at stars.astro.illinois.edu/sow/pisco.html additionally discusses some difficulties in astrophysical modelling); further photometric study advisable? ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ mv, B−V values are for π Sco Aa,Ab combined light ¶ E(B–V) =+0.08
T	CrB A	16 00.6+25 51	9.90v†	1.40†	M3 III†	—	0.6	2500?	0.011	329	−29 SB	recurrent nova 1866&1946 V=3&2;V =9.9 on 2024 Aug. 08 only ten galactic recurrent novae are currently known (2010ApJS..187..275S; these are by definition novae known to recur, and yet lacking the short periods of dwarf novae) ¶ T CrB A partner in the recurrent-nova activity, T CrB B, is WD with hot circumstellar accretion (dominating the aggregate T Cr AB signal in UV) of MK type Bep, orbit 227.5 d or 227.6 d, A-to-B distance ~0.5 au; according to WDS as viewed 2025 March 13, angular separation has been measured only 3 times (in 1946 (considered doubtful by WDS) and 2010 and 2013, as 0.3″ and 0.7″ and 0.5″ respectively) ¶ mv, B−V values are for T CrB AB combined light ¶ long documented in *Handbook* as mag. 10.08, T CrB AB (combined light) brightened from February 2015, attaining ~9.2 in April 2015 (while V mag. 9.555, 9.655, 10.157, 10.019, on the other hand, are reported in general AAVSO database (not AAVSO(VSX) database) for 2022 Feb. 15, 2022 Jul. 12, 2024 April 13, 2024 May 16); AAVSO(VSX), while noting the recurrent nova status, additionally notes light variations due to ellipsoid-photosphere geometry, at period of the SB (AAVSO(VSX) assessment as of 2024 April 13: status flag = confirmed variability; 190533 AAVSO observations found; variability classification symbol = "**NR+ELL**"; period = 227.55 d); Bob King in *Sky&Telescope* 2016 Apr. 20 gives recent history, and AAVSO has a backgrounder at www.aavso.org/t-crb; next eruption 2026, or earlier? ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)
η	Lup A†	16 01.9−38 28	3.41†	−0.23†	B2.5 IVn†	7	−2.2	440	0.033	211	+8 V	B: 7.5, 14.8″, PA 22°→19°, 1834→2020 orbit ≥ 26,000 y: a hierarchical system, with faint (mag. 10.8) remote outlier D at angular separation 135.5″ in 2016 (AB-to-D distance ≥ 18,000 au, period ≥ 750,000 y), with D experiencing the AB pair as essentially a point mass; η Lup C is not part of this (triple) system, C's angular proximity to AB being a mere line-of-sight coincidence (mag. 9.4; 115″→115″, PA 248°→248°, 1890→2015) ¶ m_v, B−V values are for η Lup AB combined light; GCPD additionally gives, for η Lup B, 7.87, 0.16 ¶ although η Lup A is a rapid rotator (< 1.1 d), there is no evidence of a circumstellar disk, and in particular

											there seems to be no documentation of “Be phenomenon” spectral behaviour ¶ further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 08: status flag = suspected variable; no AAVSO observations found; variability classification symbol = “**CST:**”; V-passband range stated as “3.41–?”) ¶ the JMDC 2021 Sep. 13-or-14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ η Lup B is chemically peculiar	
δ	Sco A[†]	16 01.9−22 42	2.32v[†]−0.12	B0.5 Ve[†]	7	−3.6	440	~0.037	~196	−7	pro-am photm., spectr. data still desirable in 2025 (periastron was 2022 May): the δ Sco AB interferometrically resolvable SB has been measured since 1973 (0.2″ in 1973, 0.1″ in 2021), although binarity was reported from lunar occultation as early as 1901; period is 10.8 y; previous recent periastra were in 1990, 2000, and 2011; orbit is discussed in. e.g. 2012ApJ...757...29C (slightly refining the orbital solution of 2011ApJ...729L...5T); orbit is remarkable for its extreme elongation (*e* = 0.94; for most Be binaries with a non-degenerate secondary component, *e* ≈ 0); the suggestion that δ Sco A is itself a tight binary, with period ~20 d, is not now generally favoured (2013ApJ...766..119M argues against the suggestion); connected with the unexpectedly high-eccentricity AB orbit, however, might be some as-yet-undetected distant orbiter, with period ~200 y, perhaps participating in a Lidov-Kozai interaction (2013ApJ...766..119M, and additionally cf. en.wikipedia.org/wiki/Kozai_mechanism); AB angular separation can become as great as ~200 mas, but at periastron diminishes to 5.9 mas, with AB physical distance diminishing to within 0.8 au (a distance ~25x the radius of δ Sco A, so tidal interaction, perhaps even the generation of a tidal trail of ejecta, is to be expected at periastron); orbital plane is inclined only rather gently to the plane of the sky (2020ApJ...890...86S gives the angle as 38°), making this binary far from eclipsing ¶ important instance of “Be phenomenon” (in 2011A&A...535A..67L, Fig. 7 is an image of δ Sco AB, from the PIONIER beam-combining facility at VLTI; the “Be phenomenon” disk of δ Sco A is marginally resolved, with AB separated in this observation by ~14 mas), offering opportunity to examine a recent disk-building event: δ Sco system seemed unremarkable in much of the 20th century, and was even taken as a B0 IV MK standard; 1993A&A...274..870C, however, reported Be phenomenon, from spectroscopy at or near the 1990 periastron; at or near the periastron of 2000, Be-phenomenon behaviour in δ Sco A became for the first time strongly evident, with pronounced Hα emission in spectroscopy, and also with brightening in photometry; the system faded somewhat in 2005, both in V band and in IR, while Hα equivalent width (a signature of material toward the outer reaches of the Be-phenomenon disk around δ Sco A) increased; the system again brightened in V passband in 2010 (a signature of material being added to the inner reaches of the disk), and stayed bright, with minor V fluctuations, through the 2011 periastron (and for at least some of this period, notably for 2009 through 2012, cyclic photometric variability was observed on timescales of ~60 d to ~100 d (similar behaviour had been found also for 2000 through 2002; but the orbital periods of the inner and outer portions of the disk are on the order of 0.5 d and 1.5 d, and so are on a different timescale), consistently with a variable rate of mass transfer upward to the disk out of the δ Sco A photosphere); the speed of disk growth seems unusually high in the general population of Be stars, where an episode of growth can take decades, and yet rapid rotator δ Sco A does not appear to be rotating so rapidly as to diminish	Dschubba

effective photosphere gravity at equator down to ~0; on the modelling of 2020ApJ...890...86S, the Be-phenomenon Hα-emitting portion of the disk of equatorially ejected gas around δ Sco A was of radius 10 R* in 2000, 14 R* in 2002, 11 R* in 2007 (there was a temporary partial dissipation of the disk in 2005), 46 R* by 2018 (the temporary partial dissipation was followed on this modelling by a period of variability from 2005 to 2009, and by a disk-growth process from 2010 to 2011, with a rather steady state attained from 2011 to 2018 or beyond); 2020ApJ...890...86S remains agnostic on the question whether gravitational perturbations, especially at the outer reaches of the disk, have affected dissipation and growth (for instance, through tidal effects, including the tidal locking, at periastron, of a local density enhancement, such as a spot or a spiral wave? with disk possibly even overflowing δ Sco A Roche lobe at periastron, yielding mass transfer to δ Sco B (although mass transfer is rejected by a CHARA disk-imaging team, at 2012ApJ...757...29C)?)); it is to address this question that photometry and spectroscopy have been sought, especially around the 2022 May periastron, both from professionals and from amateurs (cf pro-am 2022-campaign request at www.aavso.org/delta-sco-campaign; AAVSO additionally has a circa-2011 background briefing, with emphasis on the photometry, at www.aavso.org/vsots_delsco; 2013ApJ...766..119M describes pro-am spectroscopy contributions at the 2011 periastron, involving on the amateur side nearly 20 observers from Australia, France, Germany, Portugal, Spain, and USA); AAVSO(VSX) assigns γ Cas-type, and yet not λ Eri-type, variability, with range 1.59−2.32 in V; AAVSO(VSX) assessment of δ Sco system as of 2024 May 08: status flag = confirmed variable; variability classification symbol = "**GCAS**"; as of 2024 May 08, no recent V-filter (as distinct from merely visual) photometry is available in the AAVSO-observers' database; the database does, on the other hand, have reports from one and the same (V-equipped) observer (coded as "VOL") over the period 2023 June 17 through 2023 July 16, finding several values from 1.66 to 1.68; further, the observer "VOL" found 1.73 on 2020 June 27, and 1.69 on 2020 June 23; the overall AAVSO V-passband light-curve from 2010 onward suggests overall stability, with at most minor fluctuations; δ Sco B (not known to be variable) is reported by WDS as of mag. 4.62; our apparent and absolute magnitudes do not reflect the post-2000 combined light of δ Sco AB
¶ the JMDC 2021 Sep. 13-or-14 edition reports only one interferometric measurement of angular diameter (0.46 mas ± 9%, with limb-darkening correction, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia
¶ we follow 2020ApJ...890...86S in assigning MK type B0.5 V, which we take to be appropriate for the combined binary-system light (but elsewhere in the literature, a slightly different MK type is assigned); 2020ApJ...890...86S suggests B2 V as an MK basis for modelling δ Sco B
¶ we follow 2020ApJ...890...86S in assigning, consistently with our policy for using rounding-off to reflect uncertainties, D = 440 ly, and on this basis asserting π to be, with reasonable rounding-off, 7 mas
¶ δ Sco AB (and its remoter gravitationally bound third star, if there is such a companion) may possibly be a low-velocity runaway system with ISM bow shock
¶ E(B–V)=+0.16

β	Sco Aa†	16 07.0−19 53	2.56†	−0.07†	B0.5 V	8	−2.9	400	0.025	192	−1 SB	Aa: 2.9; B: 10.6, 0.3″ (2023); C: 4.5, 14″ (2021)	Acrab

														(AC astrometry in more detail: 14″→14″, PA 25°→19°, 1779→202); in gross terms a visual binary (as AC), with A-to-C distance ≥ 2200 au, period > 16,000 y, but in fact putatively a sextuplet; en.wikipedia.org/wiki/Beta_Scorpii summarizes the sextuplet hierarchy in a diagram (Aa with Ab (6.82 d), and B experiencing Aa+Ab as essentially a point mass (610 y); E as an as a not-yet-resolved SB (although Wikipedia in an informal spirit writes “Ea” and “Eb,” WDS, whose terminology we in this *Handbook* article take as normative, cannot as of 2025 March 13 do so; period of this unresolved SB is 10.7 d), and C experiencing the binary system that is as yet just (in WDS-formal terms) “β Sco E” as essentially a point mass (39 y, β Sco E combined light mag. 6.60); the B+(Aa,Ab) triple is in a wide, > 16,000-y orbit with the C+E triple, around the centre of mass shared by this pair of triples, thereby delivering the gross visual- binary phenomenology studied as β Sco AC since 1779; the Aa,Ab angular separation is too small to yield a measure for WDS as at 2025 March 13; the CE separation is tight, measured as 0.1″ in 2023; the entire sextuplet has an outlying celestial-sphere neighbour, physically unrelated to the sextuplet, WDS-catalogued as β Sco D (mag. 7.5; 520″→519″, PA 31°→30°, 1860→2016)) ¶ m_v, B−V values are for β Sco Aa,Ab,B combined light; for β Sco C, GCPD additionally appears to give m_v, B−V values 4.91, −0.02 ¶ further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 08: , flagged as suspected variable; a single AAVSO observation found; no variability classification symbol assigned; possible range in V passband stated as 2.61–2.67) ¶ the JMDC 2021 Sep. 14 edition does not report any direct interferometric measurement of angular diameter for any star in the β Sco hierarchical system (while, however, giving some occultation results, including for the two-star "β Sco A" part of the system measurements from a 1971 May 13 Jupiter occultation, without limb-darkening correction, of 0.246 mas ± 7% and 0.422 mas ± 6%, at the visible-violet wavelength 393.4 nm) ¶ lunar occultations possible, planetary occultations possible yet rare (1971 May 14 occultation by Jovian satellite Io) ¶ the name Graffias is not IAU-official
δ	Oph A	16 15.7	−3 46	2.73†	1.58	M1 III†		~19.1	−0.9	171	0.150	198	−20 V	poss. slight var.: type unkn. (2.72–2.75 in V?) Yed Prior† further photometric study advisable? (1992IBVS.3792....1P finds no variability, but says variability cannot be excluded; AAVSO(VSX) assessment as of 2024 May 08: flagged as suspected variable; only a single AAVSO observation found; no variability classification symbol assigned; possible range in V passband stated as 2.72–2.75) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 9.93 mas ± 0.09%, at 2300 nm, from the AMBER beam-combining facility at VLTI ¶ slow rotator ¶ high metallicity ¶ although δ Oph has finished core hydrogen fusion, its exact evolutionary state is uncertain (cf stars.astro.illinois.edu/sow/yedprior.html) ¶ Astron. Alm. (epoch 2021.5) assigns MK type M0.5 III ¶ naked-eye neighbour Yed Posterior is a mere optical companion, too greatly separated in space for true binarity; the “prior” and “posterior” in the

												traditional, and as of 2016 IAU-official, names denote the order in that these two (physically unrelated) stars cross the local meridian	
ε	Oph A	16 19.7 −4 45	3.23†	0.97	G9.5 IIIb†	31	0.7	106	0.093	64	−10 V	slight var.: pulsator, range 0.003 in V (AAVSO(VSX) assessment as of 2024 May 08: status flag = confirmed variable; one single AAVSO observation found; V passband range given as 0.003; variability classification symbol = "**PULS**"); 2008A&A...478..497K, using *MOST* mission data, finds pulsation modes favourable to asteroseismology ¶ cyanogen and carbon notably underabundant, suggesting that ε Oph is an interloper from outside the galactic thin disk; Astron. Alm. (epoch 2021.5) assigns MK type G9.5 IIIb Fe–0.5 ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter, and the sole reported measurement with limb-darkening correction, is 2.966 mas ± 2%, in the 550 nm–850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ	Yed Posterior
σ	Sco <u>Aa1</u>†	16 22.8−25 39	2.87†	0.14†	B1 III†	5	−3.7	700	0.019	213	+3 SB†	slight var.: 2.86–2.94, 0.25 d; B: 8.4, B9 V, 20.5″ (2019) (AB astrometry in more detail: 22″→20″, PA 270°→269°, 1783→2019); recent studies, including lunar occultation measures, show σ Sco to be a quadruple system, with σ Sco Aa1,Aa2 in fact SB (33.0 d; considered by WDS to be successfully resolved, although only one PA measurement, from 2010, is documented in WDS as of 2025 March 15), and with the entire 3-star σ Sco A configuration (where the (Aa1+Aa2), Ab period is > 100 y) in some slow, wide orbit with σ Sco B; orbital solution has been published for Aa1,Aa2, but not for Aa,Ab; 2007MNRAS.380.1276N announces interferometric solution for the SB orbit, proposing for primary and secondary the respective MK types B1 III, B1 V ¶ in the SB pair, the primary is a variable of the β Cep type (AAVSO(VSX) assessment as of 2024 May 08: status flag = confirmed variable; V-passband range 2.86–2.94; salient period = 5.9241 h; variability classification symbol = "**BCEP**"); 1992A&A...261..203P discusses period changes ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) for any member of the σ Sco A system ¶ m_v, B−V values are for σ Sco Aa1,Aa2,Ab combined light ¶ photography shows σ Sco to be embedded in diffuse nebula ¶ E(B–V) =+0.4 (pronounced reddening)	Alniyat
η	Dra A	16 24.4+61 27	2.73†	0.91†	G8 IIIab	35.4	0.5	92	0.059	343	−14 SB?	B: 8.2, 4.7″, PA 150°→142°, 1843→2016 orbit ≥ 1000 y, separation ≥ 140 au ¶ a "Red Clump" resident (evolved, presently stable, performing core-helium fusion) ¶ believed to be a slow rotator (~400 d) ¶ a modest X-ray source ¶ further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 08: status flag = suspected variable; no AAVSO observations found; no conjectured variability-type symbol assigned; possible V-passband range stated as 2.70−2.74) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 3.47 mas ± 0.3%, in the 550 nm−850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ	Athebyne

												¶ mv, B−V values are for η Dra AB combined light ¶ the η Dra AB pair has a reasonably bright outlying celestial-sphere neighbour, WDS- catalogued as η Dra C: mag. 8.10, angular separation from η Dra A 565″→566″, PA 245°→240°, 1866→2016 ¶ near the radiant of the η Draconids meteor shower	
α	Sco A†	16 31.0 -26 29	0.99v†	1.83	M1.5 Iab†	6	−5.1	600	0.026	207	−26 SB	semireg. var.: 0.75–1.21, 5.97 y; B: 5.40, 2.7″ (2019) one of the two first-mag. supergiants (the other being α Ori Aa (Betelgeuse)) ¶ AB astrometry: PA 273°→277°, 1847→2019; orbit 2500 y? the large magnitude difference makes this a difficult binary (the binarity was discovered only in 1819, through controverted lunar-occultation work (1972JBAA...82..431K describes the 18.6-year 1940-through-2050 cycle of lunar occultation possibilities); the binarity was established beyond controversy still later, in the 1840s); B shares in the proper motion of A, indicating true binarity: AB separation is ≥ 530 au, period possibly ~1200 y ¶ AAVSO(VSX) assessment as of 2024 May 08: status flag = confirmed variable; 1979 AAVSO observations found; variability classification flag = “**SRC**”; V-passband range stated as 0.75–1.21; period = 2180 d = 5.97 y; cf also 2013AJ....145...38P, where a true period is found for radial-velocity variations, and the detected variation is judged to be more likely of pulsational than of orbital origin; the variability has also been called, outside AAVSO(VSX), irregular; 2018AuJAn..29...89H reports that variability was observed by, and incorporated into the oral tradition of, aboriginals in southern Australia; asserted by Eratosthenes to be fainter than β Lib, and by Ptolemy to equal β Lib ¶ in interferometry from the AMBER beam-combining facility at VLTI, the α Sco A photosphere has been imaged, and additionally a velocity map has been obtained, indicating localized large-clump downdrafts and upwellings (both results in 2018Msngr.172...35W, Fig. 4; cf also 2015Msngr.162...46O); the JMDC (2021 Sep. 14 edition) reports several interferometric measurements of angular diameter, of which only the most recent has limb-darkening correction: 39.759 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson; angular diameter has also been studied in lunar occultations (1972JBAA...82..431K describes the 18.6-year 1940-through-2050 cycle of lunar occultation possibilities); in all this interferometric and occultation work, it must be borne in mind not only that the physical extremity of a highly evolved red star is wavelength-dependent, but additionally that α Sco A is a pulsator; one can perhaps take 3.4 au as a rough upper bound on what might reasonably be taken as the α Sco A physical radius; for comparison, Mars orbital radius is ~1.5 au, Jupiter orbital radius ~5.2 au) ¶ significant stellar wind, with mass loss almost 1e-6 $M_\odot$/y, within which α Sco B has created a locally ionized region ¶ Astron. Alm. (epoch 2021.5) assigns MK type M1.5 Iab–Ib ¶ the most massive member of the Sco-Cen Association (the nearest OB association) ¶ location (within zodiac) makes the classical Greek name for “rival of Mars” appropriate not only as regards naked-eye colour but also as regards sky geometry	**Antares**†
β	Her Aa	16 31.4+21 26	2.78†	0.93†	G7 IIIa†	23	−0.4	140	0.100	261	−26 SB†	poss. slight var. (2.76–2.81 in V band?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 08:	Kornephoros†

													status flag = suspected variable; no AAVSO observations found; no variability classification symbol assigned; possible V-passband range 2.76–2.81) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 3.472 mas ± 0.2%, in the 550 nm−850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ SB period computed 1908, and again 2008, in both cases ~410 d; 1977ApJ...214L..79B announces speckle-interferometry resolution of the β Her Aa,Ab SB, with angular separation 43 mas; as of 2025 March 13, WDS documents 4 astrometric measurements of the Aa,Ab SB as a visual binary, 1975→1984; Aa,Ab possesses, and AB lacks, a published orbit ¶ m_V, B−V values are for β Her Aa,Ab combined light ¶ X-ray emission from the SB primary indicates magnetic activity ¶ Astron. Alm. (epoch 2021.5) assigns MK type G7 IIIa Fe–0.5 ¶ Kaler, noting that primary has N enhanced relative to C, says in his overall summation “a very normal star for its state of age” ¶ “Kornephoros” = Gk “club-bearer,” in reference to the weapon of Hercules (compare α Her, which in the pictorial-atlas tradition, marks the hero’s head); the corresponding constellation in Ptolemy, however, is “the Kneeler”, given without a club
τ	Sco	16 37.5 −28 16	2.82	−0.25	B0 V†	7	−3.0	500	0.025	203	+2 V	Paikauhale†	intrinsically more luminous than σ Sco, but more heavily obscured by ISM ¶ anomalous in its UV lines (P Cyg profile) ¶ O and Fe are underabundant ¶ 2006MNRAS.370..629D discusses τ Sco magnetic topology (poloidal, with also a warped toroidal component of modest strength), including both its origin (more likely a fossil field from the star’s (recent) birth than a dynamo effect) and its connection with winds and with the observed hard-X-ray emission; the authors note that the topology is stable over the 1.5-y period of their observations (in contrast with a strongly differential-rotation star, such as Sun); in additionally announcing a (refined) rotation period of 41.033 d, the authors comment, “the second-slowest rotator so far known among high-mass stars” ¶ Kaler: “among the most-observed stars in the sky”; however, AAVSO(VSX) situation as of 2024 May 08 is as follows: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter (0.338 mas ± 3%, with limb-darkening correction, in the near-infrared I passband, from the VEGA beam-combining facility at CHARA) ¶ E(B-V)=+0.06 ¶ the τ Sco name Paikauhale was IAU-approved in 2018 Aug. 10; the not-IAU-official “Al Niyat,” or “the arteries of the Heart,” on the other hand, denotes σ Sco and τ Sco jointly, as flanking α Sco
ζ	Oph	16 38.6 −10 37	2.57†	0.02	O9.5 Vne†	9	−2.7	370	0.029†	32	−15 V†		the nearest O-type star (and consistently with this extreme temperature, resident in an H II region) ¶ unusual in being an “Oe,” i.e. an O-star instance of the “Be phenomenon” ¶ “runaway star” (consistently with this extreme speed-relative-to-LSR, forming bow shock in ISM), perhaps formerly the secondary

													in a binary pair whose primary perished in a supernova; 2011AN....332..147H confirms magnetic field, discusses X-ray properties, suggests PSR B1919+10 as remnant of the hypothesized defunct companion ¶ line of sight to ζ Oph is one of the most used in spectroscopic studies of ISM ¶ 2014MNRAS.440.1674H is a recent discussion of variability, from radial and non-radial pulsation modes; AAVSO(VSX), assigning magnitude range 2.56–2.58 in V and period 4.6 h, follows GCVS in treating ζ Oph as a variable with Be-phenomenon behaviour, and yet lacking the history of outbursts founds in the γ Cas class (AAVSO(VSX) assessment as of 2024 May 08: status flag = confirmed variable; 70 AAVSO observations found; variability classification symbol = "**BE**"); ζ Oph is, on the other hand, classified as γ Cas-variable (and is termed a shell star) in BSC5; still elsewhere, ζ Oph has been treated as a prototype for the "ζ Oph variables" ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.54 mas ± 2%, at 800 nm, from the PAVO beam-combining facility at CHARA ¶ E(B-V)=+0.32 (pronounced reddening; if ISM were not present, ζ Oph would reach nearly first mag.) ¶ recapitulations of recent ζ Oph studies include 2012MNRAS.427L..50G (MK classification problem, also mass-loss rate in context of "weak-wind problem"), 2014MNRAS.440.1674H (rotation, pulsation, Hα emission episodes, inferred circumstellar decretion disk, satellite-based photometry), 2015ApJ...800..132C (distance, age, mass, effective temperature, bow shock in ISM, …); additionally, 2012A&A...543A..56D is among the papers describing not only the specific interaction of ζ Oph with ISM, but also the quite general ISM bow-shock topic (noting inter alia that not all runaway stars produce bow shocks)
ζ	Her A†+1P?	16 42.3+31 33	2.81†	0.64†	G1 IV†	93	2.7	35	~0.575	~307	−70†	SB	B: 5.40, G7 V, 1.6″, PA 110° (2019), orbit 34.45 y orbit well studied since F.G.W. von Struve 1826 micrometry (however, it was Herschel, not von Struve, who discovered the binarity); separation 8 au min, 21 au max, 15 au average, 34.45 y; considered one of the few binaries in which ratio of B mass to sum of A and B masses can be studied both via traditional (non-interferometric) astrometry and via spectroscopy; WDS indicates, however, that an inner binary with orbit ~12 y has been suspected repeatedly, and that the inner-binary component has been detected in IR speckle interferometry (but WDS, at any rate as of 2025 March 13, continues to write simply "ζ Her A," without as yet distinguishing between ζ Her Aa and ζ Her Ab) ¶ m_v, B−V values are for ζ Her AB combined light ¶ Astron. Alm. (epoch 2021.5) assigns MK type G0 IV ¶ ζ Her A is unusual in its evolutionary phase, being in the Hertzsprung Gap (and so in rapid evolutionary transition) ¶ further photometric study advisable?

												(AAVSO(VSX) assessment as of 2024 May 08: status flag = suspected variable; no AAVSO observations found; no conjectural variability-type symbol assigned; possible V-passband range 2.78–2.85) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.266 mas ± 0.6%, in the 550 nm–850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ [2001A&A...379..245M](https://ui.adsabs.harvard.edu/abs/2001A&A...379..245M) summarizes previous work, presents detailed physical modelling for A and B, and discusses asteroseismology, remarking in conclusion that “among the binaries to be calibrated with some confidence, ζ Herculis is one of the most interesting owing to the difference of evolutionary state of components” ¶ high velocity relative to Sun	
η	Her A	16 43.8+38 52	3.50†	0.92	G7.5 IIIb Fe–1†	30.0	0.9	109	0.092	157	+8 V?	slight var. (RS CVn type?), 3.47−3.50 in V passband further photometric study advisable? (AAVSO(VSX) as of 2022 July 30 flagged η Her system as possibly harbouring variability, but as of 2024 May 08 flagged for confirmed variability, applying, however, the conjectural variability-type classification symbol “RS:”, rather than the known variability-type symbol “RS”; on 2022 July 30, and again on 2024 May 08, only 2 AAVSO observations found) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.493 mas ± 0.7%, in the 550 nm−850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ the outlying (116″, 84″) and faint (mag. 11.7, 13.9) celestial-sphere neighbours η Her B and η Her C aside, a close (0.3″) celestial-sphere neighbour of η Her A was suspected in 1842, without subsequent detection ¶ in evolutionary terms a resident of the “Red Clump” (fusing helium in stable core) ¶ Astron. Alm. (epoch 2021.5) assigns MK type G7 III Fe–1 ¶ Fe is notably underabundant	
α	TrA A	16 51.5−69 04	1.91	1.45	K2 IIb–IIIa†	~8.4	−3.5	390	0.036	150	−3	anomalous for its MK type, with flares and X-ray emission, perhaps from as-yet-undetected magnetically active companion (a companion would indeed be indicated by the claimed “barium star” status of α TrA; stars.astro.illinois.edu/sow/atria.html, in discussing the possibility of a companion, also remarks, however, “the classic ‘hybrid star,’ a giant that shows evidence for blowing a cool wind from its surface, yet having a hot surrounding magnetic corona at the same time”; ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20040086627.pdf further discusses both α TrA and β Dra, as (solitary) stars, which are in this particular posited sense “hybrid”; the faint (mag. 11.4) and outlying (angular separation 92″) celestial-sphere neighbour α TrA B cannot be the postulated flaring and X-ray-bright companion ¶ AAVSO(VSX) situation as of 2024 May 08: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification flag ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter (9.24 mas, with the very small uncertainty ± 0.02%, with limb-darkening correction, at 2300 nm, from the AMBER beam-combining facility at VLTI)	**Atria**
ε	Sco	16 51.9−34 20	2.29†	1.15	K2 III	51	0.8	64	0.666†	247	−3†	possible var. (2.24−2.35 in V passband?) further photometric study advisable?	Larawag

												(AAVSO(VSX) assessment as of 2024 May 08: status flag = suspected variable; seems no AAVSO observations found; no conjectural variability-type symbol assigned) ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ slow rotator (possibly even 1.3 y) ¶ evolved, and yet not a clump star; stars.astro.illinois.edu/sow/epssco.html discusses the uncertainty in evolutionary stage (brightening, with He core as yet awaiting ignition? dimming, with He core fusion in progress? or brightening, with dead C-and-O core, He-core fusion now over?) ¶ high velocity relative to Sun indicates origin outside the galactic thin disk (and metal underabundances are consistent with such an origin)	
μ^1	Sco A	16 53.7	−38 05	3.04v†	−0.21	B1.5 IVn	7	−2.9	500	0.024†	206	−25† SB2†	ecl.: 2.94–3.22 in V passband, 1.45 d (more precisely, in AAVSO(VSX) as viewed 2021 Dec. 14, 2022 Jul. 14, 2024 May 08 1.44626907 d); 2 published solutions for the orbit give *e*=0.019, *e*=0.0; semidetached, partially eclipsing binary system, with mass transfer, resembling β Lyr in its never-constant light and in exhibiting both primary and secondary minima (AAVSO(VSX) assessment as of 2024 May 08: status flag = confirmed variable; 513 AAVSO observations found; variability classification symbol = "**EB/SD**"); 1948MNRAS.108..398S gives the light curve, and also discusses early observational history (this is the third eclipsing SB discovery in astronomy (made by Bailey, 1896)); distance between components is ~0.07 au; since the SB is not as yet resolved, even interferometrically, WDS as of 2025 March 13 is not able to write "μ1 Sco Aa," "μ1 Sco Ab" ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ μ^1 Sco has celestial-sphere neighbor μ^2 Sco, at mag. 3.5 (so just barely fainter than our chosen "Brightest Stars" magnitude cutoff), at angular separation ~5.8′ (Mizar-Alcor angular separation is just under 12′; normal naked-eye resolution is taken in ophthalmology, under at any rate some reasonable selection of consulting-room eye chart, to be ~1′); μ^1 Sco and μ^2 Sco are the "Little Cat's Eyes," as distinct from the "Cat's Eyes" which are λ Sco and υ Sco; the IAU-official name "Xamidimura" applies just to the primary in the SB which is the right, unresolved, two-star μ^1 Sco system; for the Khoekhoem nomadic pastoralists of SW Africa, on the other hand, "Xami di mura" is "eyes of the lion," as a designation for the naked-eye challenge pair μ^1 Sco, μ^2 Sco ¶ μ^1 Sco and μ^2 Sco are not gravitationally bound, although both belong to the (gravitationally unbound) "Upper Sco" subgroup of the Sco-Cen Association ¶ a little confusingly, μ^2 Sco is also formally "μ^1 Sco H" (μ^1 Sco AH astrometry: 333″→347″, PA 71°→72°, 1752→2015); additionally, the unresolved μ^1 Sco A SB has two other WDS-documented celestial-sphere neighbours, both reasonably bright, μ^1 Sco B (mag. 8.9, 8.9″→9.2″, PA 211°→210°, 1999→2000) and μ^1 Sco G (mag. 9.4, 81″→81″, PA 257°→257°, 1935→2016)	Xamidimura
κ	Oph	16 58.9	+9 20	3.20†	1.16	K2 III	36	1.0	91	0.292†	268	−56 V†	now known to be non-variable slow rotator (possibly as slow as 1.6 y) ¶ historical assertion of variability may be due to a confusion between κ Oph and χ Oph; completely apart from this historical problem, however, 2001BaltA..10..593A discusses the	

												possible variability both of κ Oph and of other Red Clump stars; AAVSO(VSX) for its part asserts constant light (AAVSO(VSX) assessment as of 2024 May 08: status flag = confirmed non-variable; variability classification symbol = "**CST**") ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 3.608 mas ± 1%, at 700 nm, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ high velocity relative to Sun suggests origin outside the galactic thin disk	
ζ	Ara	17 00.8−56 02	3.12	1.60	K4 III	7	−2.7	490	0.041	206	−6	one of the rather rare instances of a giant excessively bright in far IR (1997A&A...323..513P suggests that such giants are more likely to be radiating their IR excess from circumstellar debris disks than from winds, and so are to be considered evolved-star analogues of the unevolved (and IR-bright) α Lyr) ¶ AAVSO(VSX) situation as of 08 May 2024: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter (7.09 mas, with the very small uncertainty ± 0.02%, with limb-darkening correction, at 2300 nm, from the AMBER beam-combining facility at VLTI)	
ζ	Dra A	17 08.9+65 41	3.17	−0.12	B6 III†	10	−1.8	330	0.028	314	−17 V	ζ Dra A and ζ Dra B are mags. 3.2, 4.2 respectively; a difficult binary, resolved interferometrically, but as of at any rate 2025 March 19 with just 10 WDS-documented astrometry measurements (AB 0.0″→0.1″, 1981→1994); on the preliminary orbital solution offered in 1998A&AS..133..149M, the orbital plane coincides with the plane of the sky, and the orbit is circular, with radius 67 mas; 1998A&AS..133..149M suggests, tentatively, that ζ Dra A and ζ Dra B are "a pair of giants" ¶ given the recent formation of the ζ Dra system, Fe is anomalously underabundant ¶ AAVSO(VSX) situation as of 2024 May 08: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter (0.488 mas ± 5%, with limb-darkening correction, in the visible-light R passband, from the PAVO beam-combining facility at CHARA) ¶ E(B–V) =+0.03	Aldhibah
η	Oph AB†	17 11.9−15 45	2.43†	0.06†	A1 IV + A1 IV?†	37	0.3	90	~0.107	~22	−1 SB	A: 3.0; B: 3.3, A3 V, 0.3″ (2023), orbit 87.6 y highly eccentric orbit: separation 2 au min, 65 au max; PA was 222° in 2023 ¶ under IAU rules, "Sabik" designates η Oph A, not η Oph B ¶ mv, B−V values are for η Oph AB combined light ¶ our present assignment of MK types (confident for η Oph A, tentative for η Oph B) is from the literature; our Handbook predecessor R.F. Garrison, however, himself favoured "A2.5 Va," perhaps for the AB composite; Astron. Alm. (epoch 2021.5), perhaps again for the AB composite, assigns MK type "A2 Va+ (Sr)" ¶ it is possible that A, or B, or both A and B, are superabundant in metals ¶ AAVSO(VSX) situation as of 2024 May 08: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry	**Sabik**†

												or by any other direct means)
η	Sco A	17 14.1−43 16	3.33†	0.40	F5 IV†	~44.4	1.6	73	0.290	175	−28	possible variability: unknown type, unknown range further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 08: status flag = suspected variable; no AAVSO observations found; no conjectural variability-type symbol assigned; possible V-passband range stated as “3.31–?”) ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ we now take MK type (slightly evolved beyond stable core-hydrogen fusion, because in luminosity class “IV”) from NASA NStars work summarized at 2006AJ....132..161G (with Garrison the third author); Garrison had himself previously, in this *Handbook* table, proposed the dwarf MK type “F2 V:p(Cr)”; the intricacy of his previous type hints at difficulties in classification, and indeed even “dwarf barium star” has been asserted elsewhere; Astron. Alm. (epoch 2021.5) assigns the same MK type as legacy-Garrison ¶ rapid rotator (< 1 d); the observed X-ray emission is consistent with magnetic effects (including coronal heating?) stemming from rapid rotation
α	Her Aa†	17 15.9+14 22	3.06†	1.45†	M5 Ib–II	9	−2.4	400	0.032	347	−33 V	semireg. var.: 2.73–3.60 in V; B: 5.4, 5″ (2023) Rasalgethi† the second-nearest AGB star (the nearest being the more dramatic visual variable o Ceta Aa (Mira) ¶ WDS catalogues α Her Aa,Ab, but with the caveat that the asserted duplicity may not be real (only 3 measurements are available (0.2″→0.2″, 1986→1991), and attempts to resolve the asserted binary failed over the period 1985→1997, even with speckle interferometry at BTA-6; a period of ~10 y has been suspected if the Aa,Ab pairing is real); the IAU-official name Rasalgethi applies to α Her Aa if the Aa,Ab pairing is real, and to α Her A otherwise; although we use WDS nomenclature (for this as for all stars in this table), the literature also (e.g. 1993A&A...274..838T, 2013AJ....146..148M) uses an alternative terminology, on which Rasalgethi is designated “α¹ Her A,” and the two as-yet-unresolved SB components are designated “α² Her A” and “α² Her B”; the as-yet- unresolved SB (MK types G8 III and A9 IV–V, period 51.578 d, distance between the unresolved components ~0.4 au) which both for WDS and for us is designated α Her B is mag. 5.4 (5″→5″, PA 112°→102°, 1779→2023); AB orbital solution asserts period 3600 y; this makes the α Her system at least a (kinematically stable, hierarchically organized) triple; WDS, in its note on α Her, indicates that despite the weakness of the observational record for the putative pairing α Her Aa,Ab, the radial-velocity record suggests the presence of at least 5 stars in the α Her system; the faint celestial-sphere neighbours α Her C (mag. 15.5) and α Her D (mag. 11.1), on the other hand, are not part of the system ¶ m_V, B−V values are for α Her Aa,Ab,B combined light ¶ the mass of Rasalgethi has been controverted (mass as high as ~15 $M_{\odot}$, putting Rasalgethi into the same mass league as (admittedly less evolved) Betelgeuse and Aldebaran; or, rather, as low as ~2 $M_{\odot}$, putting Rasalgethi into the same mass league as its AGB peer Mira?); 2013AJ....146..148M, proceeding from the surely safe assumption that the three known stars in the α Her AB system are of the same age (being surely born in a single ISM cloud condensation event), and taking the system age from the MS star that is the secondary in the α Her unresolved SB (age is more safely determined from an MS star than from an evolved star), and using photometry sensitive to TiO to obtain a fluctuating effective temperature for Rasalgethi (and thereby, via the Stefan-Boltzmann law, fluctuating luminosity and fluctuating radius) via a 55-track grid of evolutionary models (with each track tracing evolution stepwise until the depletion of core helium that

													marks a star's arrival on AGB) deduces that the Rasalgethi mass is in the range [2.175 M⊙, 3.250 M⊙]; the authors remarks that "very few AGB stars have reliable ages and masses"; the luminosity and effective temperature deduced for Rasalgethi agree to within uncertainties with the Rasalgethi interferometry results of 2004A&A...418..675P ¶ AAVSO(VSX) assessment as of 2024 May 08: status flag = confirmed variable; 24430 AAVSO observations found; variability classification symbol = "**SRB**"; V-passband range = 2.73−3.60; period = 125.6 d; 2010Ap&SS.328..113M reports "up to seven" pulsation modes, with one period of ~1343 d (a radial pulsation), other periods on the order of ~125 d (and cf. also light curve in Fig. 5 of 2001PASP..113..983P); two typical measurements in V band, from AAVSO database, from one and the same observer, are mag. 3.10 (2024 April 13) and mag. 3.02 (2024 April 25) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 36.026 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson; Rasalgethi physical size variation, associated with the photometric variation, is assessed in 2013AJ....146..148M as 264 R⊙ min, 303 R⊙ max; en.wikipedia.org/wiki/List_of_largest_stars shows ranking of Rasalgethi in the overall known cosmic population of highly evolved stars ¶ 1956ApJ...123..210D initiated the successful analysis of mass loss from Rasalgethi (mass loss is to be expected, in an AGB star, and in the case the consequent circumstellar material is so copious as to extend significantly along our line of sight); 1956ApJ...123..210D proceeds by examining the radial velocity of the Rasalgethi ejecta (as seen in absorption, as very cold gas, in the spectrum of the α Her B brighter component, and (crucially) not sharing in the ~52 d fast SB orbital motion of that component); 2007ApJ...658L.103T finds interferometric evidence for an exceptionally violent episode of mass loss, comprising about 10e−6 M⊙ (cp. Mira, for which we take as usual mass-loss rate ~2.5e−7 M⊙/y), with the ejected material (condensing as dust) flowing outward at exceptionally high speeds, possibly ≥ 72 km/s, and with no similarly drastic mass loss until at least the conclusion of the study (~2003); this suggests to us, as the *Handbook* team, that ongoing photometric study is advisable ¶ in the pictorial-atlas tradition, α Her marks the head of hero Hercules (with β Her marking his club; for summer-evening observers in the northern hemisphere, the hero is to be visualized inverted, with feet high in the sky, club and head lower; indeed the IAU-official Arabic name "Rasalgethi" derives from the Arabic for "the kneeler's head")
π	Her	17 16.0+36 47	3.16†	1.44	K3 IIab†	8.7	−2.2	380	0.027	276	−26	V?	possible var. near visual threshold (3.07−3.16 in V?) further photometric study advisable? (whereas AAVSO(VSX) was on 2022 July 30 noting existence of NSV entry and nonexistence of AAVSO observations, with possible V-passband range 3.07−3.16, as of 2024 May 08 AAVSO(VSX) has no π Her entry) ¶ the large-amplitude photometry aside, low-amplitude photometric variations with low-amplitude radial-velocity variations, 613 d, perhaps favour the hypothesis of non-radial pulsation over the competing hypotheses of an undetected low-mass companion and of rotation with starspots ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 5.159 mas ± 0.2%, in the 550 nm−850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ Astron. Alm. (epoch 2021.5) assigns MK type K3 II

δ	Her Aa†	17 16.1+24 49	3.12†	0.08†	A1 Vann	43.4	1.3	75	~0.158	~188	−40 SB†	B: mag. 8.3, 14″ (2023) is mere optical companion Sarin δ Her A, being SB (and also resolved as a binary in interferometry, with angular separation 60 mas; inter-component distance ≥ 1.45 au, period ≥ 335 d; WDS documents just 5 astrometry measurements (0.1″→0.1″, 1978→1989)), is strictly δ Her Aa,Ab ¶ mv, B−V values are for δ Her Aa,Ab combined light ¶ δ Her Aa is a fast rotator (< 9 h) ¶ as with δ Her B, so also δ Her C and δ Her D, at respective angular separations 174″ (2013) and 192″ (2009), are most likely mere optical companions ¶ AAVSO assessment of δ Her assemblage, as of 2024 May 09: status flag = confirmed variable (the assemblage had, however, been flagged as confirmed non-variable when AAVSO(VSX) was viewed 2022 July 30); no AAVSO observations found; variability type symbol = "**DSCT**"; V passband range = 3.12–3.14 ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)
θ	Oph A†	17 23.6−25 01	3.26†	−0.22	B2 IV	~7.5	−2.4	440	0.025	197	−2 SB†	slight var.: β Cep type, 3.26–3.29 in V passband, 3.37 h ¶ θ Oph A is classified as an unresolved SB, with period variously stated in secondary literature as 11.44 d (Kaler) and 56.71 d (Wikipedia), and with inter-component distance proposed by Kaler as ~0.25 au; θ Oph B is mag. 6.2, 0.2″→0.2″, 1992→2023, with 12 astrometry measurements documented in WDS; lunar occultations occur, and indeed a lunar occultation event might possibly (Kaler, stars.astro.illinois.edu/sow/thetaoph.html) have split the SB that is θ Oph A ¶ according to AAVSO(VSX) as viewed 2022 March 3, 2022 July 14, and 2024 May 09, the θ Oph assemblage presents slight variability of both the β Cep type and "slowly pulsating B" type, with period = 3.37267 h and variability classification symbol = "**BCEP+SPB**" (only 2 AAVSO observations found as of 2024 May 09) ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)
β	Ara	17 27.5−55 33	2.84	1.46	K3 Ib–IIa†	5	−3.6	600	0.027	199	0	slight var. (2.82–2.86 in V passband) slow rotator (possibly as much as 2.33 y) ¶ high metallicity ¶ AAVSO(VSX) assessment as of 2024 May 09 (no assessment had been offered when AAVSO(VSX) was viewed in 2022): confirmed variable; no AAVSO observations found; variability classification symbol = "**LC**" (for irregular variable supergiants; other instances of this type have varied by ~1 magnitude in V passband); discovery credited to Sebastian Otero ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ not gravitationally bound to γ Ara AB
γ	Ara A	17 27.6−56 24	3.33†	−0.14†	B1 Ib	~2.9	−4.4	1100	0.016	182	−3 V	broad lines for Ib ¶ γ Ara A is rapid rotator (both "~4.8 d" and "< 2.5 d" have been asserted, and yet rapid rotation is unusual for the (evolved) γ Ara A luminosity class) ¶ 1997A&A...318..157P finds via *IUE* spectroscopy that, consistently with this rapid rotation, the stellar wind of γ Ara A may be equatorially enhanced (and more generally, that the wind is variable, and is structured with two components, its structure being not typical of stars in this

												portion of the HR diagram) ¶ γ Ara AB is not gravitationally bound to β Ara; γ Ara B is faint (mag. 10.21: 18″→18″, PA 324°→326°, 1835→2016) ¶ m_v, B−V values are for γ Ara A (not for γ Ara AB combined light) ¶ AAVSO(VSX) situation as of 2022 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ E(B–V) =+0.08
β	Dra A	17 31.0+52 17	2.80†	0.97†	G2 Ib–IIa	8.6	−2.5	380	0.020	308	−20 V	slight var. (unknown type, 2.78−2.79 in V band) Rastaban in evolutionary terms, β Dra A is somewhat unusual, as a yellow more-than-giant (having been a stable core-hydrogen fuser just 0.5 My ago, the star is in transition to being redder, and of still larger radius) ¶ it is also noteworthy that β Dra A, while lying in the HR diagram IS, has not been observed to pulsate; however, AAVSO(VSX), as of 2022 Jul. 30 and again 2024 May 09, documents Gabriel Cristian Neagu as discovering slight variability, range 2.780−2.794 in V, finding as yet no AAVSO observations, and assigning as variability classification symbol simply "**VAR**": further photometric study advisable? ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter (3.225 mas ± 2%, with limb-darkening correction, at 800 nm, from the Mark III beam-combining facility at Mount Wilson) ¶ m_v, B−V values are in principle for β Dra AB combined light (where, however, the contribution from β Dra B, at mag. ~14, is negligible)
υ	Sco	17 32. 6−37 19	2.70	−0.23	B2 IV†	6	−3.5	600	0.030	185	+8 SB	Lesath although we here give spectral type B, type Be has also been asserted ¶ υ Sco and λ Sco are not gravitationally bound (although both belong to the (gravitationally unbound) Sco-Cen OB association, and have as an optical double been called the "Cat's Eyes") ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification flag ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ E(B–V) =+0.02
α	Ara A	17 33.9−49 54	2.94v†	−0.17†	B2 Vne†	12†	−1.7	300†	0.075	206	0 SB	var.: λ Eri & γ Cas types, 2.73−3.00 in V passband an instance of the "Be phenomenon," with (since the star, with its equatorial ejecta, is seen nearly equator-on) "shell" spectrum: 2007A&A...464...59M says, "For the first time, we obtain the clear evidence that the [equatorial ejecta] disk is in Keplerian rotation, closing a debate that has continued since the discovery of the first Be star γ Cas by Father Secchi"; on the authors' modelling, α Ara is rotating near breakup speed (and consequently is oblate), with an enhanced wind from its poles; the authors note the possibility that equatorial ejecta disk is truncated by an unseen companion at 32 stellar radii; Section 5 of 2022A&A...659A.192L discusses interferometric observations of the disk; however, the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter for the star itself (whether through interferometry or by any other direct means) ¶ AAVSO(VSX) assessment as of 2024 May 09:

													status flag = confirmed variable; 48 AAVSO observations found; variability classification symbol = “**LERI+GCAS**”; period = 23.550 h ¶ the SB that is α Ara A is not as yet resolved, even in interferometry (so WDS cannot as yet write “α Ara Aa,” “α Ara Ab”) ¶ m_V, B−V values are in principle for α Ara A, not for α Ara AB combined light (but the contribution of α Ara B would in any case be negligible, since α Ara B is at mag. ~11) ¶ IR excess is unusually high for a Be star ¶ for problem of distance (the *HIPPARCOS* distance given here may be too high) cf 2005A&A...435..275C and 2007A&A…464…59M	
λ	Sco Aa,Ab†	17 35.4−37 07	1.62†	−0.23†	B1.5 IV + n.a.	>6†	−4.6	400†	0.032	195	−3	SB2	slight ecl. var.: 1.59−1.65 in V passband, 5.13 h (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; a single AAVSO observation found; variability classification symbol = “**BCEP+EA**”; period = 5.1288 h) ¶ λ Sco Aa,Ab are respectively of mags. 2.1, 2.7, and are an instance of an interferometrically resolved SB2 (39 measurements, 1999→2021; cf 2006MNRAS.370..884T); period of the SB2 is 5.9525 d; strictly a hierarchical triple system, however, in which the wide λ Sco AB pairing has period ~1000 d; B is elusive, at mag. 14.9; there is additionally a less elusive celestial-sphere neighbour, λ Sco C, at mag. 9.2, at a rather wide angular separation from A (AC: 95″→94″, PA 331°→330°, 1897→2016) ¶ m_V, B−V values are for λ Sco Aa,Ab combined light ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ the IAU-official name “Shaula” applies not to the λ Sco Aa,Ab system, but only to λ Sco Aa ¶ we take here the *D* and π values implied by comparing the Aa,Ab orbit semi-major axis angular measure against the computed Aa,Ab orbit physical semi-major axis length rather than the π value measured by *HIPPARCOS* and its corresponding *D*; generally speaking, *HIPPARCOS*, like other fine-grained trigonometric-parallax determinations of distance, risks degradation through astrometric wobble if a star has a stellar-mass gravitationally bound companion ¶ although λ Sco Aa,Ab has a published orbit, λ Sco AB does not (and indeed WDS takes no position on the question whether this wide double is a true binary) ¶ λ Sco Aa is a β Cep variable; since full orbital coverage is available in this case (as also with β Cep itself; in most or all other β Cep-class cases, full orbital coverage is presently unavailable), mass determination becomes feasible, making the λ Sco Aa,Ab binary important in β Cep-variable research; λ Sco Ab is itself of interest, as a possible pre-main-sequence star (this would be consistent with the observed X-ray emission) ¶ 1975MNRAS.173..709L gives some photometry ¶ a flare was observed in vicinity of λ Sco on 1975 Jun. 01 ¶ 2004A&A...427..581U summarizes previous work on λ Sco, considers masses, and discusses tidal effect on β Cep pulsation ¶ λ Sco and υ Sco are not gravitationally bound (although both belong to the (gravitationally unbound) Sco-Cen OB association, and have as an optical double been jointly called the “Cat’s Eyes”) ¶ E(B–V) =+0.03	**Shaula**
α	Oph A†	17 36.2+12 33	2.08†	0.16	A5 Vnn	67	1.2	49	0.247	154	+13	SB	slight var.: δ Sct & γ Dor types (< 0.01 in V?) AAVSO(VSX), as viewed 2022 Feb. 21, 2022 July 15, and 2024 May 09,	**Rasalhague**

												gives period 77.14 min (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; no AAVSO observations found; variability classification symbol = "**DSCT+GDOR**"); asteroseismology mission *MOST* has identified ~50 pulsational modes in α Oph A ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.855 mas ± 0.6%, in the 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ α Oph A is a fast rotator (oblateness has been imaged interferometrically), seen nearly equator-on ¶ B is mag. 5.0 (AB: 0.8″→0.7″, PA 243°→248°, 1982→ 2023, 29 observations); the SB system α Oph Ab, although tight, has been observed interferometrically, with 17 measurements 1982→2018; the binary system has become better understood with the recent, 2011ApJ...726..104H, determination of masses and orbit geometry, through coronagraph and adaptive optics (period 3148.4 d, angular distance at periastron passage ~50 mas; the now-achieved determination of masses in this particular system has implications for astrophysics generally, since it potentially facilitates the refining of numerical models for rapidly rotating hot stars)
ξ	Ser Aa†	17 39.1−15 25	3.54†	0.26	F0 IIIb†	31	1.0	105	0.073	215	−43 SB	possible slight var. (δ Sct type? 3.52−3.54 in V passband?) hierarchically organized triple system, comprising the resolved (with just one measurement, in 1987: 0.3″) single-lined SB that is ξ Ser Aa and ξ Ser Ab, experienced as essentially a point mass by the outlying ξ Ser B; period of the single-lined SB Aa,Ab is 2.29 d; ξ Ser B is faint, at mag. 13.0, with AB period possibly ~15,000 y; there is additionally a faint celestial- sphere neighbour ξ Ser C, at mag. 13.8 ¶ ξ Ser Aa has been asserted to be very slightly hotter than Garrison's "F0 IIIb," and moreover to be chemically peculiar, being on this (more recent?) determination of MK type A9 IIIp Sr ¶ further photometric study advisable? (AAVSO assessment as of 2024 May 09: status flag = suspected variable; no AAVSO observations found; conjectural variability symbol = "**DSCT:**") ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ Kaler comments at stars.astro.illinois.edu/sow/xiser.html: "the star /…/ remains cryptic" **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**
θ	Sco Aa†	17 39.2−43 01	1.86†	0.40	F1 III	~11	−3.0	300	0.006	119	+1	poss. slight var.: type unknown (1.84−1.88 (V)?) Sargas† rapid rotator, in the sense that *v* sin *i* is (according to 2005yCat.3244....0G) 125.0 km/s; since, however, θ Sco is a (rapidly evolving) giant, its high *v* sin *i* may correspond to a not-spectacularly short rotation period, of up to 10 d; if, as asserted in literature, θ Sco A system truly harbours a rapid rotator, this star will resemble β Cas A (a rapid rotator that, strikingly, has evolved beyond the MS) ¶ θ Sco Aa,Ab is a tight pair (0.2″→0.3″, PA 97°→98°, 2021→2022, 5 observations); θ Sco B is catalogued by WDS as mag. 5.4, with θ Sco AB 6″→6″, PA 322°→315°, 1896→1991, but with the caveat (in WDS Notes) that θ Sco B information may be erroneous (grid-step error in *HIPPARCOS* data reduction? erroneous work in 1896?) ¶ further photometric study advisable?

												(AAVSO(VSX) status as of 2022 July 30 and 2024 May 09: status flag = suspected variable; seems no AAVSO observations found; no conjectural variability type symbol assigned; possible V-passband range 1.84−1.88) ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ although it is the Sumerian name Sargas that is IAU-official as of 2016 Aug. 21, θ Sco, like κ Sco, has also been known under the different, not IAU-official, name Girtab (originally applied by the Sumerians to an entire asterism)	
κ	Sco†	17 44.3−39 02	2.41†	−0.23	B1.5 III	7	−3.5	480	0.026	193	−14 SB2	slight var.: β Cep type, 2.41–2.42 in V passband, 4.80 h ¶ since the SB has not yet been resolved, even interferometrically, WDS cannot, at any rate as of 2025 April 6, write “κ Sco A” and “κ Sco B”; the SB has orbital period 195.65 d, with inter-component distance 1.7 au ¶ the SB primary is a rapid rotator (1.9 d), in addition to being a variable of β Cep type (4.79593 h in AAVSO(VSX) as viewed 2021 Jan. 16, 2022 March 3, 2024 May 09 (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; 12 AAVSO observations found; variability classification symbol = “**BCEP**”); 1975MNRAS.173..709L gives some photometry, confirming a beat period ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ κ Sco, as a single naked-eye object, has (like θ Sco) been known under the different, not IAU-official, name Girtab (originally applied by the Sumerians to an entire asterism)	
β	Oph	17 44.8 +4 34	2.77†	1.17	K2 III†	~39.8	0.8	82	0.165	345	−12 V	poss. slight var.: type unkn. (2.75−2.77 (in V)?) ¶ 1996ApJ...468..391H finds multiple pulsation periods, in behaviour paralleling α Boo (“it may well be that these [two] stars represent a new class of radially and unradially pulsating stars”), and also a possible long period of 142.3 d; the authors suggest that if the latter is real, then although the more likely explanation is a 142.3-d rotation, nevertheless gravitational pull from an unknown exoplanet is conceivable; further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; seems no AAVSO observations found; no conjectural variability type symbol assigned) ¶ Astron. Alm. (epoch 2021.5) assigns MK type K2 III CN 0.5 ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 4.511 mas ± 0.2%, in the 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ	Cebalrai
μ	Her Aa†	17 47.5+27 43	3.42†	0.75†	G5 IV	~120.3	3.8	27.1	0.804	201	−16 V	BC: 9.8 comb., A−BC 35″, PA 240°→249°, 1781→2016 this stable “double double” is the third-closest quadruple star system to the Sun, and is one of the best-studied double doubles (2016AJ....151..169R consequently writes that μ Her “serves as an archetype for understanding stellar system formation”): μ Her Aa,Ab is in tight orbit, and μ Her BC is in tight orbit, with each of these two pairs experiencing the other as essentially a point mass; 2016AJ....151..169R gives Aa,Ab a period of ~100 y, with wide uncertainties, concluding also that Ab is an M-dwarf (and thus more massive than a mere substellar object; Aa	

												is mag. 3.5, Ab mag. 12.7, with this magnitude difference making the astrometry difficult; the Aa,Ab binary has been measured 24 times, 1998→2015 (angular separation 1.8″ in 2015)); BC has period 43.127 y, B-to-C distance 1.5 au min, 3.6 au max, 2.2 au average (angular separation 0.6″ in 2016, 1.0″ in 2021), abundantly observed (376 measurements, 1854→2021), with B, C of respective mags. 10.2, 10.7; the distance between the Aa,Ab centre of mass and the BC centre of mass is ≥ 300 au, with orbital period ≥ 3700 y; in contrast with the two pairings Aa,Ab and BC, there is no published orbital solution for the wide and slow pairing AB ¶ m_v, B−V values are for μ Her Aa,Ab combined light; additionally, GCPD gives m_v, B−V values 9.77, 1.50 for μ Her AB combined light ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification type ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.88 mas ± 0.4%, in the 550 nm–850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ despite having finished core-hydrogen fusion, μ Her Aa is a fast rotator, and is consequently magnetically active and an X-ray source	
ι^1	Sco A	17 49.4−40 08	3.02	0.51†	F2 Ia	2†	−5.9	2000†	0.006	180	−28 SB	a rare instance of a yellow (type F) supergiant since the SB that is ι^1 Sco A is not as yet resolved (even by interferometry), WDS is not, at any rate of 2025 April 06, able to write "ι^1 Sco Aa," ι^1 Sco Ab" ¶ a rare instance of a yellow supergiant (dead helium core; the star is now cooling, and is now in transition to the less exotic status of red supergiant) ¶ radius estimates vary; CADARS (2001A&A...367..521P) value is ~1.9 au; the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ mass loss ~1e–7 $M_\odot$/y ¶ slow rotator (≥ 0.5 y) ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ distance and mass are rather uncertain ¶ the modest angular distance of ι^1 Sco from ι^2 Sco is the result of a mere line-of-sight coincidence (with ι^2 ~2 times as distant as ι^1; again by coincidence, not ι^1 alone, but also ι^2, is a supergiant)	
G	Sco A	17 51.7−37 03	3.20	1.16	K2 III	25.9	0.3	126	0.049	56	+25	although masses of K giants are in general uncertain, in this particular case the mass is known via *WIRE* salvage-mission asteroseismology (being determined in 2008ApJ...674L..53S as 1.44 $M_\odot$, with just a 15% uncertainty) ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification flag ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	HR6630, Fuyue
γ	Dra A	17 57.2+51 29	2.23†	1.52	K5 III†	21.1	−1.1	154	0.024	200	−28	slight var.: (slow-irreg.?) range 0.01 in V band further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; seems no AAVSO observations found; variability classification symbol = "**LB:**")	**Eltanin**

												¶ in 1728, James Bradley used γ Dra to demonstrate aberration of light (“velocity aberration”); his demonstration strongly confirmed the heliocentric (and thus non-Ptolemaic) kinematics of the Solar System ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 9.86 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ Fe is slightly underabundant	
ν	Oph +2P†	18 00.5	−9 46	3.34†	1.00	G9.5 IIIa†	22	0.0	150	0.117	185	+13	poss. var.: unknown type (range ~0.4 in V passband?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; 4 AAVSO observations found; no variability classification symbol assigned) ¶ the JMDC (2021 Sep. 14 edition) reports several interferometric measurements of angular diameter, but just one with limb-darkening correction: 2.789 mas ± 0.2%, in the 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ brown-dwarf companions, not optically resolved (so WDS cannot write “ν Oph A,” “ν Oph B,” “ν Oph C”) with masses ≤ 22.2 × Jupiter and ≤ 24.7× Jupiter (deuterium fusion begins at a lower mass, 13× Jupiter), approximate periods 530 d and 3185 d (2019A&A...624A..18Q, and cf additionally 2012PASJ...64..135S; the latter paper suggests formation in circumstellar disk, with subsequent migration, in a scenario reminiscent of planet and exoplanet formation): this is the third star found to be hosting two brown dwarfs ¶ slow rotator (≤ 234 d) ¶ far-IR variability has been suspected ¶ CN underabundant, Fe overabundant ¶ Astron. Alm. (epoch 2021.5) assigns MK type G9 IIIa	
$γ^2$	Sgr	18 07.5	−30 25	2.98†	1.00	K0 III†	34	0.6	97	0.189	197	+22 SB	now known to be non-variable (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed non-variable; no AAVSO observations found; no variability classification symbol (but should the classification system “**CST**” be assigned?)) ¶ metals underabundant ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ Astron. Alm. (epoch 2021.5) assigns MK type K0+ III ¶ ε Sgr and the $γ^2$–$γ^1$ Sgr pair serve as pointers to Baade’s Window ¶ angular proximity of $γ^1$ Sgr (= W Sgr; variable, mag. range 4.28−5.10 in V; ~50′, to ~N of $γ^2$ Sgr) is a mere line-of-sight coincidence	Alnasl
η	Sgr A†	18 19.4	−36 45	3.11†	1.56†	M3.5 IIIab	22	−0.2	~146	0.211	218	+1 V?	slight irreg. var.: 3.05–3.12 (V); B: 8.0, G8: IV:, 3.5″ (2016) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; 20 AAVSO observations found; variability type symbol = “**LB:**”) ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ PA 100°→110°, 1879→2016; orbit ≥ 1270 y, A-to-B distance ≥ 165 au ¶ mv, B−V values are for η Sgr AB combined light ¶ η Sgr A is variously asserted to be on the (very highly evolved) HR diagram AGB or at the tip of the RGB ¶ effective temperature of η Sgr A not yet well determined?	
δ	Sgr A	18 22.7	−29 49	2.70†	1.38	K2.5 IIIa†	9	−2.4	350	0.041	128	−20 V?	possible var.: type and range unknown further photometric study advisable?	Kaus Media†

												(AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; no AAVSO observations found; conjectural variability type symbol = simply “**VAR:**”; V-passband range stated as “2.7–?”) ¶ Astron. Alm. (epoch 2021.5) assigns MK type K2.5 IIIa CN 0.5 ¶ possibly a weak barium (Ba) star, δ Sgr A possesses (as expected for a Ba star) a WD companion ¶ temperature of δ Sgr A not yet well determined? ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ “Kaus” is Arabic “bow,” with Kaus Borealis (λ Sgr), Kaus Media (δ Sgr), and Kaus Australis (ε Sgr) the three delineating stars of the archer’s bow; by coincidence, the archer turns out to be aiming rather close both to Baade’s Window and (prolonging the line of firing) to the Sgr A* black hole at the galaxy’s centre
η	Ser A	18 22.7 −2 53	3.25†	0.94	K0 III–IV†	54	1.9	~60.5	0.890	218	+9 V?	poss. var.: type unknown (0.91−1.28 in near-IR K band?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; no AAVSO observations found; no conjectural variability-type symbol assigned) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 3.062 mas ± 2%, at 700 nm, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ slow rotator (but ≤ 1.9 y) ¶ high velocity relative to Sun suggests that η Ser is an interloper (born outside the galactic thin disk? consistently with this conjecture, Fe is underabundant)
ε	Sgr A	18 25.9−34 22	1.84	−0.03	A0 IIn (shell?)†	23	−1.4	~143	0.130	198	−15	**Kaus Australis**† fast rotator (consistent with shell-star classification); as might be predicted for a fast rotator, a magnetic field, and also X-ray emission, have been detected ¶ Astron. Alm. (epoch 2021.5) assigns MK type “A0 II–n (shell)” ¶ has been classified as a λ Boo star, apparently in error ¶ IR excess indicates debris disk (possibly also detected in polarimetry), at average separation 155 au; and yet a companion (other than the WDS-documented celestial-sphere neighbours ε Sgr B, ε Sgr C, ε Sgr D) is also asserted, surprisingly present within this debris-disk radius ¶ ε Sgr B,C,D are at mags. 14.3, 8.4, 9.0 respectively; AC astrometry is 2.2″→2.4″, PA 146°→142°, 1992→1999; AD astrometry (as a pair at wide angular separation) is 858″→863″, PA 36°→36°, 1980→2022 ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter (1.44 mas ± 4%, with limb-darkening correction, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia
α	Tel	18 28.9−45 57	3.51†	−0.17	B3 IV†	12	−1.2	280	0.056	198	0 V?	 stars.astro.illinois.edu/sow/alphatel.html remarks that MK luminosity class IV notwithstanding, α Tel is still on the astrophysical (as opposed to the MK-phenomenological) Main Sequence (in other words, is still fusing core hydrogen) ¶ said in 2005ApJS..158..193S to be among the (rare) He-rich stars; these authors list α Tel as a candidate-and- unconfirmed β Cep variable, and say they

												suspect it is a variable in the slowly pulsating B-star class; although α Tel has *HIPPARCOS* microvariability (0.909 d), it is absent from the AAVSO(VSX) database as viewed 2022 March 03, 2022 Jul. 31, 2024 May 09 (since no status flag, not confirmed variable, not suspected variable, not confirmed non-variable; a fortiori no variability classification symbol) ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
λ	Sgr A	18 29.6−25 24	2.82	1.04	K1 IIIb	~41.7	0.9	78	0.191	194	−43 V?	modest X-ray emission indicates some magnetic activity (not usual in a duly evolved, stable core-He-fusing, HR diagram “clump star”) ¶ λ Sgr B is mag. 9.9; AB 101″→82″, PA 188°→184°, 1911→2019 ¶ lunar occultations are possible, planetary occultations possible yet rare; most recent planetary occultation was by Venus, on 1984 Nov. 19 ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition does not report any interferometric measurement of angular diameter, but does report an occultation measurement, without limb-darkening correction: 4.2 mas ± 7% ¶ unusual in occupying fully three roles in the Western pictorial traditions: as northernmost star of the Archer’s Bow, as westernmost (handle-tip) star of the Little Milk Dipper, and as uppermost (lid-knob) star in the Teapot	Kaus Borealis†
α	Lyr A	18 37.8+38 49	0.03†	0.00	A0 Va†	130	0.6	25.0	0.350	35	−14 V	pole-on rapid rotator with circumstellar disk (rotation speed is 92% of breakup rate); the rotation, because pole-on, fails to produce the classic spectroscopic signature of line broadening, but is detectable through the analysis of low-latitudes gravitational darkening and (at these same latitudes, given the pole-on orientation) limb darkening ¶ pole-on rotators are useful for asteroseismology, since all but the axisymmetric modes (whether radially symmetric or radially not symmetric) are helpfully rendered invisible to photometry (and in a rather analogous way, equator-on rotators are also useful through suppression of some modes); α Lyr pole-on orientation represents an extreme on a continuum whose other extreme is represented by the equator-on rapid rotator α Leo A (Regulus); the α Lyr A rapid rotation (2015A&A...577A..64B, using interferometry, now confidently asserts 0.68 d) yields oblate spheroid shape (here as with α Leo A); it is this, with consequent latitude-varying photosphere (severe temperature and luminosity gradients along the arcs of photospheric longitude, with effective temperature at equator ~2300 K lower than effective temperature at poles), rather than any evolution beyond core-hydrogen-fusion stage, that explains the anomalously high luminosity (α Lyr A is in MK luminosity class Va, rather than in the slightly dimmer V class	**Vega**

that would be observed if
its orientation were to be equator-on)
¶ α Lyr A is now known to harbour
all three of the classical
circumstellar-dust regimes (~1500 K, near-IR;
~120-170 K, mid-IR, as an
analogue of our own zodiacal dust; and
~50 K, far-IR, as an analogue
of our own Kuiper Belt:
for regimes overview without
specific reference to α Lyr,
cf 2013ApJ...763..118S, section 1):
2013ApJ...763..118S is the paper
announcing discovery of the second
of these around α Lyr
(with sections 5.1 and 5.2,
respectively, summarizing
previous α Lyr A work on the
first and third of the three regimes):
a question of recent interest
is the origin of the α Lyr A
exozodiacal (warm-regime, mid-IR)
dust (episode analogous to our own
planetary system's Late Heavy
Bombardment? or, rather,
some steady-state replenishment mechanism?);
efforts at detecting exoplanet(s)
to account for the complex
inferred, and indeed in some
wavelengths also now directly imaged,
disk structure have not yet succeeded
¶ 2007ASPC..364...305G,
reviewing the history of α Lyr A
photometry, considers modest variability likely,
the historical use of α Lyr A as a photometric
standard notwithstanding;
(and indeed α Lyr A
is described at AAVSO(VSX) as
a low-amplitude δ Sct variable,
in the now-obsolete AAVSO(VSX) "DSCTC"
classification bin, fluctuating between
−0.02 and +0.07 in V, with period 5 h
(AAVSO(VSX) assessment as of 2024 May 09:
status flag = confirmed variable;
117 AAVSO observations found;
variability classification symbol = "**DSCTC**"))
¶ the JMDC (2021 Sep. 14 edition) most recent
reported interferometric measurement
of angular diameter with limb-darkening correction
is 3.28 mas ± 0.5%, in the 550 nm–850 nm passband,
from the NPOI beam-combining facility,
US Naval Observatory station at Flagstaff, AZ
¶ 2010A&A...523A..41P,
with 2014A&A...568C...2P corrigendum,
is a recent discussion of α Lyr A magnetism
(the authors note that α Lyr A
"may well be the first confirmed
member of a much larger, as yet
unexplored, class of weakly-magnetic
stars now investigatable with
the current generation of stellar
spectropolarimeters"; for origin, they
somewhat favour dynamo over fossil,
and radiative dynamo over core dynamo):
consistently with magnetism,
2015A&A...577A..64B finds,
via line-profile variations,
multiple (bright, not dark) star spots,
in some undetermined
complex pattern (authors comment
that this is "first strong
evidence that standard A-type
stars can show surface structure");
2015A&A...577A..64B is
additionally one of several papers
summarizing recent work on an
interrelated complex of α Lyr A
themes, comprising (in addition

												to magnetism) rotation, spots, photovariability, and pulsation ¶ in 2010ApJ...725.2401F, Fig. 8 with its accompanying discussion summarizes studies on elemental abundances (important because α Lyr A, as a rather “normal” star for MK temperature type A, might serve as a benchmark for appraising chemically peculiar A stars) ¶ WDS documents an exceptionally large number of celestial-sphere neighbours for α Lyr A (B,C,D,E,F,G,H, Ia,Ib,J,Ka,Kb,L,M,N,O,P,Q,R,S,T); all of these are faint apart from B and E (each at mag. 9.5, and each known to be not gravitationally bound to A): AB 37″→85″, PA 117°→185°, 1781→2023; AE 150″→83″, PA 40°→39°, 1831→2023 ¶ E(B–V) =0.00	
φ	Sgr†	18 47.3−26 58	3.17	−0.11	B8 III	14	−1.2	240	0.051	89	+22	reported in 2023 to be interferometric binary, 17.7 mas in 2023RNAAS…7…95W, using two consecutive 2017 nights at VLTI GRAVITY beam-combining facility: angular separation of 17.7 mas corresponded to projected physical separation of 1.3 au (true physical separation may have been greater); determination of orbit, including eccentricity, awaits further work; the secondary is believed to be MS star of MK type M2; this result is a contribution to the poorly-known field of B-star multiplicity; the 2023 report follows on a troubled earlier history of refuted binarity claims, including a lunar occultation judged spurious; we may expect WDS in coming years to respond by creating entries for “φ Sgr A”, “φ Sgr B” ¶ stars.astro.illinois.edu/sow/phisgr.html discusses some difficulties in physical modelling (if pole-on rotator, then there will be troublesome temperature and luminosity gradients along the arcs of photospheric longitude) ¶ AAVSO(VSX) situation as of 2024 May 21: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
β	Lyr Aa1†	18 51.1+33 24	3.42v†	0.01†	B7 Vpe (shell)†	~3.4†	−3.8	~960†	0.004	152	−19 SB	eclipsing, 3.30–4.35 in V, 13 d period is increasing at constant rate of ~19 s/y; orbital solution has been published for β Lyr Aa1, β Lyr Aa2 (although not for the wider binary β Lyr Aa, β Lyr Ab, and not for the still wider binary β Lyr A, β Lyr B); this orbit is seen nearly edge-on; prototype of the β Lyr class of eclipsing systems (but has also been assigned to the new class of “W Ser stars”: 1980IAUS...88..251P); AAVSO supplies information both via VSX database (showing, e.g. the high-precision recent determinations of period; assessment as of 2024 May 09 is as follows: status flag = confirmed variable; 49941 AAVSO observtions found; variability type = “**DPV:/EB**”; period = 12.944 d) and via https://www.aavso.org/vsots_betalyr (a detailed astrophysics discussion, with bibliography): alternating deep and shallow visible-light minima, with the object eclipsed in the deep minima (the “donor”) a Roche-lobe-filling giant, currently ~3 M☉ and diminishing, and the object eclipsed in the shallow minima (the “gainer”) embedded in a thick accretion disk, currently ~13 M☉ and increasing; mass transfer is copious (~2e–5 M☉/y); this disk renders the gainer dim, and its eclipses consequently shallow, even	Sheliak

though the (presently dim) gainer is (now, at this rather late stage in mass transfer) already ~4 times more massive than the (bright) donor (cf 1963ApJ...138..342H); further, instabilities in the accretion disk, from which ~20% of the light comes, make the light curve liable to vary slightly from cycle to cycle; the presently dim gainer is destined to be first (1) brightening, and spun up by conservation of angular momentum, as its obscuring accretion disk disappears by being dumped down into photosphere, and then (2) to become a slower rotator, tidally locked with the secondary; at stage "(1)," the system will be a so-called "Rapidly Rotating Algol," at stage "(2)," on the other hand, the system will be simply a "classical Algol"
¶ 2008ApJ...684L..95Z presents the first (CHARA-interferometric) binary-resolving imaging, achieving resolution ~0.5 mas or ~0.7 mas (and for the first time in astrophysics deduces a β Lyr Aa1,Aa2 astrometric orbit); the bright low-mass donor, and the presently dim high-mass gainer, are evident, corroborating the overall conception of 1963ApJ…138..342H; 2008ApJ...684L..95Z discusses also polar outflow jets on the gainer (these do not alter the essential situation: for the gainer, equatorial gain exceeds polar loss), and deduces a distance to ±15% (a distance consistent-to-within-uncertainties with the *HIPPARCOS* distance)
¶ available interferometric imaging succeeds in revealing the slight distortion of β Lyr Aa1 through the gravitational pull of β Lyr Aa2; surprisingly, the JMDC 2021 Sep. 14 edition does not report any direct measurement of β Lyr Aa1 angular diameter (whether through interferometry or by any other direct means); https://en.wikipedia.org/wiki/Beta_Lyrae has a multi-frame animation of the Aa1,Aa2 binary, from CHARA interferometry
¶ available interferometry makes it possible to study the circumbinary dusk disk enveloping β Lyr Aa1,Aa2
¶ 2012ApJ...750...59L discusses possible hot spot at edge of accretion disk, on the basis of spectropolarimetry (and 2013MNRAS.432..799M has modelling that provides for hot spot, and additionally for a bright spot, on the accretion disk)
¶ some observations have been made in radio and (a regime especially relevant to hot-spot studies) X-ray
¶ strictly speaking, this is a hierarchical system, Ab experiencing the binary that is Aa1+Aa2 as essentially a point mass; for the Aa+Ab pairing, and for possibility of further pairings (AB, AC, … , Be, …), cf WDS (which documents 14 observations for Aa1,Aa2 2006→2007, and a single observation, from 2002, for the wider pairing Aa,Ab (0.5″; WDS gives the respective magnitudes as 3.6, 8.2)) and (a source that reports inter alia *Gaia*) en.wikipedia.org/wiki/Beta_Lyrae
¶ m_v, B−V values are for β Lyr Aa1,Aa2,Ab combined light
¶ although we here, following Garrison, assign a rather straightforward spectral type, this should be taken only as a starting point: cf, eg., 2000A&A...353.1009B, which lists six systems of spectral lines, while repeating an old O. Struve warning that spectrum involves circumstellar matter
¶ Kaler comments in stars.astro.illinois.edu/sow/sheliak.html "one of the most confusing, heavily studied, and Important stars of the nighttime sky"
¶ the rather long period, with the large magnitude swing, and the readily discoverable difference in depths of the alternating minima, make this object a suitable binoculars-or-naked-eye photometry project (using γ Lyr A as a comparison) even from locations suffering rather frequent cloud
[THIS STAR ONLY IN ONLINE VERSION OF TABLE]

σ	Sgr Aa	18 56.9−26 16	2.08	−0.21	B3 IV	14	−2.2	230	0.056	164	−11V	fast rotator ¶ the σ Sgr Aa,Ab duplicity was discovered, with suggestion that mags. are roughly equal, but with the system not resolved, through the Narrabri intensity interferometer (1974MNRAS.167..121H); WDS as at 2025 April 06 documents 3 measurements of Aa,Ab, most recently in 2023 (in 1991 separation was found to be ~12 mas), through aperture-masking interferometry at AAT (1994A&A...290..340B); σ Sgr B, at mag. 9.95, is known to be not gravitationally bound to σ Sgr Aa,Ab; AB 309″→349″, PA 244°→239°, 1837→1999 ¶ m_v, B−V values are for σ Sgr Aa,Ab combined light ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ lunar occultations are possible, and planetary occultation possible-yet-rare (most recently Venus, 1981 Nov. 17) ¶ E(B–V) =+0.02	**Nunki**
ξ^2	Sgr	18 59.3−21 04	3.51	1.18	K1 III	9	−1.7	400	0.034	113	−20	occultations (at any rate lunar) are possible ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC (2021 Sep. 14 edition) does not report any interferometric measurement of angular diameter, but does report three occultation measurements, the most recent of these being 3.5 mas with large uncertainty ± 23%, with some type of limb-darkening correction, at 751 nm ¶ the angular proximity of ξ^1 Sgr (mag. 5.1, separation ~1°) is a mere line-of-sight coincidence **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
γ	Lyr A	18 59.9+32 44	3.25†	−0.05	B9 II†	5	−3.1	600	0.003	290	−21 V†	poss. slight var.: type unkn. (3.23−3.26 in V?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; no AAVSO observations found; no conjectural variability-type symbol assigned) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.734 mas ± 5%, in the visible-light R passband, from the PAVO beam-combining facility at CHARA ¶ has been both asserted and denied to be SB ¶ 2001A&A...371.1078A reports many metals underabundant	Sulafat
ζ	Sgr AB†	19 04.3−29 50	2.60†	0.08†	A2 IV–V + A4:V:	37	0.4	90	n.a.	n.a.	+22 SB	A: 3.3; B: 3.5, 0.2″ (2023), 21.1 y, compos. spectrum PA is 133° in 2023; the system is astrometrically well observed, with 214 astrometry measurements 1867→2023; A-to-B distance is 10.6 au min, 16.1 au max, average 13.4 au ¶ m_v, B−V values are for ζ Sgr AB combined light ¶ under IAU rules, “Ascella” designates ζ Sgr A, not ζ Sgr B ¶ stars.astro.illinois.edu/sow/ascella.html discusses uncertainty in masses, remarks that temperatures are not yet directly measured ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable) ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ ζ Sgr C (72″ in 2017) is probably a mere optical companion	Ascella
ζ	Aql A†	19 06.6+13 54	2.98†	0.01†	A0 Vann	~39.3	1.0	83	0.096	184	−25 SB	poss. slight var.: unknown type (2.98−2.99 in V?)	Okab

													among the most rapidly rotating stars known (period 16 h) ¶ since the SB is not as yet resolved (not even interferometrically), WDS is unable, at any rate as of 2025 April 06, to write “ζ Aql Aa,” “ζ Aql Ab”; in the faint angular-proximity grouping ζ Aql B,C, D, E, ζ Aql B, at mag. 12.0, has been asserted to be a gravitationally bound companion of the ζ Aql A SB pair (5″→7″, PA 60°→46°, 1874→2016; A-to-B distance is ≥ 125 au, period ≥ 800 y); also, the exceedingly faint (mag. 16.2) ζ Aql E may be gravitationally bound ¶ m_v, B−V values are in principle for ζ Aql AB combined light (where, however, the contribution of faint ζ Aql B is negligible) ¶ ζ Aql assemblage may harbour slight variability; further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; no AAVSO observations found, no conjectural variability-type symbol assigned; possible V-passband range 2.98–2.99) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.888 mas, with the large uncertainty of ± 15%, in the 800 nm–1300 nm passband, from the KIN beam-combining facility at the W.M. Keck Observatory ¶ 2008A&A...487.1041A reports near-IR excess around ζ Aql A, and suggests that an unseen close companion is a more likely source than a close-in hot debris disk	
λ	Aql	19 07.7	−4 50	3.43	−0.10	B9 Vnp (kB7HeA0)†	26	0.5	120	0.093	192	−12 V†	possible SB ¶ rapid rotator (< 21h) ¶ suspected chemically anomalous (metals-weak, in λ Boo class); Astron. Alm. (epoch 2021.5) assigns MK type “A0 IVp (wk 4481)” ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.57 mas ± 5%, in the visible-light R passband, from the PAVO beam-combining facility at CHARA	
τ	Sgr	19 08.6	−27 38	3.32	1.18	K1.5 IIIb†	27	0.5	120	0.255†	191	+45†	possible SB ¶ high velocity relative to Sun suggests origin outside galactic thin disk; underabundance of metals is consistent with this conjecture ¶ slow rotator (≤ 270 d) ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
π	Sgr AB†	19 11.3	−20 59	2.89†	0.36†	F2 II–III + n.a.	6	−3.1	500	0.036	182	−10	possible variability now discounted (AAVSO(VSX) assessment as of 2024 May 09: status flag = nonvariable (had been flagged as suspected variable when AAVSO(VSX) was viewed 2022 July 31); seems no AAVSO observations found; variability-type symbol = “CST”) ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ in HR-diagram terms, π Sgr A lies on blue edge of IS, without being presently observed to pulsate ¶ tight triple system, seldom successfully resolved π Sgr A is mag. 3.6, π Sgr B is mag. 3.6, and π Sgr C is mag. 6.0; AB 0.1″→0.1″,	Albaldah

												PA 152°→179°, 1936→1989 (only 5 astrometry measurements), with A-to-B distance ≥ 13 au, AB orbit ≥ 15 y; AB-C 0.4″→0.3″, PA 122°→136°, 1936→1939 (only 3 astrometry measurements), with AB-to-C distance ≥ 40 au, orbit ≥ 100 y; under IAU rules, "Albaldah" designates π Sgr A, not π Sgr B or π Sgr C ¶ mv, B−V values are for π Sgr ABC combined light ¶ lunar occultations of ABC are possible, planetary occultations possible yet rare (next by Venus, 2035 Feb. 17)	
δ	Dra A	19 12.5+67 42	3.07	0.99	G9 III	33.5	0.7	97	0.133	46	+25 V	AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 3.254 mas ± 2%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson	Altais
δ	Aql Aa	19 26.8 +3 10	3.36†	0.32†	F2 IV†	64	2.4	51	0.268	72	−30 SB†	slight var.: (γ Dor type?), 3.36−3.37 in V band, 1.045 d fast rotator (> 0.9 d) ¶ Astron. Alm. (epoch 2021.5) assigns MK type F2 IV–V ¶ the SB that is δ Aql Aa,Ab has been observed just once in successful astrometry (speckle interferometry, 1979, with 1.9 m telescope at OHP, with angular separation found to be 132 mas ±8%); the Aa,Ab duplicity was discovered astrometrically, through periodic perturbation in proper motion of δ Aql Aa, in 1929 (Alden, as reported in 1936AJ.....45..193A); an astrometric-spectroscopic orbit is offered in 1989AJ.....98..686K, with period 3.426±0.006 y, *e*=0.36±0.07 (rotational broadening makes the spectroscopy difficult; also, this paper deduces a large magnitude difference between δ Aql Aa and δ Aql Ab, diminishing the prospects for easy interferometry) ¶ stars.astro.illinois.edu/sow/deltaaql.html discusses points of uncertainty (incl. the just-mentioned binarity, and possible δ Sct variability; although in 2018 δ Aql was not in the AAVSO(VSX) database, AAVSO(VSX) as viewed 2022 July 31 flags the δ Aql assemblage as a confirmed variable, giving V-passband range 3.36−3.37 and period 1.04524 d, and assigning the variability-type symbol "**GDOR:**", for possible-and-yet-not-certain γ Dor variability; same assessment is given by AAVSO(VSX) as viewed 2024 May 09 (noting that no AAVSO observations have been found); further photometric study advisable? ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ m_v, B−V values are for δ Aql Aa,Ab combined light	
β	Cyg Aa†	19 31.8+28 01	3.08†	1.13†	K3 II†	10†	−2.3	330†	0.009	229	−24 V	B: 4.7, 35″; Aa, Ab, Ac ≤ 0.3″ (2023) B is of B−V colour −0.09, MK type B9.5 Ve ¶ if AB is true binary, orbit is possibly ≥ 100 000 y; the competing mere-optical-companions thesis is argued by Bob King in *Sky & Telescope* 2016 Sep. 21; same conclusion is reached in 2018 by P. Plait at www.syfy.com-syfywire/long-standing-as tronomical-mystery-solved-albireo-is-not-a-binary-star, on strength of fresh *Gaia* data (which yield for β Cyg B **π** = 8.4 mas ±2%, implying distance for β Cyg B, to two significant figures, 390 ly; however, further analysis is needed, since astrometry of β Cyg A is potentially perturbed by the multiplicity of A (en.wikipedia.org/wiki/Albireo recaps literature, with some reference to recent interferometry)); WDS takes the firm view that AB is not a true binary, citing discrepancy in its accepted parallaxes, while also noting the binarity defence arguments of R. Griffin in	Albireo

												1999JRASC..93..208G (Griffin's assumed parallaxes are for their part not discrepant; in arguing for binarity, Griffin also *(a)* cites the statistical improbability of two such bright objects appearing on the celestial sphere at so tight an angular separation if they are not gravitationally bound, and *(b)* notes the possibility of shared proper motion (with, he stresses, proper motion observations rendered difficult by possible astrometric wobble in the photocentre of the Aa,Ac binary)) ¶ Aa,Ab,Ac are at mags. ~3.4, ~5.0, ~5.2 respectively; m_v, B−V values are for β Cyg Aa,Ab,Ac combined light; Ab, Ac have been detected in speckle interferometry ¶ the Aa,Ac binary has been measured in astrometry 67 times, 1976→2023 (typical angular separation ~0.3″); 2008AN....329...54S offers a preliminary Aa,Ac orbit (with *e*~0.3; since period is ~210 y, the orbit will remain only imperfectly known over coming decades); the Aa,Ab binary has been measured in astrometry just twice (1978,1995, with the 1978 angular separation 0.1″) ¶ our values, for β Cyg A, of **π** = 10 mas (strictly, 9.5 mas ± 6.0%), with D consequently computed to two significant figures as 330 ly, are taken uncritically from *Gaia* ~2018, rather than (as in our previous Handbook editions) from *HIPPARCOS*; we do not here attempt a critical investigation of uncertainties ¶ β Cyg B is a fast rotator (< 0.6 d), and consistently with this is in emission (as "Be," rather than plain "B": being very evolved, this star is not, however, an instance of the "Be phenomenon" as discussed in Section 5.9 of our accompanying essay) ¶ β Cyg B is not now thought to be a binary, but a single star (WDS note, and WDS "X" flag) ¶ AAVSO(VSX) assessment of β Cyg A system (not including β Cyg B) as of 2024 May 09: status flag = suspected variable; no AAVSO observations found; no conjectural variability type assigned; possible V-passband range 3.05–3.12); as of 2024 May 09, AAVSO(VSX) has no assessment for β Cyg B ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter for β Cyg Aa (4.834 mas ± 1%, with limb-darkening correction, at 800 nm, from the Mark III beam-combining facility at Mount Wilson), and reports no direct determination of angular diameter (whether through interferometry or by another other direct means) for β Cyg B ¶ the name "Albireo," colloquially associated with the AB pairing as visible in a small telescope, applies under IAU rules only to β Cyg Aa
δ	Cyg A†	19 45.8+45 12	2.91†	−0.03	B9.5 III	20	−0.7	160	~0.066	~42	−20 SB	B 6.3, F1 V; 1.9″→2.8″, PA 41°→214°,1826→2022 Fawaris orbit 780 y; separation 84 au min, 230 au max, 157 au average, period 780 y ¶ m_v, B−V values are for δ Cyg AB combined light ¶ δ Cyg A is a rapid rotator ¶ δ Cyg C is gravitationally bound to the AB pair: mag. 12, angular separation (2017) 62.5″, PA (for AC): 66°→67°, 1913→2017 ¶ variability has been suspected both in A and in B; nevertheless, AAVSO(VSX) asserts constant light (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed non-variable; no AAVSO observations found; variability classification symbol = "**CST**"; we take our apparent-magnitude value from this assessment) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.884 mas ± 7%, in the near-infrared H passband, from the CLIMB beam-combining facility at CHARA

												¶ E(B–V)=+0.05	
γ	Aql A	19 47.5+10 41	2.72†	1.51	K3 II†	~8.3	−2.7	390	0.017	100	−2 V	possible variability: unknown type and range further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; only 2 AAVSO observations found; conjectural variability-type symbol = simply “VAR:”; passband range stated as “2.72–?”) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 7.056 mas ± 1%, in the 550 nm–850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ radius ~0.5 au ¶ a rare instance of a “hybrid” star (possessing a (hot) corona, like our Sun’s, and yet also emitting the cool high-mass wind typical in an evolved star)	Tarazed
χ	Cyg A	19 51.6+32 59	to 3.3v†	1.92	S6,2e-S10,4e(MSe)	6	–	~500	3	298	+1.6	Mira-type variable (408 d; max. in 2024 July was 4.4 in V) ¶ we take MK type range from AAVSO(VSX), which follows 1974ApJS...28..271; the unusual type “S” is in temperature terms similar to MK type “M,” but signifies anomalous composition, with carbon and oxygen both abundant, and their abundances roughly equal; the comma notation, as explained at en.wikipedia.org/wiki/S-type_star, seeks to document both temperature and composition; Astron. Alm. and 1980ApJS...43..379K for their part do not attempt to give an MK range, assigning simply the one S-type “S6+/1e” (where “1e” is not a luminosity class, but is a carbon-versus-oxygen abundance index) ¶ AAVSO(VSX), as viewed 2024 May 09, gives the V-band range as 3.3−14.2 and the period as 408.05 d, assigning variability-type classification symbol “**M**”; the two brightest visually estimated maxima since 2000 Jan. 01 were at some point in 2006 August (with AAVSO recording a visual estimate of ~3.1 on 2006 Aug. 13; there is no V-band measurement from this time in the AAVSO archive) and in 2013 May (with AAVSO recording a visual estimate of ~3.3; there is additionally a V-band measurement from 2008 May 13, of mag. 3.77 with uncertainty 0.04); the second most recent maximum was in 2022 April (visual estimate ~4.4, 2022 April 21, in reasonable agreement with V-band measurement 4.69 from 2022 April 22); the most recent maximum was in 2023 May (visual estimate ~4.7, 2023 May 10 through 2023 May 26 (~constant light), in good agreement with V-band measurement 4.8 from 2023 May 19, 2023 May 20), with the next maximum consequently being due around 2024 June ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric study of angular diameter, without limb-darkening correction, with three measurements at 700 nm, and one measurement at each of the wavelengths 710 nm, 833 nm, 902 nm, in a study of pulsation conducted with aperture-masking interferometry at the William Herschel Telescope, Roque de los Muchachos Observatory, in the Canary Islands (so the available interferometry for χ Cyg A is somewhat less extensive than the available interferometry for that more celebrated "Mira" pulsator, Mira itself, i.e. o Cet Aa): the three results for 700 nm are 34.0 mas ± 5%, 40.0 mas ± 10%, and 43.5 mas ± 9% ¶ we take D, and by inference π, from 2009ApJ...707..632L,	

													(which, modifying the Baade-Wesselink method, compares interferometrically measured angular size fluctuations against spectroscopically measured radial velocities); this method agrees to within uncertainties with the *HIPPARCOS* 2007 determination (the uncertainty in both cases being large, on the order of 20% or 25%). ¶ we compute the M_V range from the m_V range, using the 2009ApJ...707..632L value of ***D*** **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
α	Aql A	19 52.1	+8 56	0.76†	0.22	A7 Vnn	195	2.2	16.7	0.660	54	−26	rapid rotator (~7 h or ~8 h, latitude-dependent) the first MS star, other than the Sun, to yield a measurement of photospheric oblateness (2001ApJ…559.1155V); 2007Sci…317..342M announces CHARA imaging with angular resolution ~0.65 mas (the first direct imaging of any MS star other than the Sun; news.bbc.co.uk/2/hi/science/nature/6709345.stm is a news writeup); 2007Sci…317..342M shows oblate rotation-flattened photosphere, brighter at poles than at equator; equatorial diameter of α Aql A is roughly 20% greater than polar diameter; the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ, is 3.309 mas ± 0.2%, in the 550 nm to 850 nm passband (we at the *Handbook* presume, for the wider axis of the apparent distorted disk: NPOI, unlike CHARA, does not yield separate measurements of the wider and narrower axes) ¶ found in 2005ApJ…619.1072B, via *WIRE* salvage mission, to be a slight variable of the δ Sct type, a classification now followed by AAVSO(VSX) (which indicates a fluctuation of 0.004 mag in V, period 91.32 minutes (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; 7 AAVSO observations found; variability classification symbol = "**DSCT**")); *WIRE* makes this the brightest known δ Sct variable; second-brightest is β Cas; the 2005ApJ…619.1072B authors suggest that many δ Sct variables, as residents of the IS, may be oscillating at such low amplitudes as to evade detection except by such sensitive facilities as *WIRE* (their suggestion helps relieve a longstanding astrophysical puzzlement over IS residents that appear, inexplicably, not to be pulsating) ¶ drawing on interferometry, spectroscopy, and the 2005ApJ…619.1072B δ Sct asteroseismology, 2020A&A…633A..78B, while conceding a failure of uniqueness, and consequently conceding the need for further spectroscopy, offers a physical model that takes account of the rapid rotation (by assuming mere cylindrical symmetry, and not the outright spherical symmetry that would be appropriate in the modelling of a slow rotator); Table 5 of the paper summarizes its results, comparing them against earlier modelling; the paper finds a typical core rotation period ~0.6 of the rotation period of the photosphere, and with only modest latitude variation (shearing) in the rotation period in the photosphere (with middle altitudes ~7.7 h, equator ~7.8 h, immediate vicinity of poles ~8.1 h); the paper deduces a value for core metallicity that makes α Aql A young, aged only ~100 My (but some other recent literature proposes instead ~1.2 Gy; both suggested ages are consistent with the failure of α Aql A to have progressed significantly off the MS); the paper ascribes to α Aql A a remarkable variation in envelope temperature, with the envelope convective (because cooler) at low latitudes and radiative (because hotter) at high latitudes (a similar	**Altair**

													latitude-governed bifurcation in envelope characteristics is believed present in the rapid rotator α Cep A (Alderamin)); consistently with this latitude-dependent temperature variation, 2009A&A…497..511R finds modest coronal X-ray emission, attributed to modest dynamo activity at the low or intermediate latitudes (the authors note that of the stars not in a tight binary system, α Aql A is among the hottest known to have coronal X-ray emission) ¶ 2017A&A…608A.113N reports time-varying IR (K-band) excess, suggestive of tenuous circumstellar material (possibly debris disk: the "Be phenomenon," present in many hot, young rapid rotators, is believed to involve a gas disk rather than a debris disk) ¶ since proper motions of α Aql A and α Aql B are discrepant, AB is not a true binary (AB astrometry: 143″→196″, PA 335°→286°, 1781→2015); under IAU rules, the name "Altair" designates just α Aql A	
η	Aql A†	19 53.8	+1 05	3.65v†	0.68	F6–G1 Ib	2	−4.3	1000	0.011	140	−15 SB	Cepheid var.: 3.49–4.30 in V passband, 7.2 d (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; 33513 AAVSO observations found; variability classification symbol = "**DCEP**"; period = 7.17679 d (same value as given 2022 March 03 and 2021 Jan. 28, and in 2019 January); BSC5 asserts 7.176641 d with period changes; 2002ApJS..140..465B (in centre panel of the author's Fig 1) gives (1990s?) photometry (to tighter than ±10 millimag), colour, and radial-velocity curves ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.804 mas ± 0.4%, in the 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ η Aql B is mag. ~10; η Aql AB has been split with HST WFC3 (cf 2020ApJ...905...81E, A-to-B distance is ~200 au, AB period ~900 y); the AB astrometry, documented in WDS as of 2025 April 11, consists of just 3 observations (0.7″→0.6″, 2011→2022); A is for its part an SB not as yet resolved, for which 2020ApJ...905...81E gives period 4 y, suggesting that the orbit is eccentric and is seen nearly face-on (i.e. is seen in the orientation least favourable for the radial-velocity investigation required in orbit spectroscopy) ¶ in the case of novice Northern Hemisphere observers troubled by frequent cloud, its rather long period makes η Aql A a better high-amplitude Cepheid demonstration than the more celebrated δ Cep A **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
γ	Sge	19 59.9	+19 34	3.51†	1.57	M0 III†	13	−1.0	260	0.070	71	−33 V?	slight var.: type unknown, range 0.004 in V band, 6.38 d further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; no AAVSO observations found; V passband variation given as "3.51 (0.004)"; period = 6.37836 d (same value as when AAVSO(VSX) was viewed 2022 July 31); variability-type classification symbol simply "**VAR**") ¶ Astron. Alm. (epoch 2021.5) assigns MK type M0– III ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 6.225 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ already has a dead carbon core, is not yet a Mira **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
θ	Aql Aa	20 12.7	−0 44	3.24†	−0.07†	B9.5 III†	11	−1.5	290	0.036	81	−27 SB2†	a good marker of celestial equator slight "HB" var. (*TESS*); AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable (had been flagged as confirmed non-variable when AAVSO(VSX) was	Antinous

												viewed in 2022); no AAVSO observations found; variability-type classification symbol = “**HB**” (for binaries with a “heartbeat”-shaped lightcurve, reminiscent of ECG trace in cardiology; the unusual light-curve is a consequence of tidal distortions, as the binary components attain periastron in their highly eccentric orbit; cf further en.wikipedia.org/wiki/Heartbeat_star); the slight variability, over V-passband range 0.010, was discovered by NASA *TESS* mission; period= 7.12425 d) ¶ there may be some unclarity in the literature regarding “Aa,” “Ab” nomenclature (cf WDS Note): it is at any rate clear that the SB2 that is θ Aql A has now been interferometrically resolved, and that two quite similar orbital solutions have been published (period 17.124 d, e≈0.6); recent discussions include 1995AJ....110..376H, 2000A&AS..145..215P ¶ m_v, B−V values are for θ Aql Aa,Ab combined light (respective individual mags. are ~3.5, ~5.0) ¶ θ Aql A pairing is metal-rich ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ Astron. Alm. (epoch 2021.5) assigns MK type B9.5 III+	
β	Cap Aa†	20 22.5−14 42	3.08†	0.79†	K0: II:†	10	−2.0	300	0.046	81	−19 SB	hierarchical quintuplet (or greater) en.wikipedia.org/wiki/Beta_Capricorni has a diagram summarizing the known gravitationally bound hierarchy: Aa, Ab1 (seen), Ab2 (unseen), Ba, Bb, where Aa is mag. 3.1, Ab1Ab2 is mag. 4.9, Ba is mag. 6.2, Bb is mag. 9.1 (but Wikipedia needs a caveat: since Ab is not yet resolved, even in interferometry, the designations “Ab1,” “Ab2” are not, at any rate as of 2025 April 13, WDS-conformant); WDS also lists, as nearby in angular separation, C (mag. 8.8, 226″), D (mag. 13.0, 116″), and E (mag. 14.4, 3.9″ from D): Ab1, Ab2 period is 8.7 d; Aa experiences Ab1,Ab2 as essentially a point mass, recently at angular separation 50 mas (period 3.77 y, inter-component distance ~4 au); Ba, Bb 0.4″, according to WDS (and yet en.wikipedia.org/wiki/Beta_Capricorni states 3″), PA 106°→51°, 1884→2023; AB 205″, PA 268°→266°, 1800→2016; each of (Aa,Ab), (Ba,Bb) experiences the other as essentially a point mass, at separation ≥ 0.34 ly, with the (Aa,Ab)+(Ba,Bb) orbit ≥ 700,000 y; orbital solutions have been published for Aa,Ab and for Ba,Bb, but not for the wide (Aa,Ab)+(Ba,Bb) pairing ¶ m_v, B−V values are for β Cap Aa,Ab combined light ¶ spectral type of β Cap A is controverted; entire system appears in spectrograph as K0: II: + A5: V:n ¶ β Cap A is overabundant in Hg, Mn, and several other heavy elements ¶ lunar occultations are possible, planetary occultations possible-yet-rare: the JMDC (2021 Sep. 14 edition) reports no interferometric measurements from either the three β Cap A stars or from the two β Cap B stars; this source does, on the other hand, report several measurements of β Cap Aa from lunar occultations, the most recent being 5.5 mas ± 15%, with limb-darkening correction, from occultations on 1976 Sept. 05 and 1977 Oct. 20 ¶ further photometric study advisable? (AAVSO(VSX) assessment of the β Cap A (not β Cap B) part of the assemblage, as of 2024 May 09: status flag = confirmed variable; seems no AAVSO observations found; very slight variability (V passband range 0.003, period 1.40657 d); variability-type symbol = simply “**VAR**”;	Dabih

												as of 2024 May 09, AAVSO(VSX) does not have an entry for the β Cap B part of the assemblage)	
γ	Cyg A†	20 23.2+40 21	2.21†	0.67	F8 Ib†	2	−6.5	2000	0.003	111	−8 V	possible variable: type unknown (2.15–2.26 in V?) further photometric study advisable? (AAVSO assessment as of 2024 May 09, for the entire γ Cyg assemblage: status flag = suspected variable; a single AAVSO observation found; no conjectural variability-type symbol assigned) ¶ a rare instance of a yellow (F-type) supergiant (among supergiants, it is the hotter and the cooler types that are more usually encountered; γ Cyg A resides near the HR diagram IS: 2010AJ....140.1329G first surveys the observational literature, then discusses spectral variations (possibly pulsation-style oscillation, or alternatively large convection cells are possible; and indeed convection cells can be a driver of oscillation)) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.018 mas ± 0.8%, in the near-infrared K passband, from the PTI beam-combining facility at Palomar Observatory (the correction is large: the uncorrected value is 2.903 mas); stars.astro.illinois.edu/sow/sadr.html has a discussion of the difficulty in assigning a physical radius (offering ~1 au) ¶ BSC5: “no demonstrable connection” between γ Cyg and the so-called γ Cyg supernova remnant	Sadr
α	Pav A	20 27.7−56 39	1.93†	−0.20†	B2.5 V	18	−1.8	180	0.086	175	+2 SB†	poss. var.: type unknown (1.93−1.96 in V?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; seems no AAVSO observations found; no conjectural variability-type symbol assigned) ¶ SB, not as yet resolved (so WDS is not, at any rate as of 2025 April 13, able to write “α Pav Aa,” “α Pav Ab”), 11.753 d, inter-component distance 0.21 au ¶ the SB that is α Pav A has celestial-sphere neighbours α Pav B (mag. 9.1), α Pav C (mag. 9.7), α Pav D (mag. 9.7), at rather wide angular separations from α Pav A, with rather scant astrometry coverage (AB 245″→249″, PA 85°→80°, 1879→2008, with just 7 measurements; AC 226″→244″, PA 80°→77°, 1879→2010, with just 3 measurements; AD 59″→62″, PA 249°→254°, 1904→2010, with just 3 measurements; BC 18″→17″, PA 332°→332°, 1835→2010, with just 10 measurements) ¶ m_V, B−V values are for the combined light in the unresolved α Pav SB ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.80 mas ± 6%, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia ¶ 1988A&A...201..273V discusses galactic-astronomy implications of puzzling deuterium paucity in α Pav A ¶ E(B–V)=+0.02 ¶ the name, although anomalously English, is nevertheless IAU-official: its origins lie in 1930s RAF Air Almanac project, which directed HM Nautical Almanac Office that no air-navigation star was to be left nameless	**Peacock†**
α	Ind A	20 39.4−47 12	3.11	1.00	K0 III CN−1†	33	0.7	98	0.083	37	−1	 Fe overabundant (α Ind AB born in metal-rich ISM cloud?) ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori	

												no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	
α	Cyg A	20 42.3+45 23	1.25†	0.09†	A2 Ia	2†	−6.9	~1400†	0.003	47	−5	blue supergiant, of radius ~0.5 au or ~1 au for context pertaining to this particular BSG in the general population of hypergiants and supergiants, cf en.wikipedia.org/wiki/List_of_largest_stars (which adopts "~1 au"); for current state of theoretical investigations into BSG populations (crossing Hertsprung-Russell diagram for the first time, redward? or, rather, after episode of mass loss, crossing for the second time, blueward?) cf, e.g. 2014MNRAS.439L...6G ¶ slightly variable, and the prototype of the α Cyg variables (AAVSO(VSX) assessment for α Cyg as of 2024 May 09: status flag = confirmed variable; 192 AAVSO observations found; variability classification symbol = "**ACYG**"; V-passband range 1.21–1.29); seemingly irregular (in the α Cyg variables, many short-period oscillations are superimposed); 2011AJ....141...17R discusses α Cyg A, reporting a 1977-through-2001 campaign in both photometric and spectroscopic variability ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.017 mas ± 1%, in the near-infrared K passband, from the PTI beam-combining facility at Palomar Observatory (the correction is large: the uncorrected value is 2.285 mas) ¶ α Cyg A core hydrogen-fusion career started in MK spectral type B, or possibly even in the rare MK spectral type O ¶ present mass-loss rate is ~8e-7 $M_{\odot}$/y ¶ slow rotator (period possibly as long as 0.5 y, consistently with its large radius and its ongoing mass loss) ¶ public-outreach astro audiences enjoy comparing and contrasting distance, and therefore intrinsic luminosity, of α Cyg A with distance, and therefore intrinsic luminosity, of the other two Summer Triangle stars (nearby α Lyr A (Vega), nearby α Aql A (Altair); all three are similar not only in their apparent magnitudes, but also in falling within MK type A, and consequently in lacking tint, even through binoculars); it is perhaps worth stressing in such lectures that the α Cyg A distance, although large (1500 ly? more?), is nevertheless not yet well known; Kaler in stars.astro.illinois.edu/sow/deneb.html, accepting ~1500 ly, writes that if placed at distance of α Lyr A, α Cyg A "would /…/ be as bright as a well-developed crescent Moon, cast shadows on the ground, and easily be visible in broad daylight"	**Deneb**
η	Cep A	20 45.8+61 56	3.42†	0.92†	K0 IV†	70.1	2.6	46.5	0.823†	6	−87†	high velocity relative to Sun indicates interloper status in galactic thin disk (and observed underabundance of Fe is consistent with interloper status) ¶ mv, B−V values are in principle for η Cep AB combined light (where, however, the contribution of faint η Cep B, at mag. ~11, is negligible) ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.882 mas ± 3%, at 700 nm, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ	

ε	Cyg Aa†	20 47.3+34 04	2.47†	1.03†	K0 III	44.9	0.7	73	0.486†	47	−11† SB†	the SB that is ε Cyg Aa,Ab (period ≥ 15 y, only one set of lines visible) has been interferometrically measured-and-resolved just twice, in the period 1983→1991 ¶ mv, B−V values are for ε Cyg Aa,Ab combined light ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 4.61 mas ± 0.4%, in the near-infrared K passband, from the MIRC beam-combining facility at CHARA ¶ velocity of Aa,Ab (and of faint, outlying, gravitationally bound red dwarf C, mag. 13.4) relative to Sun is high ¶ the name "Gienah" (from Arabic "Al-Janāh", "The Wing"), has been used for ε Cyg, but is not IAU-official (being, instead, the IAU-official name for γ Crv, in a different celestial bird; "Corvus" and "Cygnus" are, respectively, "crow" and "swan")	Aljanah
β	Pav	20 47.3−66 06	3.42	0.16	A6 IV†	~24.1	0.3	135	0.044	283	+10	still a fast rotator (≤ 2.3 d), although core hydrogen fusion is ended or is close to ending ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ Astron. Alm. (epoch 2021.5) assigns MK type A6 IV^{-}	
ζ	Cyg Aa†	21 14.1+30 20	3.21†	0.99†	G8 IIIa Ba† 0.5	23	0.0	140	0.069	175	+17 SB	in evolutionary terms, possibly a Red Clump resident (stable helium fusion in core); but it might also be the case that core-helium fusion has yet to begin ¶ SB is resolved, as ζ Cyg Aa, ζ Cyg Ab: 1992Obs...112..168G discusses spectroscopy, reviewing the history at a level of detail so instructive as to make this a case study for spectroscopy technique generally, even outside the particular domain of the ζ Cyg system; an orbital solution for Aa,Ab has been published, asserting period 6489 d (~18 y), with *e*=0.22; on this solution inter-component distance is 8 au min, 13 au max, 11 au average, and angular length of semimajor axis of the rectified orbit is ~190 mas; Ab is a WD, of mag. 13.2; the Aa,Ab binary was first split with far-UV imaging from IUE (in general, UV is a desirable regime for observing binaries with an elusive WD secondary, since WDs, although faint in the V band, are UV-bright); additionally, 2001MNRAS.322..891B announces direct imaging with HST WFPC2 (elongated smear, WD partly resolved, possibly 36 mas; but this observation was made under unfavourable conditions, near periastron); as of 2025 April 13, WDS documents just one successful astrometric data point for Aa,Ab, from the year 2000; the ζ Cyg Aa,Ab SB binary, long observed spectroscopically, and now open to space-based UV astrometry, is of interest for WD studies, since determination of orbit yields determination of WD mass (admittedly, a very small number of WD orbits, notably including the respective WD companions of two stars in this Handbook table, Sirius (in α CMa) and Procyon (in α CMi), have been determined even from terrestrial astrometry; with the advent of space-based UV astrometry, the overall WD mass-determination situation, historically something of a bottleneck, may now be expected to improve) ¶ mv, B−V values are in principle for ζ Cyg Aa,Ab combined light (but contribution	

												of Ab, at mag. ~13, is negligible) ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.821 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ ζ Cyg Aa is chemically a mild barium star (Astron. Alm. (epoch 2021.5) assigns MK type "G8+ III–IIIa Ba 0.5"); before becoming a WD, ζ Cyg Ab, as a mass-shedding AGB star, deposited barium onto ζ Cyg Aa	
α	Cep A	21 19.2+62 42	2.46†	0.22	A7 Van†	66.5	1.6	49.1	0.158	72	−10 V	fast rotator, unusual envelope tmpr. gradient rotation period < 12h; the rotational shape distortion, into an oblate spheroid, gives α Cep A a remarkable variation in envelope temperature, with the envelope convective (photosphere ~6600 K) at equator and radiative (photosphere ~8600 K) at poles (the transition temperature is ~8300 K); 2009ApJ...701..209Z presents CHARA/MACIM interferometric imaging of α Cep A, in which gravity darkening at the equator is evident (the authors caution, further, that their observed gravity darkening does not quite fit the usual modelling): a similar latitude-governed bifurcation in envelope characteristics is present (cf 2011ApJ…732…68C Fig. 9) in the rapid rotator α Aql A (Altair) ¶ Astron. Alm. (epoch 2021.5) assigns MK type A7 V^+n ¶ listed by AAVSO(VSX) as δ Sct variable, nominal m_v 2.46 with range 0.002 in V (*TESS* mission), salient period 71.7 minutes (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; 33 AAVSO observations found; variability classification symbol = "**DSCT**") ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter (1.577 mas ± 6%, with limb-darkening correction, in the 800 nm - 1300 nm passband, from the KIN beam-combining facility at the W.M. Keck Observatory ¶ several factors, including X-ray emission (consistent with corona, as might be expected for convection-harbouring latitudes of the envelope) indicate magnetic activity	Alderamin
β	Cep Aa†	21 29.0+70 41	3.23v†	−0.22†	B1 III†	5	−3.4	700	0.015	56	−8 SB	variable: 3.16–3.27 in V, 0.19 d; B: 8.6; 13.5″ (2024) PA 255°→248°, 1779 →2024 ¶ variability range 3.16−3.27 in V; the prototype of the β Cep variables (although stars of this same type are sometimes called the "β CMa variables"), and (as is typical for the type) known to be multiperiodic: AAVSO supplies a 2010 Apr. 13 backgrounder at www.aavso.org/vsots_betacep; AAVSO(VSX) as viewed 2021 Jan. 16, 2022 July 16, 2024 May 09 asserts salient period 4.57171 h; AAVSO archives a notice for an August 2009 β Cep campaign (coordinated photometry, spectroscopy, CHARA) at www.aavso.org/aavso-special-notice-162 (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; 1722 AAVSO observations found; variability classification symbol = "**BCEP**") ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter (0.28 mas ± 6%, with limb-darkening correction, in the visible-light R passband, from the PAVO beam-combining facility at CHARA) ¶ β Cep Aa is a magnetic star ¶ system comprises at least (the much-studied variable) Aa and Ab (mag. 6.6, probably a	Alfirk

													Be-phenomenon star, and the origin of the Be-phenomenon behaviour observed in AaAb); Aa,Ab period is variously suggested as 50 y, 85 y; astrometry is now quite good, with 85 measurements over the period 1971→2007 (angular separation 0.3″→0.2″); if β Cep B is gravitationally bound to the Aa,Ab SB (no AB orbital solution has been published), then period is ≥ 40,000 y, with (Aa,Ab)-to-B distance 3,000 au ¶ m_v, B−V values are for β Cep Aa,Ab,B combined light; GCPD gives directly measured m_v, B−V values for β Cep Aa,Ab combined light as 3.19, −0.23; GCPD gives directly measured m_v, B−V values for β Cep B as 7.83, 0.12 ¶ MK luminosity class III (“giant”) notwithstanding, β Cep Aa is still fusing hydrogen in its core	
β	Aqr A	21 33.0	−5 27	2.90†	0.83†	G0 Ib†	6	−3.2	500	0.020	114	+7 V?	rare instance of a yellow (G-type) supergiant β Aqr A is possibly now evolving blueward in a second crossing of the HR diagram ¶ spectroscopically a “hybrid” star, combining signature of hot corona with signature of cool massive wind; 2005ApJ...627L..53A, in a study jointly covering β Aqr A and the astrophysically similar hypergiant (likewise a hybrid) α Aqr A, reports *Chandra* observation of coronal X-rays (first X-ray detection from a hybrid G supergiant; such supergiants are X-ray deficient, their coronae notwithstanding) ¶ β Aqr lies in the IS on the HR diagram, and yet is not known to be a pulsator ¶ their ~10° separation on the celestial sphere notwithstanding, β Aqr A and α Aqr A have shared proper motion and similar parallaxes (and WDS β Aqr A is the same object as WDS α Aqr C; this pairing of β Aqr A a.k.a. α Aqr C with α Aqr A is further discussed in bestdoubles.wordpress.com/2014/12/15/the-alpha-beta-gamma-of-aquarius-%CE%B1-%CE%B2-and-%CE%B3-aquarii/) ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter with limb-darkening correction (2.704 mas ± 0.3%, in the 550 nm–850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ)	Sadalsuud
μ	Cep A	21 44.3	58 54	4.0v†	2.35†	M2$^-$ Ia	1?†	−8?	3000?†	0.007	155	+21	red supergiant ¶ semiregular var., 3.4−5.1 in V 1997JBAA..107..135B, using 1959-1993 data, finds periods of ~840 d and ~4400 d, and notes (“Table 3”) the broad consistency of this result with 7 other multi-decade photometric studies, all starting from various points in the 19th century; rather sparse AAVSO data, with visual observations rather than with V-passband filter, suggest a recent maximum (most recent available datum, as of 2024 May 22: mag. 3.4, from 2024 March 09); another recent brightness plateau, in the ~30+day period centred on 2022 July 01, yielded V-band measurements of mag. ~3.4 (AAVSO(VSX) assessment as of 2024 May 22: status flag = confirmed variable; 86128 AAVSO observations found; variability classification symbol = **SRC**; period = 835 d); for wider μ Cep A photometric context, cf. en.wikipedia.org/wiki/List_of_semiregular_variable_stars ¶ we take MK type from 1989ApJS...71..245K; however, 2011ARep...55...31S asserts emission (at temperature type M2, luminosity class Ia) ¶ the determination of ***D*** is difficult, with the *HIPPARCOS* parallax very uncertain, and with μ Cep A parallaxes in general	Garnet Star

												troubled by the non-negligible angular diameter of this extraordinarily distended star; following Table 2 in 2020MNRAS.493..468D, we compute ***D*** as 940 pc * (3.26 ly/pc) = 3064 ly, stating this to one significant figure (the cited “Table 2” gives a large uncertainty in the direction of increase, almost 15%, while giving a smaller uncertainty in the direction of decrease) as 3000 ly; the “Table 2” determination of ***D*** is based on reliable *Gaia* DR2 (2018) parallaxes for hot (and to the *Gaia* telescope adequately punctiform) celestial-sphere neighbours of μ Cep A, assumed by the “Table 2” compilers to belong to the stellar association into which μ Cep A itself was born; en.wikipedia.org/wiki/Mu_Cephei refers to this “Table 2” determination, but additionally to two other very discrepant determinations; upon conversion to our own favoured units of ly, followed by reduction to a single significant figure, these Wikipedia-cited determinations become 1000 ly and 6000 ly, thereby yielding a discouragingly wide distance bracket ¶ we compute ***π*** directly from the “Table 2” ***D*** determination, as 1 mas ¶ as of 2024 Sep. 19, μ Cep A has the IAU-official name, “Garnet Star”: in 1783, W.Herschel noted to its “very fine deep garnet colour,” and indeed many garnets are deep red; the star colour, although unremarkable to the naked eye, is vivid in binoculars ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter with limb-darkening correction (20.584 mas ± 2%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson) **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**
ε	Peg A	21 45.5+10 00	2.39†	1.52†	K2 Ib†	5	−4.2	700	0.027	89	+5 V	slight irregular var.: 2.37–2.45 in V (flare in 1972) **Enif** (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; 2179 AAVSO observations found; variability classification symbol = “**LC**” (irregular cool supergiants)); 1972IAUC.2392....1W reports extreme flare-like brightening, ~10 minutes, to V mag. 0.7 ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 7.459 mas ± 3%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ orange-class supergiant ¶ Astron. Alm. (epoch 2021.5) assigns MK type K2 Ib–II ¶ 1987MNRAS.226..563S discusses abundances, finding that, earlier literature notwithstanding, ε Peg A is unremarkable in its barium (and unremarkable in its strontium), and therefore discounting an earlier suggestion that ε Peg A outer layers have hosted nucleosynthesis in slow-neutron capture ¶ m_v, B−V values are for ε Peg A alone (i.e. are not combined-light values) ¶ BSC5 suggests “cooler shell surrounding” ¶ WDS documents as celestial-sphere neighbours the faint ε Peg B (mag. ~13, known to be not gravitationally bound to ε Peg A (angular separation 83″ in 2013), and additionally the less faint ε Peg C (mag. 8.7; AC astrometry is 138″→144″, PA 323°→318°, 1825→2018)
δ	Cap A	21 48.5−16 00	2.86v†	0.30	A3mF2 IV: †	84	2.5	38.7	0.396	139	−6 SB†	ecl. binary: Alg. type, V 2.83–3.05, 1.0 d **Deneb Algedi** ¶ since SB has not been measured as a visual binary (not even interferometrically; the binarity has, admittedly, been demonstrated in at least one occultation: lunar occultations are possible, planetary

												occultations possible-yet-rare), WDS is not, at any rate as of 2025 April 13, able to write “δ Cap Aa,” “δ Cap Ab”; the δ Cap A pair is classified at AAVSO(VSX) as an Algol-type eclipsing binary, 1.0227688 d in AAVSO(VSX) as viewed 2021 Jan. 16, but 1.0227672 d as viewed 2022 Feb. 23, 2022 July 16, 2024 May 22; AAVSO(VSX) as viewed 2022 July 16, 2024 May 22 asserts also δ Sct variability (denied, however, by 1994MNRAS.266L..13L) in the δ Cap assemblage; further, AAVSO(VSX) has O–C, i.e. period-monitoring, plotting from 2016; secondary in the SB is ~3 mag. fainter than primary and is judged in 1992MNRAS.259..251W to be mildly active, possibly tidally locked, with large spot; A is known to be SB since 1906 (Slipher), and yet is known to be eclipsing only as of 1956PASP...68..541E; 1994MNRAS.266L..13L remarks that “given the brightness of the system, δ Cap is poorly observed,” with period awkward for any one solitary observatory (an implication of this remark is that coordinated intercontinental photometry would now be helpful); AAVS(VSX) as of 2024 May 22 indicates that the AAVSO database has just 24 observations (the count was 23 on 2022 July 16), assigns variability classification symbol “**EA+GDOR+DSCT**”: further photometric study advisable? ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ Astron. Alm. (epoch 2021.5) assigns MK temperature type F2m and does not assign an MK luminosity class	
γ	Gru	21 55.5−37 14	3.00	−0.12	B8 IV–Vs	15	−1.1	210	0.099	98	−2 V?	¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means)	Aldhanab
α	Aqr A	22 07.1 −0 11	2.94†	0.97†	G2 Ib†	6	−3.1	~520	0.021	117	+8 V?	a good marker of the celestial equator ¶ a rare instance of a yellow supergiant; possibly now evolving blueward in a second crossing of the HR plane; resides in the IS (under at least one definition of IS) and yet is nonpulsating (cf further 2017AstL...43..265U) ¶ spectroscopically a “hybrid star,” combining signature of hot corona with signature of cool, massive wind; 2005ApJ...627L..53A, in a study jointly covering α Aqr A and the astrophysically similar supergiant (likewise a hybrid star) β Aqr A reports *Chandra* observation of coronal X-rays (first X-ray detection from a hybrid G supergiant; such supergiants are X-ray deficient, their coronae notwithstanding) ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability-classification symbol ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 3.066 mas ± 1%, in the 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ despite their ~10° separation on the celestial sphere, α Aqr A and β Aqr A have shared proper motion and similar parallaxes (and WDS β Aqr A is the same object as WDS α Aqr C; this pairing of β Aqr A a.k.a. α Aqr C with α Aqr A is further discussed in bestdoubles.wordpress.com/2014/12/15/the-al pha-beta-gamma-of-aquarius-%CE%B1-%CE%B2- and-%CE%B3-aquarii/)	Sadalmelik
α	Gru A	22 09.9−46 50	1.74†	−0.14	B7 Vn	32	−0.7	101	0.194	139	+12	poss. slight var.: type unknown (1.70−1.76 in V?)	**Alnair**

												further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status = suspected variable; seems no AAVSO observations found; no conjectural variability-type symbol assigned) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.02 mas ± 7%, at the very short wavelength of 443 nm, from the pioneering intensity interferometer at Narrabri Observatory (now Paul Wild Observatory) in Australia ¶ rapid rotator (< 1d) ¶ E(B–V)=–0.02
θ	Peg	22 11.5 +6 20	3.52†	0.09	A2mA1 IV–V†	35	1.3	90	0.284	84	−6 SB2	poss. slight var.: type unknown (3.48−3.56 in V?) Biham further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; seems no AAVSO observations found; no conjectural variability-type symbol assigned); assertion of δ Sct variability, from somewhere in the earlier literature, seems to be now discounted ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter (0.862 mas ± 2%, with limb-darkening correction, in the near-infrared K band, from the CLASSIC beam-combining facility at CHARA) ¶ rapid rotator (< 20 h); consistently with rapid rotation, and therefore with a stirred atmosphere, elemental abundances are unremarkable
												[THIS STAR ONLY IN ONLINE VERSION OF TABLE]
ζ	Cep	22 11.8+58 20	3.35†	1.57†	K1.5 Ib†	3.9	−3.7	800	0.014	69	−18 SB	slight irregular variability (3.31−3.40 in V passband) (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; 133 AAVSO observations found; variability classification symbol = "**LC**" (for irregular cool supergiants)) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter, and the only measurement given with limb-darkening correction, is 5.234 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ orange supergiant either approaching core-helium fusion or already in core-helium fusion ¶ an eclipsing companion has been suggested, with suggestion later questioned ¶ metals somewhat overabundant
α	Tuc	22 20.3−60 08	2.85	1.39	K3 III†	16	−1.1	200	0.081	241	+42 SB†	Lang-Exster SB 11.5 y, separation possibly 11.5 au ¶ primary in the SB is a giant, with carbon underabundant, nitrogen overabundant ¶ stars.astro.illinois.edu/sow/alphatuc.html discusses uncertainties in the evolutionary stage of this giant, offering three scenarios ¶ AAVSO situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ in contrast with the usual cases of IAU names for binaries (if a binary is resolved, IAU applies its official name only to the primary component), "Lang-Exster" is IAU-official for the entire (unresolved) binary system; IAU comments, as of 2025 Sep. 19, that "the star is a spectroscopic binary which is why it makes sense to give it a double-name for the visible dot; the name may be split for the components later"; "Lang" is Malayan-Indonesian for "hornbill", and "Exster" Dutch for "magpie"; both avian words ultimately derive via Dutch sailors from

												an indigenous (notably, Dayak) cultural tradition	
δ	Cep A†	22 30.2+58 33	3.60v†	0.48	F5–G2 Ib	4†	−3.0	900†	0.016	77	−15 SB†	the prototype Cepheid variable: 3.49–4.36 in V band, 5.4 d second-nearest Cepheid (α UMi is still nearer) ¶ AAVSO a backgrounder at www.aavso.org/vsots_delcep; additionally, the first three sections of a paper directed inter alia to AAVSO observers, 2016JAVSO..44..179N, constitute a deeper backgrounder on the Cepheids ¶ AAVSO(VSX) has, as viewed 2021 Jan. 28, 2022 Feb. 24, 2022 July 16, 2024 May 09, has period 5.366266 d (is this value possibly now stale?); although Cepheids experience both period jitter and (monotonic) period slide, with a slide of even 200 s/y possible, 2014ApJ...794...80E finds δ Cep period sliding slowly, at just −0.1 s/y (period decrease-increase is a signature of evolution, specifically of density increase-decrease, as a Cepheid passes across the HR diagram (δ Cep is now making its second such passage, moving blueward)) (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; 63672 AAVSO observations found; variability classification symbol = "**DCEP**") ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 1.018 mas ± 0.7%, in the near-infrared K passband, from the PTI beam-combining facility at Palomar Observatory (the correction is large: the uncorrected value is 1.423 mas) ¶ 2015ApJ...804..144A announces that δ Cep A is SB, with period 2201 d ¶ accurate distances to Cepheids are foundational in cosmology, which needs independently known (galactic) Cepheid distances before embarking on its external-galaxy distance deductions through applications of the Cepheid Period-Luminosity (PL) Law; it is reassuring that the 2007 *HIPPARCOS* distance and the distance implied by the usual PL calculation agree to within uncertainties; although we have here stated the 2007 *HIPPARCOS* parallax, on which distance of δ Cep depends, as 4 mas, the cited 2007 *HIPPARCOS* determination is more formally, with decimal fractions and the uncertainty made explicit, 3.77±0.16 mas; 2015ApJ...804..144A proposes instead 4.09±0.16 mas, with the remark that impending *Gaia* may be expected, in part in the light of these authors' SB announcement, to secure an authoritative parallax; an already reassuring state of affairs may thus be expected to improve further ¶ mass loss ~1e–6 M⊙/y; bow shock in ISM has now been detected ¶ δ Cep C, at mag. 6.1, is in slow and wide orbit with δ Cep A (no orbital solution published; period 345,000 y; AC astrometry is 42″→41″, PA 195°→191°, 1800→2018) **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
ζ	Peg A	22 42.8+10 58	3.41†	−0.09	B8.5 III†	16	−0.6	210	0.078	98	+7 V?	slight var.: 3.40–3.41 in V passband, 23.0 h AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; no AAVSO observations found; variability classification symbol = "**SPB**"; period = 22.952 h (same period as was seen in AAVSO(VSX) 2022 July 16);; additionally, 2007PASP..119..483G discusses satellite detection of amplitude ~0.5 millimag ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 0.562 mas ± 5%, in the visible-light R passband, from the PAVO beam-combining facility at CHARA ¶ our (Garrison) MK spectral type notwithstanding, B8 V has been suggested ¶ fast rotator (< 1.4 d)	Homam
β	Gru	22 44.2−46 45	2.11v†	1.62†	M5 III†	18	−1.6	180	0.135	92	+2	semiregular var.:, 1.90–2.3 in V passband, 37 d	Tiaki

												classified at AAVSO(VSX) as semiregular late-type giant, perhaps on the basis of 2006JAVSO..34..156O (this paper might serve as a case study for effective amateur-budget intercontinental photometry collaboration) (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; 457 AAVSO observations found; variability classification symbol = "**SRB**") ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ among the rather uncommon cool red giants, with radius slightly > 0.8 au ¶ Astron. Alm. (epoch 2021.5) assigns MK type M4.5 III
η	Peg Aa†	22 44.2+30 22	2.95†	0.85†	G8 II−III + F0 IV	15	−1.2	210	0.029	153	+4 SB	composite spectrum, SB period 813 d Matar the η Peg Aa,Ab SB is resolved in speckle interferometry, with orbital solution published (66 measurements: 0.1″→0.1″, 1975→2005); BC is itself a tight pairing of equally bright stars, probably a true binary (0.3″→0.2″, 1889→2014; combined light yields mag. ~9.9), probably in orbit with the Aa,Ab binary, making this a hierarchically organized quadruple system; A,BC astrometry is 90″→92″, PA 339°→338°, 1824→2012 ¶ we take the MK type from WDS Note ¶ m_V, B−V values are for η Peg Aa,Ab combined light; it is known that individually, in the R passband as distinct from the V passband, η Peg Aa and η Peg Ab are respectively mag. 4.1, mag. 6.9 ¶ further photometric study advisable? (AAVSO(VSX) assessment for η Peg assemblage as of 2024 May 09: status flag = suspected variable; seems no AAVSO observations found; no conjectural variability-type symbol assigned; possible V-passband range 2.92–2.96) ¶ the JMDC 2021 Sep. 14 edition reports one interferometric measurement of angular diameter without, and one with, limb-darkening correction, the latter being 3.471 mas ± 0.8% in the 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ η Peg Aa is a slow rotator (818 d?)
ε	Gru	22 50.1−51 11	3.48†	0.08	A2 Va	25	0.5	130	0.126121		0 V	poss. slight var.: type unknown (3.47−3.53 in V passband?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; seems no AAVSO observations found; no conjectural variability-type symbol assigned) ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ rapid rotator (< 0.65 d) **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**
ι	Cep A	22 50.6 +66 20	3.52	1.06	K0 III†	28.3	0.8	115	0.141	208	−12	B: 6.5, at separation > 8°, a possible escaped companion (the escaped-companion scenario is discussed in 2011ApJS..192….2S) Astron. Alm. (epoch 2021.5) assigns MK type K0⁻ III ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter (2.646 mas ± 2%, with limb-darkening correction, in the visible-light R passband, from the VEGA beam-combining facility at CHARA) **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**
μ	Peg	22 51.3 +24 45	3.49	0.94	G8 III†	31	0.9	106	0.151	106	+1	Sadalbari Astron. Alm. (epoch 2021.5) assigns MK type G8+ III ¶ AAVSO(VSX) situation as of 2024 May 09: no status flag (so not confirmed variable, not suspected variable, not confirmed non-variable), and a fortiori no variability classification symbol

												¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 2.496 mas ± 2%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson **[THIS STAR ONLY IN ONLINE VERSION OF TABLE]**	
δ	Aqr	22 56.1 −15 41	3.27[†]	0.06	A3 IV–V	20	−0.2	160	0.051	237	+18 V	poss. slight var.: type unknown (3.25−3.29 in V band?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; seems no AAVSO observations; no variability-type classification symbol assigned) ¶ the JMDC 2021 Sep. 14 edition does not report any direct measurement of angular diameter (whether through interferometry or by any other direct means) ¶ weak λ4481 ¶ rapid rotator (< 3.0 d)	Skat
α	PsA Aa[†]	22 59.1 −29 29[†]	1.16	0.09	A3 Va[†]	130	1.7	25.1	0.368	1 17	+7	2008 (HST) image was debris cloud, not exoplnt HST putative 2008 "exoplanet" α PsA Ab was IAU-named Dagon, after a Semitic deity; at ~125 au, in the outermost of the debris rings; Dagon was in always-wide (albeit eccentric) orbit, making direct imaging, as opposed both to spectroscopy (for star Doppler wobble) and astrometry (for star transverse wobble) the tool of choice: 32 au min, 320 au max; period ~1700 y; in more recent years, it was suggested that Dagon could be a mere dust cloud, or an aggregation of rubble, or a single rocky body; an explanation was needed for the fact that Dagon proved so readily HST-visible (e.g. visibility enhanced by circumplanetary dust sphere, or by circumplanetary ring system?); Dagon mass was uncertain (< 2× Jupiter, perhaps even ~Earth); but with Dagon now no longer HST-visible, it would appear that the 2008 HST image was of an expanding debris cloud, now become too tenuous for detection ¶ 2009A&A...498L..41L reports interferometric examination of debris disk alignment: "there is strong evidence, but no definite proof, that the [debris-disk plane] is in the equatorial plane of the central star"; the nested circumstellar dust rings extend as far as radius ~150 au (a distance recalling the Solar System Kuiper Belt); 2017ApJ...842....8M reports complete outer debris-ring mapping, via ALMA (223 GHz radio), finding ring mass of 0.015 Earths, eccentric, with α PsA Aa offset from the ring centroid ¶ α PsA Aa is a fast rotator (< 1d) ¶ in evolutionary terms, α PsA Aa is sufficiently young to be undergoing an analogue of the Solar System's Late Heavy Bombardment (and consistently with this, 2017ApJ...842....9M writes that exocometary gas is detected, in ALMA 230 GHz radio) ¶ 2017ApJ...842....8M comments that "given its unique characteristics and architecture, the Fomalhaut system is a Rosetta stone for understanding the interaction between planetary systems and debris disks" ¶ α PsA Aa has low metallicity ¶ 2013AJ....146..154M, working both from proper motion (across the celestial sphere) and from velocities along the line of sight, concludes that α PsA Aa, α PsA B, and α PsA C belong to the same system: B (a flare star) is V mag. 7, at angular separation almost 2° from Aa (period ≥ 7.6 My), while C is V mag. 13, at enormous angular separation 5.7° from Aa (and yet at a sufficiently low distance from Aa-with-B to have the Aa-with-B gravitational field dominate the general external gravitational field at its location; period is ≥ 35 My) ¶ further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 09: status flag = suspected variable; seems no AAVSO observations; no conjectural variability-type symbol assigned; V-passband range stated as "1.15–?") ¶ the JMDC (2021 Sep. 14 edition) most recent	**Fomalhaut**

												reported interferometric measurement of angular diameter with limb-darkening correction is 2.223 mas ± 1%, in the 800 nm - 1300 nm passband, from the KIN beam-combining facility at the W.M. Keck Observatory ¶ β Peg, α Peg serve as pointers: since α PsA Aa lies a couple of arcminutes N of DEC=−30°, α PsA Aa rises (if briefly) above the horizon even for such Canadian subarctic communities as Churchill, and for such Scandinavian communities as Stavanger	
β	Peg A	23 05.1+28 14	2.46v†	1.67	M2 II–III†	16.6	−1.5	~196	0.232	54	+9 V	semireg. var.: 2.31–2.74 in V passband, 43.3 d (AAVSO(VSX) assessment as of 2024 May 09: status flag = confirmed variable; 12903 AAVSO observations found; variability classification symbol = "**SR**") ¶ as is appropriate for a pulsator, β Peg A has been subjected to many interferometric studies of angular diameter, including prewar Michelson-interferometer (single telescope, with outrigger mirrors) work by the Pease team at Mount Wilson and 1970s intensity-interferometer work by the Hanbury Brown team at Narrabri; the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 17.982 mas ± 1%, at 800 nm, from the Mark III beam-combining facility at Mount Wilson ¶ Astron. Alm. (epoch 2021.5) assigns MK type M2.5 II–III ¶ an intermediary between straightforward red giant and red bright giant (radius ~0.5 au); mass-loss rate is notably low for such a star (≤ 1e-8 $M_{\odot}$/y; i.e. ~100× lower than mass loss rate of α Ori Aa (Betelgeuse); IRAS detected no IR excess)	Scheat
α	Peg	23 06.1+15 21	2.48†	−0.04	A0 III–IV	24	−0.6	133	0.073	124	−4 SB	suggested variability is now discounted (AAVSO(VSX) assessment as of 2024 May 09: status flag = non-variable; 143 AAVSO observations (same as on 2022 July 16); classification symbol = "**CST**") ¶ the JMDC 2021 Sep. 14 edition reports only one interferometric measurement of angular diameter (1.052 mas ± 6%, with limb-darkening correction, in the visible-light R passband, from the PAVO beam-combining facility at CHARA); CHARA has achieved imaging ¶ rapid rotator (1.5 d)	**Markab**
γ	Cep A†+1P†	23 40.5+77 47	3.21†	1.03	K1 III–IV†	71	2.5	46	0.135	339	−42 V?	poss. slight var.: type unknown (3.18−3.24 in V?) further photometric study advisable? (AAVSO(VSX) assessment as of 2024 May 22: status flag = suspected variable; no AAVSO observations found; no conjectural variability-type symbol assigned) ¶ the JMDC (2021 Sep. 14 edition) most recent reported interferometric measurement of angular diameter with limb-darkening correction is 3.254 mas ± 0.6%, in the 550 nm - 850 nm passband, from the NPOI beam-combining facility, US Naval Observatory station at Flagstaff, AZ ¶ γ Cep B is mag. 7.3; the binary γ Cep A, γ Cep B has been split with adaptive optics at Subaru, with direct imaging reported in 2007A&A...462..777N (AB astrometry: 8 measurements, 0.9″→1.8″, PA 257°→15°, 2006→2020); the IAU-official name "Errai" applies to γ Cep A rather than to the two-star system γ Cep AB; Errai hosts an exoplanet, IAU-named Tadmor, which is not as yet astrometrically observed by any optical technique (so WDS is not as yet able to write "γ Cep Aa," "γ Cep Ab"); Tadmor, circumstellar without being circumbinary, is among the few exoplanets discovered in a two-star system; Tadmor orbital period is 2.47 y, with average distance from Errai 2.05 au, and with mass between 3× Jupiter and 16× Jupiter; A-to-B distance is 12 au min, 25 au max, AB orbital period (orbital solution has been published) is 66 y or 67 y ¶ Errai rotation period is possibly 781 d (making this	Errai

star a slow rotator)
¶ Astron. Alm. (epoch 2021.5) assigns MK type K1 III−IV CN 1