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Journal

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Journal

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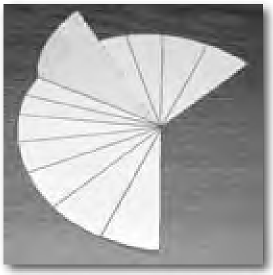

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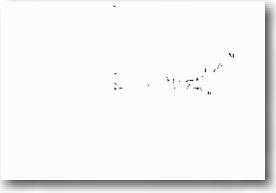

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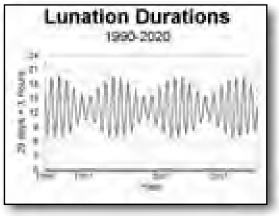

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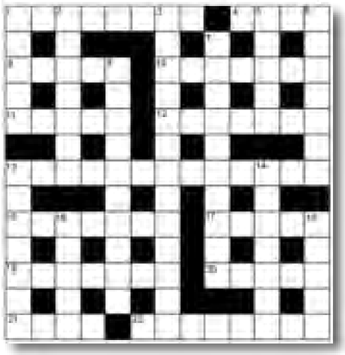

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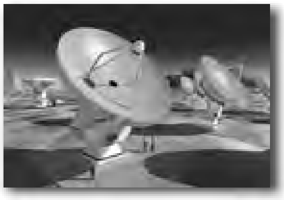

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President's Corner

by Robert F. Garrison (garrison@astro.utoronto.ca)

Finally, it is safe to celebrate the new millennium in earnest. The beginning of the year 2001 is of course the true start of the next millennium, but does it really matter? After all, the various conjectures for an astronomical event marking the birth of Christianity give rise to dates spread over several years. There is no one precise astronomical observation favouring one origin over the other.

There were some advantages to the confusion between zero and one. For one thing, it allowed a two-year celebration. The year 2000 was a recognition of three zeros, which was at least worthy of numerological celebration, since it hadn't happened for a thousand years. Besides giving a boost to the economy — the so-called Y2K problem — it has also been a good vehicle for raising the level of public awareness of the relevance of time and space. We now have another thousand years to forget the lessons.

I've been reading a delightful new book about amateurs: *For the Love of It: Amateuring and Its Rivals* by Wayne Booth, published by the University of Chicago Press. It won't be sent to us for review, so I'd like to give a small pitch here. Wayne Booth is Professor Emeritus of English at Chicago and has written about amateur musicians, but most of his deeply perceptive observations can be applied to amateurism in astronomy as well; just change a few words, and it could have been written about all of us. It is a small book, but well-written and well worth reading. Booth's book has made me more aware than usual of the social dynamics of amateur organizations like ours, so it is especially meaningful for me in preparing to visit centres around this wonderful country.

It has become traditional for the President to tour all of the RASC centres during his or her two years in office. With 25 centres spread over all ten provinces and a couple more negotiating to join, the visits are quite a challenge. During one week in October, I managed to visit all three of the British Columbia centres and discovered why it is important to see people in their natural environment and to meet members who don't attend the National Council meetings or the General Assembly (GA). Thanks to Alan Whitman who arranged the entire tour for me; without his help, I probably still would be trying to set it up.

The big advantage of such tours is the building of bridges so more members will feel a better connection with the National Executive. On the other hand, I now have images of where the members meet and of the kind of equipment they have. Some of the instrumentation is quite impressive, even from the point of view of a professional. I'm convinced that the two groups should be cooperating more. I'll address this latter point in a future column after several more tours.

One of the best parts of the tour was being invited to stay

Journal

The *Journal* is a bi-monthly publication of the Royal Astronomical Society of Canada and is devoted to the advancement of astronomy and allied sciences. It contains articles on Canadian astronomers and current activities of the RASC and its centres, research and review papers by professional and amateur astronomers, and articles of a historical, biographical, or educational nature of general interest to the astronomical community. All contributions are welcome, but the editors reserve the right to edit material prior to publication. Research papers are reviewed prior to publication, and professional astronomers with institutional affiliations are asked to pay publication charges of $100 per page. Such charges are waived for RASC members who do not have access to professional funds as well as for solicited articles. Manuscripts and other submitted material may be in English or French, and should be sent to the Editor-in-Chief.

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overnight in the homes of members and seeing them in context. It feels good to get to know a few people better, forming friendships that might grow with time.

Alan Whitman and Jim Tisdale met me at the Kelowna airport in time for a brief tour and a short rest before my lecture. Jim and Bitten are wonderful hosts. I woke up early to a glorious view of the Okanagan Lake and Valley before being treated to an exceptionally tasty pancake breakfast.

The flight over the mountains from Kelowna to Victoria was smooth and uneventful. Bill Almond, whom I already knew from the 1999 GA, met me and served graciously as host. Bill has a small but powerful telescope with a CCD detector. The dome is conveniently built right onto his garage. Some good friends from DAO (Jim and Betty Hesser, Chris Aikman) and UVic (Colin Scarfe) attended my talk that night.

In the morning, it was off to Vancouver, where Angela Squires had arranged a busy social schedule (at my request; it wasn't her fault that I wanted to do too much for the two days scheduled). The hosts for the night were Bill and Linda Ronald with their daughter Lisa, who was in the throes of writing a thesis. Not only did we have some good conversations, but Bill is a great cook, so for the second time on the tour, I enjoyed out-of-this-world pancakes.

I did manage, courtesy of Craig Breckenridge, to visit David Halliday at AGRA Industries. Their subsidiary, Coast Steel, built the Canada-France-Hawaii Telescope dome as their first foray into astronomical construction, paving the way to many contracts for large domes and gigantic telescopes — a good example of the spin-off idea; the taxes paid on foreign contracts gave back to the government many times the relatively small initial investment.

One of the highlights of the trip was a visit to CARO, the observatory for the Vancouver Centre. A computer running IBM's OS/2, my favourite operating system, runs the whole operation, so I was very anxious to see it. Duncan Munro is the architect of the system. In spite of being sick with flu and fever, he drove up to give me a tour. That is dedication, something that characterizes those lucky people who are bitten by the astronomy bug, regardless of whether they are amateurs or professionals.

GREAT ASTROPHOTOS WANTED

A new feature coming to the *Journal* is a regular gallery where we will feature members' astrophotographs. As well, we always have a use for photos that can be used to illustrate articles in the *Journal*.

For many of our members astrophotography is a passion. The search for the perfect shot of some faint fuzzy can consume countless frigid nights and buggy evenings — as long as the sky is clear and dark, some RASC member is out there shooting the stars and planets and other related phenomena such as aurorae and other atmospheric events.

We invite you to send us your best shots. We can handle prints, transparencies (from 35mm to 8×10 inches), and high resolution digital or scanned images in most popular formats. Your image will most likely be printed in black and white, but if you have a great colour shot, send it along as we try to print at least one colour section per year.

Contact the editors (addresses can be found on the masthead at the beginning of this magazine).

Editorial

by Michael Attas, Associate Editor (michael.attas@nrc.ca)

Do you like to write? If you are reading this journal, you already have an interest in things astronomical. Maybe you also have expertise in some aspect of astronomy, or some experiences you would like to share with other RASC members. The editors of the JRASC would like to hear from you. Editor-in-Chief Wayne Barkhouse, who has generously lent me his soapbox *(i.e.*, editorial column) this month, is keen to find new authors for articles, notes, and columns. And so is the Associate Editor, General (me).

Who knows what might happen? My background is in nuclear science and archaeology, but my interest in the night sky has led me here. For a few years now, I've been proofreading issues of the *JRASC* just before they go to press. That role resulted from some complaining I did to a former editor about errors slipping through the cracks. More recently, I was invited (*i.e.*, had my arm twisted) to help in smoothing out articles on their way to being published. Now that I'm an editor, I can better appreciate all the work that goes into producing each issue of this fine journal. I feel that the more time authors and editors spend making articles clear, accurate, and easy to read, the more appealing they become. In other words, more effort put in by us results in less effort required by the readers. The easier the *Journal* is to read, the more it will get read. So I'm happy to work with authors in preparing their drafts.

The *Journal* contains a wonderful mix of material at many levels. Every issue includes at least one research paper, a publication of original work at the forefront of science. The feature articles and education notes treat specific subjects in some detail, with either a personal or an objective point of view. Most of the columns are personal in nature, but they appeal to a universal thirst for knowledge and a desire to share experiences. Finally, the departments and "Across the RASC" sections bring us news of events and activities within Canada and beyond. I particularly enjoy reading the extracts from early issues of the *JRASC*, entitled "From the Past/Au fil des ans." The French title evokes the image of a thread running through decades of time, connecting us with the past. Somehow, seeing how far we have come lets us more easily dream about where we could go in the future.

The public image of science these days is being battered by special interests of all kinds. In particular, some mass media and politicians have very narrow interests and may seem keener to point out how money is "wasted" doing esoteric research than to celebrate the new knowledge that research can bring. We are very lucky that astronomy gets good press, and new discoveries are often reported purely as an opportunity for wonder. We find out about new extra-solar planets, immense galaxies, or black holes, and we are amazed at the incredible distances, masses, and energies that make up the universe. The night sky is one of the delights of our world, and imagining what lies beyond our vision is a uniquely human trait. Let's encourage this wonder. We can do it by the written word, by taking photographs, by offering peeks through the eyepiece, and by speaking in public. Who knows what might happen?

Correspondence
Correspondance

Dear Sir:

I read with interest, in the August/October issue of the *Journal*, Dr. Leslie J. Sage's article "Weighing the Universe." Dr. Sage mentions how Paolo de Bernardis of the University of Rome and David Wittman of Bell Labs along with their collaborators have determined two of the most important properties of the universe, the total density of matter and energy and the fraction of the total amount that is matter.

The total density of matter and energy of the universe is of course based on the "observable universe," is it not? The so often called "missing or sparsity of matter" problem may be easily explained by the possible fact that we have as yet not reached the so-called end or edge of the universe, if there is one.

William R. Glenfield

[Dr. Sage replies: Mr. Glenfield is confusing total mass and mass density. Think of it like measuring the density of air between an observer and an instrument a few metres away. You don't need to know the total mass of the Earth's atmosphere in order to get a good estimate of the local density. And, by assuming that the observer's location is nowhere special, you can extrapolate to say that you have measured the density of the whole atmosphere (at the elevation above sea level). In just the same way, Wittman has measured the density of mass along the line of sight between us and the cluster that was his source. There is no need to involve any missing mass because it is not relevant to the measurement.]

News Notes
En Manchettes

CANADA JOINS ALMA

Canada has agreed to join an international consortium in the construction and use of a giant millimetre-wavelength telescope high in the Chilean Andes. The Atacama Large Millimetre Array (ALMA) represents the next generation of telescopes that will examine the electromagnetic Universe between the infrared and radio wavelengths. Its construction will be directed by eleven research organizations in Europe, the United States, and now Canada.

Canadian officials from the National Research Council have signed a Letter of Intent with the National Science Foundation that outlines a cooperative effort between the US and Canada. A total of $38 million in Canadian funds is earmarked to help in the construction of the massive telescope array estimated to cost a total of $600 million Cdn. An additional $15 million will also be sought for construction of additional equipment by the Herzberg Institute of Astrophysics. In return, Canadian astronomers will be granted access to ALMA and increased access to all major US national radio astronomy observatories.

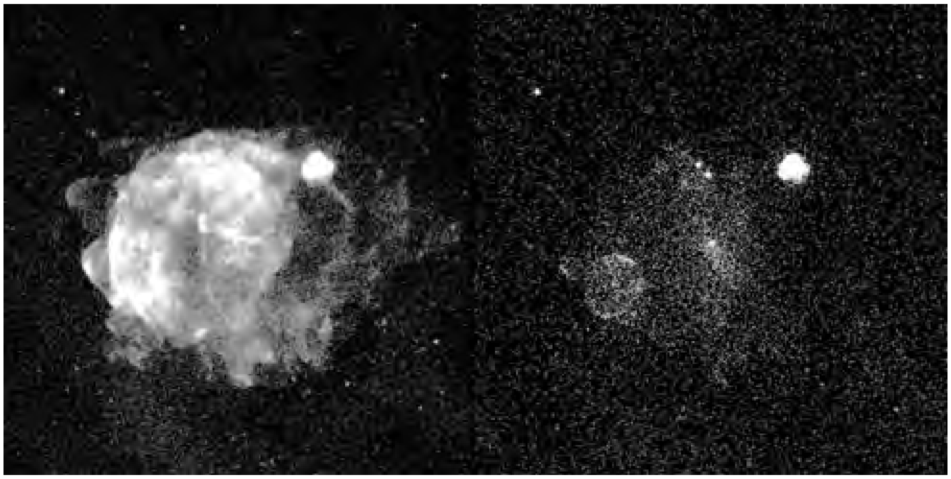
The current plans envisage a cluster of sixty-four antennae each 12 metres in diameter. The individual telescopes can be arranged into baselines up to 10 kilometres in length giving a maximum angular resolution of 10 milli-arcseconds. This is equivalent to resolving detail as small as 20 metres on the surface of the Moon. The total collecting area will be over 7000 square metres. To achieve the telescope's optimum resolution, the parabolic dish antennae must maintain their shape to better than 0.025 millimetres.

The array will be 50 kilometres east of the village of San Pedro de Atacama at an elevation of 5020 metres. The extreme altitude and local climate combine to produce an atmosphere that is exceptionally clear and dry. From almost any other place on the surface of the Earth, additional water vapour in the atmosphere would block much of the millimetre wavelength radiation. Once in operation, ALMA will be the highest continuously operated observatory in the world. The air is so thin at these altitudes that the astronomers will be forced to control the telescope remotely from the Operations Support Base in San Pedro de Atacama at an elevation 2440 metres. Acclimatized workers at the array will have access to buildings with oxygen enriched ventilation.

A conceptual image of the Atacama Large Millimetre Array (Image courtesy of the European Southern Observatory).

One of the primary scientific objectives of the instrument is to examine the formation of the earliest and most distant galaxies. It will also be able to peer into dust-obscured stellar nurseries where it will unravel the mysteries of star formation and witness the birth of planetary systems. The telescope will also produce detailed atmospheric studies of planets and comets in our own Solar System.

Construction is slated to begin in 2001 with first light scheduled for 2005 and full operation in 2009.



Images of the Vela region taken by the *ROSAT* orbiting X-ray observatory. The left image was taken at an energy level between 0.1 and 2.4 keV, while the right image was taken at energies greater than 1.3 keV. In the left image the new supernova remnant is overshadowed by the larger and more distant Vela remnant. The small bright spot in the upper right is Puppis A, another supernova remnant. The new Vela remnant (GRO/RX J0852–4622) can be seen to the lower left of centre in the right hand image. (Images courtesy of B. Aschenbach, Max Planck Institute for Extraterrestrial Physics)

A TRIAD OF FIREBALLS

There is virtually nothing better than the sudden appearance of a brilliant nighttime fireball for exciting public interest in matters astronomical. While it is clear that the great beauty of these coruscating sky-trails is greatly appreciated by the general public, it can be, as Jeremy Tatum and Laura Strumpf, of the Department of Physics and Astronomy at the University of Victoria have recently found out, a frustrating exercise to reconstruct the details of what actually took place. Writing in the November issue of the *Publications of the Astronomical Society of the Pacific*, Tatum and Strumpf present their collected results and experiences from a series of investigations concerning three spectacular fireballs recently seen over Vancouver Island.

The fireballs investigated by Tatum and Strumpf appeared during a remarkable five week period in early 1998. Great care and effort was taken by the authors to interview eyewitnesses *in situ* and to determine accurate positional fixes on the beginning and end height sky-positions of the fireballs. This task sounds easy enough, but as anyone who has ever tried to gather such data readily knows, it is amazing how rapidly memories fade and what little real detail the casual observer actually takes in. Nature can also play a confusing role. Indeed, as Tatum and Strumpf record, "The evening of 1998 March 18 was an eventful one for residents of the Alberni Valley in central Vancouver Island. At 5:43 p.m. PDT there was a mild earthquake. Two minutes later a house blew up. At 2 minutes past 10 p.m. a brilliant light streaked across the sky. And at 11:30 p.m. a deafening bang of unknown origin was heard in the vicinity of Sproat Lake and recorded on local seismographs." Struggling against these odds, many researchers would have retired to reverie, but Tatum and Strumpf did assemble enough data to at least predict approximate ground tracks for the three events.

While it appears that there is little chance of any meteorites being recovered from the fireball events, one of the fireballs, that of April 15, has been linked to the production of electrophonic sounds. A number of eye-witnesses reported hearing a hissing sound at the same time that the fireball was seen. Others reported hearing a whistling or whirring sound. Tatum and Strumpf place themselves squarely in the 'open-minded camp' with respect to electrophonic sounds, and indeed they prefer to buck current trends and refer to the phenomena by the somewhat archaic, but perhaps more descriptive term of simultaneous sound. There is much that is not understood about the production of electrophonic sounds and, as Tatum and Strumpf note, the reality of such sound "is not unquestionably proven, but the evidence for its existence is copious and persuasive and cannot be ignored."

EVIDENCE OF NEW VELA SUPERNOVA FOUND IN ANTARCTIC ICE

Every few centuries a nearby supernova erupts and appears in our skies. However, for reasons still unknown, some supernovae go unnoticed. Recent data from the *ROSAT* orbiting X-ray observatory has uncovered a supernova that apparently went unrecorded (see figure). The remnant called GRO/RX J0852–4622, is situated within the same part of the sky as the well-known Vela supernova remnant. By studying the decay of radiative isotopes within the remnant and examining its expansion rate, the radiation from the supernova was estimated to have reached the Earth about 700 years ago.

Now Clifford Burgess of McGill University and Kai Zuber of the Universität Dortmund in Germany have suggested that evidence of this cosmic explosion is contained in ice cores taken at the South Pole (*Astroparticle Physics*, August 2000). According to current theory, the gamma radiation from the supernova ionizes some of the Earth's atmosphere, producing the nitrate ion NO_3^-. This compound eventually precipitates out of the atmosphere and is then preserved in the permanent ice sheets of the Antarctic.

The chemical history of the Earth's atmosphere can then be read from these ice cores. Like tree rings, the ice cores are dated by counting annual deposits of dust or, in cases of ambiguity, through isotopic analysis. Previous researchers found dramatic spikes in the nitrate concentration at the same time as Kepler's supernovae in 1604 AD, Tycho's supernova in 1572 AD and the 1181 AD supernova recorded by Chinese and Japanese observers. Burgess and Zuber suggest a forth spike near the bottom of the core at the 1320 AD layer may be the telltale signature of the new Vela supernova.

However, Burgess and Zuber agree these findings are not conclusive. Ice cores taken from the Antarctic Taylor Dome and from nearby Vostok, plus additional cores from Greenland show little or no evidence of these nitrate signatures. Burgess and Zuber suggest that the addition of the new Vela supernova nitrate signature makes the possibility of simple coincidence much less likely. However, a reasonable mechanism must be found to explain the uneven nature of the nitrate fallout. The team suggests that the effects of auroral activity may have caused the nitrate signature to be lost in the other cores. Deeper ice cores at the South Pole would help settle this issue by examining the nitrate ion concentration around the time of the 1054 AD (Crab) and 1006 AD supernovae.

A FLURRY OF NEW SATURNIAN MOONS

A combination of three 100 second exposures showing the motion of S/2000 S 2 during 15 minute intervals on the night of August 7, 2000. The field is approximately 1.3 by 1.6 arcminutes with north up and east to the left. These CCD images were taken with the Wide-Field Imager attached to the ESO's 2.2-m Max Planck Gesellschaft telescope at La Silla Observatory in Chile. Images courtesy of the European Southern Observatory.

The Solar System is a little more crowded than we thought. An international team of astronomers led by Brett Gladman, a Canadian who is now working at the Observatoire de la Côte d'Azur in France, and J. J. Kavelaars, of McMaster University in Hamilton, has been very busy discovering new moons around the planet Saturn (IAU Circulars 7512, 7513 and 7521). In October and November of last year the group announced the discovery of six new irregular Saturnian moons. Irregular moons can be distinguished from regular moons by their relatively large distance from the parent planet and their highly eccentric and/or inclined orbits. Due to these unusual orbits, it is believed that these moons were captured after the planet formed. These objects may have formed much earlier than the planets themselves and could be some the oldest objects in the Solar System.

This brings Saturn's total to 24 moons which has overtaken the 21 known moons of Uranus to become the current record holder. The moons are estimated to be only 10–50 km in diameter and probably made mostly of ice with dark crusts. They orbit between 10 and 15 million km from the planet and have an R-band magnitude between about 20 and 23.

The team found these tiny moons by looking for objects that moved in the same direction and at the same speed as the parent planet. Since irregular moons are very far from the planet, their orbital motion around the planet will be slow and their motion across the field will follow the motion of Saturn. Deep CCD images were taken with seven major telescopes including the 3.5–m European Southern Observatory's New Technology Telescope, the 3.6–m Canada-France-Hawaii Telescope, and the newly commissioned 8–m UT1 Very Large Telescope.

There still exists the slim possibility that these objects are actually comets that just happen to be passing Saturn. Continued observations in the next few months will firmly establish their true identity. Once this is accomplished, the objects can be named. For the moment, they have been given the rather prosaic designations S/2000 S 1 to S/2000 S 6. The IAU Circulars with some preliminary orbital elements can be found at: `cfa-www.harvard.edu/iauc/07500/07521.html`.

> "I think there should be a law of Nature to prevent a star from behaving in this absurd way!"
> — *Sir Arthur Stanley Eddington*

UPGRADING YOUR CAMPUS OBSERVATORY

A New Design for an Observing Platform to Retrofit a Small Observatory

by Steve Mallory (smallory@wsu.edu) and Jeff Secker (secker@cyberus.ca)

Long, dark winter nights, clear skies and a large-aperture telescope — what more could one ask for? In our experience, a large, lightweight and versatile platform is essential for safe and successful observing. This is especially true when observing in a group or targeting objects at low elevation angles. In this article we describe the design and construction of a versatile new platform used to retrofit our small observatory.

The Jewett Observatory was built in 1953 on the Pullman campus of Washington State University (WSU), through a generous gift by a couple living in Spokane, Washington. It houses a 12-inch f/15 refractor with a primary lens that was crafted by Alvan Clark around 1889. With this large refractor and some smaller telescopes, the Jewett Observatory provides an ideal facility for the complete range of undergraduate courses offered by the Program in Astronomy at WSU. As well, the WSU Astronomy Club hosts public observing nights, and for observing Comet Hale-Bopp over 300 people visited in one night! High use of the observatory places a heavy demand on the instruments and accessories. Our project was to replace a well-worn observing platform with one that was lightweight, safe and easy to use.

At the Jewett Observatory, the original observing platform was very heavy and awkward to move. It consisted of a steel pipe frame with wooden boards for steps. The height of the top level was too low to allow the observation of objects close to the horizon. Hand railings were too low and the supports were spaced too far apart to be safe for children. We surmise that there are many other antiquated platforms in the smaller observatories around the country that get much more use than was originally conceived and now require safety upgrades or replacement. While the observing platform described in this article was built to match the physical layout of the Jewett Observatory, the general design considerations are certainly relevant to many other observatories.

Figure 1 – The full range of motion of the telescope was analyzed and considered in the design of the new platform. Note the large footprint of the observing platform, which is a result of its height.

During the design stage many solutions were envisioned and presented to the astronomy department. Designs included a simple stair/ladder configuration, alternating platform configurations, stadium-type steps that were wider at the top than the bottom, both radial and circular configurations, and even a design that was based on a spiral of circular platforms that culminated in a circular top platform. This design, when turned around a central post, would have resulted in a nearly round standing platform at any height anywhere inside the room. However, it was determined to be too expensive for our very limited budget, and the higher levels were not required near the base of the telescope.

As we evaluated the platform designs we kept three key issues at the forefront: public safety, expanding the observable range of the telescope, and meeting the budget. It was very important for the

Figure 2 – The new observing platform designed and built for use in Jewett Observatory on the campus of Washington State University. The author Steve Mallory is seen standing atop the platform.

unfamiliar public (who use this platform in the dark) to feel comfortable and be safe. Keeping the platform as light as possible while increasing the stability was important to those who operated the facility. The necessity of observing objects near the horizon dictated that the platform be taller than the original, and this resulted in a larger platform footprint. The full range of the telescope's motion in relation to a new platform and the constraints of the room had to be studied to verify that the design would work correctly (Figure 1). The budget limited the use of expensive materials and complicated metal shapes. Aluminum tubing and rectangular sections were the primary materials used in the construction.

The new observing platform is illustrated in Figure 2. It is a lightweight platform that maintains the structural strength and rigidity required for several users in a dynamic loading environment, and it meets the design requirements specified by the WSU Program in Astronomy. Specifically, an observer must feel comfortable turning outward at any location and have the resulting eye level appropriate for seeing through the eyepiece. The platform frame must be very rigid and provide a low centre of gravity for stability, yet still be light enough for ease of movement.

Wheels were required to have the ability to roll freely with a loaded or unloaded platform, lock in place, and easily support up to six observers. Wheels were also located along the back to roll around the peripheral wall of the dome (Figure 3). Handrails were positioned at 36 inches and guardrails at 42 inches along each step and around the top level. Plexiglas panels were installed for safety, to protect people from falling under the railings. Perforated aluminum safety steps were chosen because of their high strength and light weight (Figure 2). As well, material and construction costs for the new observing platform had to be within the specified budget (approximately $7,000 US).

Observing objects at low elevation angles was also a concern in the design of the platform. To permit near-horizon observing, the height of the uppermost step was raised to five feet three inches. The height of the wall at the base of the dome is 11 feet and the diameter of the dome wall is 25 feet. The height of the telescope mount is approximately 10 feet 10 inches. For the average observer of eye height 5 feet 4 inches, standing on the upper step of height 5 feet 3 inches this results in their eyes being level at 10 feet 7 inches. When coupled with the telescope configuration, an observer of average height can view objects with an elevation angle as low as 9 degrees. A person 5 feet 9 inches tall can see as low as 7 degrees above the horizon.

Schematic drawings for the new Jewett Observatory platform are available from the authors. However, it is important to note that the design of an observational platform requires structural analysis to make sure that all loading conditions are addressed for the specific design.

ACKNOWLEDGEMENTS

Julie Lutz (Astronomy Department, University of Washington; formerly Chair, WSU Program in Astronomy) and Lauren Likkel (Department of Physics, University of Wisconsin at Eau Claire) provided input to the design of the observing platform. The observing platform was funded jointly by the Dean of the WSU College of Science and the WSU Safety Committee. Construction was by Dennis Wilhelm of the WSU Facilities Operations.

Figure 3 – The back of the observing platform. Note the rear outer wheels, which contact the inner wall of the dome, and the Plexiglas panels installed for safety beneath the handrails.

Steve Mallory is a Senior Architect at Washington State University. He designed and supervised the building of the observing platform

Jeff Secker was a Visiting Assistant Professor of Astronomy at Washington State University from August 1995 to May 1998, and he was involved in the upgrade of the Jewett Observatory facilities. He is currently a research scientist at the Defense Research Establishment Ottawa.

Hubble's Nobel Prize

by Domingos S. L. Soares (dsoares@fisica.ufmg.br)

Abstract

Astronomy is not in the list of natural sciences aimed at by the Nobel awards. In spite of that, there were, throughout the 1930s until the early 1950s, effective moves by important scientists to distinguish Hubble with the Prize. A short report on these attempts is made as well as speculation on what would be the citation for the Prize in view of the broad range of Hubble's scientific achievements. Within this context, the opportunity is also taken for publicizing the Crafoord Prize, which does consider astronomy.

Introduction

The astronomer Edwin Powell Hubble never won the Nobel Prize because he died unexpectedly, at the age of almost 64, on September 28, 1953, due to a cerebral thrombosis. His long time family physician assured (!) his wife, Grace Hubble, that the death had been "instantaneous and without pain" (Christianson 1995, hereafter CHR).

Is there a Nobel Prize for astronomy? No, there is not! Hubble would have been the first one to break the old tradition and to change the statutes of the award, as I show below. In the light of this possibility, one might also wonder what Hubble would win the Prize for, given his many scientific achievements.

But before that, in the next section, I describe another first rank award series, also under the auspices of the Royal Swedish Academy of Sciences, namely the Crafoord prize. This prize includes astronomy in the list of awards. In the final section, I comment on the story behind the Nobel award to Hubble and speculate on the choice that would be made by the Nobel Committee, from among his many fundamental investigations in Astronomy, as the Prize statement.

The Crafoord Prize

The Anna-Greta Holger Crafoord Fund was established in 1980 to promote basic scientific research through yearly donations to the Royal Swedish Academy of Sciences. Holger Crafoord (1908–1982) was very active in Swedish industry. From 1964 and on, he developed and manufactured the artificial kidney, a sort of biological dialyzer that would become of vital importance in the world. His company also developed a series of medical instruments that earned him an enormous fortune.

In 1976 he became an honorary doctor of medicine at the University of Lund, followed by his wife, Anna-Greta Crafoord (1914–1994), in 1987.

Specifically, the purpose of the Fund is to promote and award research in the fields not covered by the Nobel prizes in natural sciences, namely mathematics, geosciences, biosciences (with special emphasis in ecology and rheumatoid arthritis), and astronomy. The awards follow a closed cycle based on the annual sequence:

1. mathematics,
2. geosciences,
3. biosciences,
4. astronomy,
5. geosciences,
6. biosciences,
7. mathematics.

The first Crafoord prize was awarded in 1982 to V. I. Arnold, from Moscow State University, for his contribution to the theory of non-linear differential equations. The prize amounts to $500,000 US, a gold medal, and a diploma.

The Crafoord prize is thus every six years assigned to astronomy. The first recipient was Lyman Spitzer, Jr. (1985), then Allan R. Sandage (1991) and in 1997 there were two winners, Fred Hoyle and Edwin E. Salpeter.

More information on the Crafoord and Nobel Prizes is found in the electronic pages of the Royal Swedish Academy of Sciences at the address `www.kva.se/eng/pg/prizes/index.asp`.

Hubble's Nobel

As early as the 1930s (CHR), Fred Hoyle, a frequent guest of the Hubbles at Pasadena, informed Hubble that there was a move, known of in England, by the Nobel Prize Committee in the direction of a legal amendment to the award statutes to make it possible for Hubble to be honoured with this major distinction in the natural sciences. The very same rumour was also heard from Nobel laureate Robert Millikan, Caltech's celebrated physicist.

Of course, Hubble had already been awarded many distinguished prizes, the highest being the Barnard medal, a charge of the National Academy of Sciences, which was granted to him in 1935 at Columbia University. The medal was established in 1895 and is awarded once every five years. All of Hubble's predecessors were Nobel laureates, among them Roentgen, Rutherford, Einstein, Bohr and Heisenberg (CHR). In this case Hubble was also distinguished by being both the first American and the first astronomer to win the medal. The citation in his award was for his "...important studies of nebulae, particularly of the extragalactic nebulae which provide the greatest contribution that has been made in recent years to our observational knowledge of the large-scale behaviour of the Universe."

By 1949 nothing had yet happened, but with the support of the 5-metre Palomar telescope, already in operation, Hubble's work had gained much publicity, which could have triggered a decision by the Nobel Committee (CHR). The final word was soon given when Enrico Fermi and Subrahmanyan Chandrasekhar joined their colleagues in the Committee, unanimously voting Hubble the 1953 Prize in physics (CHR). But it was too late, Hubble's death came first. Incidentally, one should recall that the Nobel prize is not awarded posthumously.

These are the facts. Let us now speculate on an alternate universe, one in which Hubble did survive that unfortunate September afternoon.

The immediate question is what Hubble would be cited for in the Nobel award. The conservative approach usually adopted by the Nobel Committee is well known. The classical example is Einstein's. Awarded the 1921 Prize, he was specially cited for his discovery of the law of the photoelectric effect. It is needless to say that both the Special and General Relativity Theories, which had already been put forward, were not explicitly mentioned.

Allan Sandage, a Crafoord laureate and the greatest of Hubble's followers, in a paper celebrating the centennial of the birth of Hubble (Sandage 1989), enumerates Hubble's four central accomplishments from 1922 to 1936. Sandage adds that any one of them guarantees Hubble a place in the history of modern science. They are:

(a) the morphological sequence of galaxy types,
(b) the discovery of Cepheids in NGC6822, with parallel work in M31 and M33, settling decisively the question of the nature of galaxies,
(c) the determination of the homogeneity of the distribution of galaxies, averaged over many solid angles, and
(d) the linear velocity-distance relation.

All of the four but one may be blurred with controversies, not only in modern times but also, and certainly, in Hubble's time. Nowadays it is recognized that the so-called Hubble "tuning-fork" scheme in (a) applies mainly to close and bright galaxies, that the homogeneity in (c) is broken by the presence of enormous structures like "walls", "streams" and "voids" of galaxies, and finally, even Hubble himself never clearly advocated the idea of a velocity-distance relation in (d); rather he usually put it as a relation between spectral shift and distance, as is evident throughout the classic book *The Realm of the Nebulae* (Hubble 1936). In short, these three otherwise fundamental advances in modern astronomy seem to collide with the spirit of Nobel citations, *i.e.*, they are not solid statements about nature.

This shortcoming is not the case, by any means, with item (b) above. Hubble's work here is the end point of the great debate about the nature of the nebulae. With the unambiguous determination of the distances to the "spiral nebulae" to be much larger than the dimensions of our stellar system, Hubble proved definitely that they are extragalactic, and as a result laid down the foundations of a new branch of research, namely extragalactic astronomy. The other three points mentioned by Sandage are immediate consequences of this major realization, which were soon recognized as such by the genius of Hubble.

Thus, the Nobel Prize to Edwin Powell Hubble goes for his *contribution to the definitive understanding of the nature of the nebulae and for the creation of a new era of scientific investigation.*

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> "Just keep away from the black hole garbage bin by the door as you leave," said the Caterpillar. "It's very useful for getting rid of theoretical papers and weak students!"
>
> — *Malcolm Longair in "Alice and the Space Telescope"*

EDWIN P. HUBBLE, 1889–1953

Edwin Powell Hubble, one of the few Honorary Members of the Royal Astronomical Society of Canada, was born at Marshfield, Missouri, on November 20, 1889, and died at Pasadena, California, on September 28, 1953 — just before the end of his sixty-fourth year.

In 1910 he obtained the B.S. degree at the University of Chicago, where he became interested in astronomy. He was chosen a Rhodes Scholar, and studied law for two years at Oxford University, where he was given the B.A. degree in jurisprudence; and he remained another year as Rhodes Memorial Lecturer.

He was admitted to the bar in Louisville, Kentucky, in 1913 and practised law for a year; but the attraction of astronomy was so great that he gave up the law and returned to Chicago in 1914 for graduate study. He obtained the Ph.D. degree three years later, although during this time he joined the U.S. army. While in it he completed his Ph.D. thesis. He became Major of infantry with the A.E.F. in France.

In 1919 he joined the staff of the Mount Wilson Observatory at which the 100-inch Hooker telescope had been put into operation the year before. Here he remained, except for his service during 1942–45 as Chief of the Exterior Ballistics Branch at the Army Ordnance Ballistic Research Laboratory at the Aberdeen Proving Ground, Aberdeen, Maryland. For his contribution to the war effort he was awarded the Medal for Merit in 1946.

During the 1920's Dr. Hubble made his outstanding investigations on the spiral nebulae. He showed that they were stellar systems beyond our Milky Way, he determined their distances, and he developed the law of the red-shifts which led to the view that the universe is expanding.

Dr. Hubble had special ability and skill in taking photographs of these difficult objects, and a genius for interpreting the photographic records which had been obtained. In the adapting of the 100-inch and the 60-inch telescopes to the securing of the spectra of faint nebulae various persons rendered assistance, but Dr. Hubble gives special credit to Milton Humason.

This work done with the 100-inch telescope clearly indicated the great desirability of a still larger and more powerful instrument, and when the evidence was presented to the Rockefeller Foundation a grant of six million dollars was authorized in 1928 for the production of a 200-inch telescope. In the designing of it Dr. Hubble rendered great assistance and when it was completed he was made a member of the staff in charge of it and carried out the first observations with it.

In the autumn of 1935 Dr. Hubble delivered the Silliman Memorial Lectures at Yale University and the volume containing them, entitled *The Realm of the Nebulae*, was published in 1936. It is an admirable presentation of our modern view of the universe, and is illustrated with many photographs of these spiral nebulae taken with the great telescopes on Mount Wilson. Later *The Observational Approach to Cosmology* was published by Dr. Hubble.

In 1924 Dr. Hubble married Grace Burke and they lived at 1140 Woodstock Drive, San Marino, a suburb of Pasadena. The couple had no children. On the day of his death Dr. Hubble was walking home for luncheon, as was his custom, and Mrs. Hubble picked him up with the car. While she was parking the car outside their home he was suddenly stricken with cerebral thrombosis.

by C. A. Chant,
from *Journal,* Vol. 47, pp. 225–226, November-December, 1953

Reflections

Make a Paper Sundial

by David M. F. Chapman (dave.chapman@ns.sympatico.ca)

In this age of the Internet and the World Wide Web, it is possible to reach out and connect with folks all around the world, people you are likely never to meet, or even speak to. Even more peculiar is the possibility that you could "e-meet" a person who lives not far away at all. This happened to me last year. In my quest for information about sundials, I came across the web site of Steve Lelievre: `www3.ns.sympatico.ca/steve.lelievre/`. Steve Lelievre is a sundial fancier who lives in Kentville, Nova Scotia, not more than an hour and a half drive away from my house. (I have never driven to see him.) He has put together a web page called "The Nova Scotia Sundial Trail," which describes all the sundials in the province he has been able to locate. Since "meeting" Steve over the Internet, I have helped him out by visiting and reporting on a few sites he was not able to visit, and by supplying some sundial photographs for his web site, taken with my digital camera.

As I have written before (*JRASC*, April 1998), in these days of atomic clocks and digital watches, the sundial has declined in stature from useful timepiece to just another lawn ornament. In spite of this, there is something appealing about a timepiece that is intimately connected to the energy source for earthly life (*i.e.* the Sun) and to the rotation and revolution that govern the daily and seasonal cycles of our planet. You can find information about sundials in books and on the Internet. A good place to start is the home page of the North American Sundial Society (NASS): `www.sundials.org.`

For me, the most fascinating part of Steve's site is his Excel spreadsheet for designing a folding paper sundial that you can customize for your own latitude and longitude. For a typical horizontal sundial, the calculations needed to define the hour lines for a horizontal sundial are straightforward (if you know a little trigonometry) and the numbers are easy to crunch with a hand calculator or a simple computer program. Steve's innovation is to use a computer spreadsheet to perform the calculations and to use the pie chart feature of the spreadsheet to automatically draw the circle of the dial, the gnomon, and the hour lines radiating from the toe of the gnomon. (The gnomon is the bit that sticks up and casts the shadow.) Once the pie chart is printed out, there are a few simple cutting, folding, gluing, and labelling operations to undertake to make your very own paper sundial. This is much easier to carry out than it sounds, believe me.

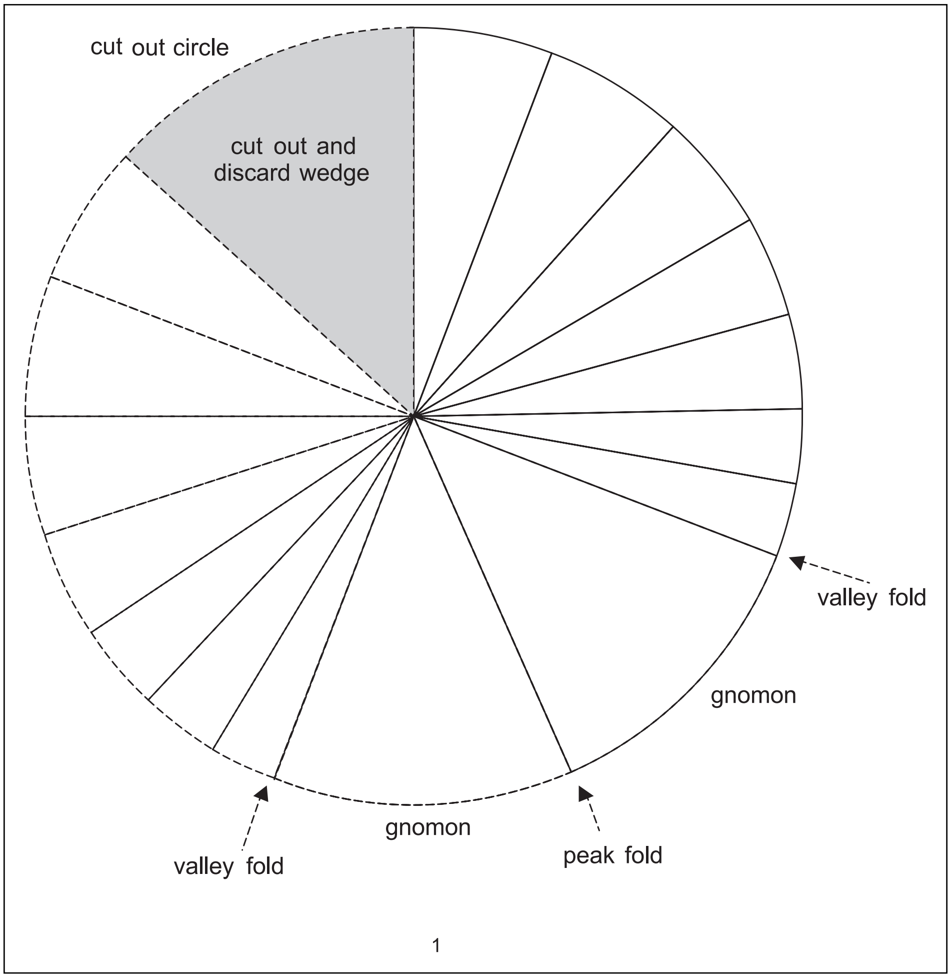

Figure 1 – Copy this figure, cut it out, and fold it according to the instructions to make a sundial for 45° N latitude.

To illustrate the principle, I have reproduced in Figure 1 a simple sundial that indicates apparent solar time for the latitude 45° N. (See Roy Bishop's essay "Time and Time Scales" on page 30 of the RASC *Observer's Handbook 2001*.) Here are the instructions:

1. Photocopy the figure onto another sheet of paper, the thicker the better. (You wouldn't want to cut up your copy of the *Journal*, would you?) I believe 32-pound stock is the heaviest that works in a photocopy machine. The graphic is also available at `www3.ns.sympatico.ca/dave.chapman/Sundials/sundial.gif`.

2. Cut out the circular pie, then carefully cut out and discard the shaded wedge.

3. Make a "peak" fold along the radial dashed line that divides the two sides of the gnomon. I used my fingernail to crease the fold on a hard, flat surface.

4. Make "valley" folds along the solid radial lines on either side of the peak.

5. Bring the two halves of the gnomon together and fasten them with glue or tape. Make sure the gnomon is exactly upright. If you have done everything correctly, it should look like the one in Figure 2.

6. Place the sundial on a flat surface with the tip of the gnomon pointing away from you. Now label the hour lines clockwise starting at 5 a.m. on the left and ending at 7 p.m. on the right. As a check, 12 noon should be the base of the gnomon. You have the option of labeling the lines to read daylight savings time by moving the numbers all one line counterclockwise, in which case the base of the gnomon would be labeled 1 p.m.

7. Now place the sundial on a sunny, flat, level surface with the gnomon pointing to true North. If you cannot determine true North, then simply rotate the sundial until the dial indicates clock time. (This ignores several necessary corrections, but is close enough to have fun.)

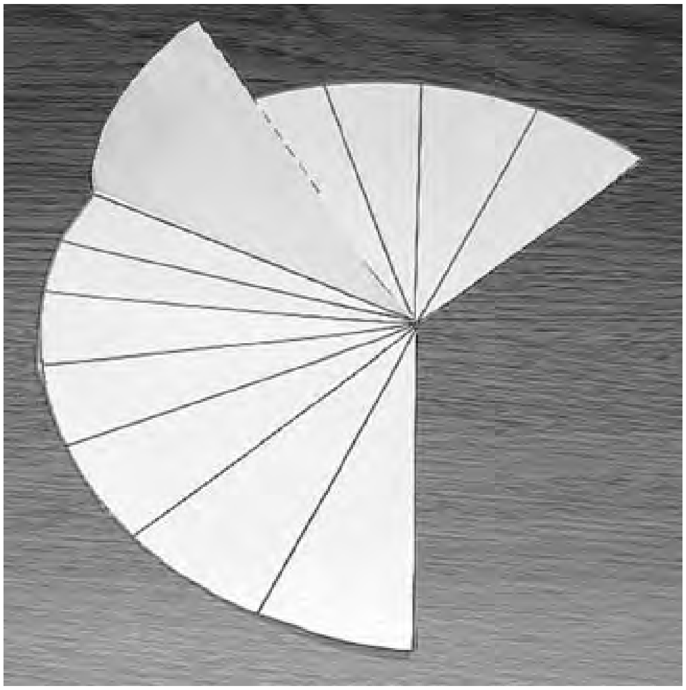

Figure 2 – The sundial after cutting, folding, and gluing, but before labeling.

I have found the paper sundial works very well. To improve accuracy, you will have to download Steve's spreadsheet and create a sundial for your own latitude. If you want a sundial corrected for your longitude (*i.e.* a sundial that indicates standard time in your time zone, rather than local solar time), Steve's spreadsheet accounts for that, too. The only correction remaining is the Equation of Time, which accounts for the Sun's variable motion in Right Ascension throughout the year. (See "Sundial Correction" on page 82 of the RASC *Observer's Handbook*.) This correction amounts to only about 5 minutes during spring and summer, but can be as much as a quarter of an hour at times in fall and winter.

For the Nova East 2000 star party I made a paper sundial handout based on Steve's model, complete with a custom-designed dial with instructions. (It turned out that the Nova East site was only 2 or 3 kilometres from the point 45° N, 64° W.) During the event, we had a few workshops, one of which was "Making a Paper Sundial." The project was a hit with young and old, and many dozen sheets were taken home. Steve liked the handout so much, he put a copy of it on his page as an example. I also made several dials for the various places we went on summer vacation. I found that the custom dials kept remarkably good time — at least good enough for vacation!

David Chapman is a Life Member of the RASC and a past President of the Halifax Centre. Visit his astronomy page (complete with sundials!) at `www3.ns.sympatico.ca/dave.chapman/astronomy_page.`

Making **Jupiters** Around Young Stars

by Leslie J Sage (l.sage@naturedc.com)

> **"Until the discovery in 1970 of dense clouds of molecular gas in the Orion Nebula, it was a puzzle to astronomers how stars actually formed because the known atomic hydrogen in interstellar space simply was not dense enough to collapse into stars."**

Until the discovery in 1970 of dense clouds of molecular gas in the Orion Nebula, it was a puzzle to astronomers how stars actually formed because the known atomic hydrogen in interstellar space simply was not dense enough to collapse into stars. The breakthrough came from an idea sent by Phil Solomon (now at Stony Brook) to Arno Penzias and Robert Wilson (of the microwave background fame). Solomon suggested that they look for emission from the carbon monoxide (CO) molecule, which his estimates indicated would be sufficiently abundant in regions of molecular hydrogen to act as an efficient tracer of the gas. Penzias and Wilson found the CO emission, and rapidly our understanding of the star formation process was revolutionized. Since that time, people studying star formation have relied on observations of CO. Now, a team led by Wing Fai Thi and Ewine van Dishoeck of Leiden University and Geoff Blake of Caltech have shown that, when looking at the disks of gas and dust out of which some young stars are forming, there is about a thousand times more gas than was believed on the basis of the CO data (see January 4, 2001 issue of *Nature*). This may well help to resolve a big problem with planet formation that had been posed by the CO observations.

The general picture of star formation is that a dense core first forms within a molecular cloud and then collapses under its own gravity. Conservation of angular momentum means the gas above and below the "poles" of the cloud collapses fairly easily towards the centre, while the gas near the plane of rotation forms a characteristic accretion disk. While this is happening, the dust associated with the gas (about one percent of the total mass is in dust) is forming into rocks, boulders, and finally planets. As the protostar accretes gas from the inner edge of the disk, it gets hotter and hotter until finally the centre is hot enough to support thermonuclear fusion, and the star is born. The radiation from the young star blows away the gas and much of the remaining dust, thereby terminating the planet formation process. Searches for CO around young stars have indicated that the gas is blown away in just a few million years; even a star as young as 49 Ceti (8±4 million years old) has very little CO.

About twenty years ago, an extended disk of dust was discovered around the young star β Pictoris. While the estimates of the mass in dust were insufficient to produce a system of planets, the presence of the dust itself has been widely taken as a strong indicator that planets and associated bodies — especially comets and asteroids — are there. Small grains of dust cannot long survive in orbits around stars because the star's light causes a "drag" that leads to the grains falling into the stars on timescales of a few million years. So any dust visible around a star older than that must have been placed there recently, probably as comets age and break up and asteroids collide with each other, producing a new population of dust.

Dusty disks have been found around many stars, and of course we now know of Jupiter-mass planets around forty or so stars. But despite intensive searches for molecular gas using CO as a tracer, little has been found. This has led to the view that planet formation must take place very rapidly, before the new star blows the gas away, which has meant serious trouble for people trying to model the formation of gas-giant planets around

“It is inevitable that this discovery will lead to a complete re-examination of the models of planet formation.”

stars. We know that these planets must form somehow, and there is little trouble putting together the rocky cores at their centres, but a few million years is insufficient for those cores to accumulate substantial atmospheres.

Blake and collaborators enter the picture here. Instead of searching for CO around young stars, they have chosen to observe molecular hydrogen (H_2) directly, eliminating any uncertainties about converting from the observed quantity to the total gas mass. Because only about one molecule in 10,000 is CO — and CO is the most abundant after H_2 — those uncertainties can be considerable.

Molecular hydrogen is very difficult to observe from the surface of the Earth because the emission that comes from the cold gas associated with star-forming clouds happens to lie in regions of the spectrum where lines from the Earth’s atmosphere are prominent. The Infrared Space Observatory (ISO), which was launched several years ago, avoids this problem, just as the Hubble Space Telescope avoids the problem of atmospheric turbulence by being in space. Thi and his team used ISO to search for emission from the lowest rotational transitions of H_2 around the stars β Pictoris, 49 Ceti, and HD135344; they found lots of molecular hydrogen.

Why the difference? Before Blake’s work — and a recent theoretical study by Inga Kamp and Frank Bertoldi (*Astronomy & Astrophysics*, 2000, 353, 276) — it was generally thought that if you had H_2, then you would have CO, and therefore the absence of CO was proof of the absence of H_2. This belief turns out to be incorrect. It turns out that it is a lot easier to get rid of CO from a disk than previously assumed, so the absence of CO emission does not tell you much about the total amount of gas around young stars.

It is not yet clear how this discovery will change our view of planet formation, and here Thi is quite cautious because the mass of gas he has found is still rather smaller than estimates for the “minimum-solar nebula” — the amount of gas needed to form our Solar System. However, it is apparent that there is a lot more gas around young stars for a lot longer than has been thought. It is inevitable that this discovery will lead to a complete re-examination of the models of gas giant planet formation.

Dr. Leslie J. Sage is Senior Editor, Physical Sciences, for Nature Magazine *and a Research Associate in the Astronomy Department at the University of Maryland. He grew up in Burlington, Ontario, where even the bright lights of Toronto did not dim his enthusiasm for astronomy. Currently he studies molecular gas and star formation in galaxies, particularly interacting ones.*

“The sky is strewn with horrible dead suns,
Dense sediments of mangled atoms.Only desperate
heaviness emanates from them,
Not energy, not messages, not particles, not light.
Light itself falls back down, broken by its own weight.”

— Levi Primo, in “The Black Stars,”
Levi Primo Collected Poems

FULL-DISC WIDEBAND PHOTOELECTRIC PHOTOMETRY OF THE MOON

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Abstract. Seventy *B* and *V* filter magnitude measurements were made of the lunar disc in 1999–2000, and from these measurements, solar phase angle coefficients and normalized magnitudes were determined. The major conclusions of this study are: 1) the *B–V* colour index of the Moon increases slightly with increasing solar phase angle, 2) there is an almost linear relationship between the normalized magnitude and the solar phase angle for both the *B* and *V* filters and 3) the magnitude of the Moon did not change by more than 0.2 magnitude as a result of the Leonid meteor storm of November 18, 1999 or the solar wind surge that occurred on February 21, 2000.

Résumé. Quelques soixante-dix mesures avec filtres des magnitudes B et V ont été prises du disque lunaire en 1999-2000, et depuis ces mesures les coefficients de l'angle de la phase solaire et des magnitudes normalisées ont été établis. Les conclusions principales de cette étude sont : 1) L'indice des couleurs B-V de la lune augmente légèrement lorsque l'angle de la phase solaire s'agrandit. 2) Il y a une relation presque linéaire entre la magnitude normalisée et l'angle de la phase solaire lorsqu'on utilise les deux filtres B et V. 3) La magnitude de la Lune n'a changé de plus de 0,2 magnitudes lors de la pluie des météores Léonides le 19 novembre 1999 ou pendant la tempète du vent solaire le 21 février 2000.
SEM

1. Introduction

Harris (1961) published an extensive review of the photometric properties of the Moon and planets. In his review, the magnitude of the Moon (when the Moon-Observer distance equals 384,400 km and the Moon-Sun distance equals 1.0 AU) is reported to be:

$$\text{Moon magnitude} = -12.74 + 3.05\,(\alpha/100^\circ) - 1.02\,(\alpha/100^\circ)^2 + 1.05\,(\alpha/100^\circ)^3\,, \qquad (1)$$

where α is the solar phase angle of the Moon. Throughout this paper, distances between objects refer to the distance between the centres of masses of the objects and the observer refers to the person or instrument making the measurements.

Lane & Irvine (1973) carried out a multi-wavelength photometric study of the Moon. Nine narrow band filters with wavelengths between 0.35×10^{-6} and 1.0×10^{-6} metres were used along with the Johnson *UBV* filters. Approximately 33 measurements were made through each of the 12 filters over a range of solar phase angles from 6° up to 120°. Their measurements were carried out in 1964 and 1965, which was near solar minimum.

The goals of this study are: 1) determine the normalized magnitude and solar phase angle coefficients in the *B* and *V* filters for both the waxing and waning phases of the Moon, 2) determine what effect solar flares and the Leonid meteor storm had on the brightness and colour of the Moon, 3) develop an equation that will enable people to compute the magnitude of the Moon using information in the Astronomical Almanac, and 4) compute the surface brightness of the Moon at different solar phase angles.

2. Method and Materials

An SSP-3 solid-state photometer, with a 0.002 metre detector size, was used in all magnitude measurements (Schmude 1992; Optec 1997). Filters that were transformed to the Johnson B and V system were also used along with a 0.030 metre f/4 lens. The lens and photometer yielded a circular field of view having an angular diameter of 55.625±0.667 arcseconds. The photometer-lens system was attached to a telescope tripod.

During the Moon measurements, aperture masks having clear diameters of 0.002 metres or less were used to prevent saturation of the detector. Three different aperture masks having diameters of 0.002, 0.0007 and 0.0003 metres were used. The magnitude reduction factors of the 0.002, 0.0007 and 0.0003 metre apertures compared to the 0.030 metre lens were measured as 6.018, 8.438 and 10.763 magnitude respectively.

Magnitude measurements were made in the order of *CMCMCMC* where *C* is the comparison star measurement and *M* is the Moon measurement. Each *C* measurement consisted of three ten-second sky measurements about 1.5° to the right of the comparison star followed by three ten-second star + sky measurements followed by three more ten-second sky measurements 1.5° to the left of the comparison star. Each *M* measurement was done in the same way as the *C* measurements. This procedure was done for both the *B* and *V* filters. Except in rare cases, each magnitude measurement in this paper is the average of three *M* measurements. The full 0.030 metre aperture was always used in taking the comparison star readings. Table I lists all comparison stars used in this report.

Table I

Comparison stars used in the magnitude measurements of the Moon

Star	Right Ascension[a]	Declination[a]	*B*-mag.[b]	*V*-mag.[b]	Spectral type[a]
γ Peg[c]	$0^h\ 13^m\ 14.2^s$	$+15°\ 11^m\ 01^s$	—	+2.84	B
α Per	$3^h\ 24^m\ 19.4^s$	$+49°\ 51^m\ 40^s$	+2.28	+1.80	F
α Cma	$6^h\ 45^m\ 08.9^s$	$-16°\ 42^m\ 58^s$	−1.46	−1.45	A
α CMi	$7^h\ 39^m\ 18.1^s$	$+5°\ 13^m\ 30^s$	+0.78	+0.35	F
β Crv[d]	$12^h\ 34^m\ 23.2^s$	$-23°\ 23^m\ 48^s$	+3.52	+2.64	G
γ Cyg	$20^h\ 22^m\ 13.7^s$	$+40°\ 15^m\ 24^s$	+2.90	+2.23	F

[a] Hirshfeld *et al.* (1991)

[b] Iriarte *et al.* (1965) except for γ Peg which is from (*Astronomical Almanac* 1999)

[c] Listed as a *UBVRI* standard star in the *Astronomical Almanac* (1999), but is reported to be a variable star (0.01 to 0.10 magnitude change) in Hirshfeld *et al.* (1991) and Sinnott & Perryman (1997). An additional 0.05 magnitude uncertainty was included in the January 11, 2000 measurement.

[d] Not listed as a variable star in (*Astronomical Almanac* 1999; Sinnott & Perryman 1997; Iriarte *et al.* 1965), but it is listed as a suspected variable in Hirshfeld *et al.* (1991). If this is a variable star, its magnitude change is expected to be below 0.01 magnitude. No additional uncertainty was added to the December 4, 1999 measurements.

3. Results

The measured magnitudes of the Moon are listed in Table II. The date in Universal Time (U.T.), filter, measured magnitude, comparison star and approximate solar phase angle (α') are listed in columns 1–5 respectively. The approximate solar phase angle is the angle between the centres of the Earth and Sun measured from the centre of the Moon. The magnitudes in Table II were corrected for both atmospheric extinction and transformation in the same way as is described by Hall & Genet (1988). Values of the secondary extinction coefficients, $k_B'' = -0.03\pm0.01$ and $k_V'' = -0.00\pm0.01$, were used. Transformation coefficients were computed using the two star method and the resulting values are: $\varepsilon_B = -0.114$ and $\varepsilon_V = -0.200$. In almost all magnitude measurements, primary extinction coefficients (k_B'' and k_V'') were measured except on November 22 where estimated values of $k_B' = 0.40$ and $k_V' = 0.26$ were used.

There are at least five unique problems with making magnitude measurements of the Moon which are: 1) scattered light from the Moon drowns out nearby stars, 2) the Moon is much brighter than comparison stars, 3) the Moon has a large angular diameter, 4) the Moon changes position by about 12 degrees every day, and 5) the

Table II

Measured magnitudes of the Moon

Date (U.T.)	Filter	Magnitude	Comparison Star	α' (degrees)
(1999)				
Nov. 16.035	B	−9.15±0.04	γ Cyg	93.8
Nov. 16.088	V	−10.04±0.03	γ Cyg	93.2
Nov. 17.058	B	−9.73±0.05	γ Cyg	82.0
Nov. 17.090	V	−10.64±0.04	γ Cyg	81.6
Nov. 18.020	B	−10.09±0.04	γ Cyg	70.5
Nov. 18.055	V	−11.06±0.04	γ Cyg	70.1
Nov. 19.143	B	−10.50±0.05	α Per	56.5
Nov. 19.167	V	−11.38±0.03	α Per	56.2
Nov. 22.063	B	−11.64±0.04	γ Cyg	17.4
Nov. 22.082	V	−12.50±0.03	γ Cyg	17.1
Nov. 22.102	B	−11.65±0.07	γ Cyg	16.9
Nov. 23.049	B	−12.09±0.06	γ Cyg	3.5
Nov. 23.070	V	−12.92±0.04	γ Cyg	3.2
Nov. 28.250	B	−10.13±0.04	α CMa	68.2
Nov. 28.272	V	−11.05±0.04	α CMa	68.9
Nov. 29.448	B	−9.54±0.04	α CMi	83.4
Nov. 29.468	V	−10.46±0.03	α CMi	83.6
Nov. 30.430	B	−9.05±0.03	α CMi	95.4
Nov. 30.452	V	−9.97±0.03	α CMi	95.6
Dec. 2.462	B	−7.89±0.04	α CMi	119.2
Dec. 2.441	V	−8.86±0.03	α CMi	119.0
Dec. 4.466	B	−6.28±0.04	β Crv	141.9
Dec. 4.441	V	−7.27±0.05	β Crv	141.6
Dec. 10.975	B	−5.87±0.15	γ Cyg	147.1
Dec. 10.972	V	−6.81±0.09	γ Cyg	147.1
Dec. 11.997	B	−6.87±0.10	γ Cyg	135.9
Dec. 11.998	V	−7.84±0.07	γ Cyg	135.9
Dec. 15.024	B	−8.89±0.02	γ Cyg	101.8
Dec. 15.045	V	−9.84±0.03	γ Cyg	101.6
Dec. 17.006	B	−9.85±0.03	α Per	78.0
Dec. 17.024	V	−10.77±0.02	α Per	77.8
Dec. 23.165	B	−12.12±0.05	α CMa	6.2
Dec. 23.146	V	−12.85±0.06	α CMa	5.9
Dec. 23.268	B	−12.10±0.04	α CMa	7.6
Dec. 23.239	V	−12.85±0.05	α CMa	7.2
Dec. 29.314	V	−10.39±0.06	α CMa	86.6
Dec. 30.467	B	−8.80±0.08	α CMi	99.8
Dec. 30.449	V	−9.78±0.03	α CMi	100.0
(2000)				
Jan. 11.055	V	−8.17±0.11	γ Peg	132.0
Jan. 12.007	B	−8.01±0.05	α Per	121.0
Jan. 13.082	B	−8.66±0.07	α Per	108.2
Jan. 13.107	V	−9.45±0.04	α Per	107.8
Jan. 14.084	B	−9.18±0.05	α Per	95.9
Jan. 14.114	V	−10.15±0.04	α Per	95.5
Jan. 16.061	B	−10.16±0.03	α Per	70.6
Jan. 16.038	V	−11.02±0.02	α Per	70.9
Jan. 19.155	V	−12.38±0.05	α CMa	28.5
Jan. 22.196	B	−11.81±0.04	α CMa	13.4
Jan. 22.173	V	−12.63±0.04	α CMa	13.4
Feb. 12.070	B	−9.02±0.09	α CMa	101.5
Feb. 12.048	V	−9.89±0.09	α CMa	101.8

Feb. 15.108	B	−10.40±0.03	α CMi	61.7
Feb. 15.075	V	−11.34±0.03	α CMi	62.2
Feb. 16.105	B	−10.80±0.08	α CMa	48.3
Feb. 16.173	V	−11.73±0.06	α CMa	47.4
Feb. 16.191	B	−10.79±0.10	α CMa	47.1
Feb. 19.085	V	−12.84±0.05	α CMa	8.0
Feb. 20.206	V	−12.79±0.03	α CMi	6.8
Feb. 21.237	B	−11.47±0.03	α CMi	20.2
Feb. 21.260	V	−12.32±0.03	α CMi	20.5
Feb. 22.260	B	−11.04±0.05	α CMi	33.1
Feb. 22.282	V	−11.99±0.05	α CMi	33.3
Feb. 23.248	B	−10.67±0.03	α CMi	45.2
Feb. 23.227	V	−11.59±0.04	α CMi	44.9
Mar. 14.076	B	−9.88±0.04	α CMi	79.6
Mar. 14.094	V	−10.85±0.03	α CMi	79.3
Mar. 18.080	B	−11.41±0.06	α CMa	27.1
Mar. 18.061	V	−12.28±0.04	α CMa	27.3
April 7.041	B	−5.50±0.10	α CMa	150.0
April 7.057	V	−6.53±0.11	α CMa	149.8

non-negligible size of the Earth compared to the Earth-Moon distance. The fifth point just mentioned is discussed further in the appendices; the first four difficulties introduced additional sources of error in the magnitude measurements. The uncertainty (U_n) in the measurements in Table II were computed from:

$$U_n = A^2 + S^2 + G^2 + K^2 + R^2 + E^2, \tag{2}$$

where A is the magnitude reduction factor uncertainty, S is the comparison star magnitude uncertainty, G is the uncertainty in the $\varepsilon\,\Delta\,(B-V)$ term on p.199 in Hall & Genet (1988), K is the uncertainty in the $k''\bar{x}\Delta\,(B-V)$ term, R is the random error and E is the extinction correction uncertainty.

The A and S uncertainties were each 0.01 magnitude while $G = (0.1)\,\varepsilon\,\Delta\,(B-V)$. The uncertainty of ±0.01 in the k_B'' and k_V'' values was the basis for the value of K. The random error, R, was computed by dividing the standard deviation of the three M measurements in the *CMCMCMC* sequence by the square root of 3.

The largest source of uncertainty usually came from the E term. Two sources arise from extinction which are: 1) value of the extinction coefficient and 2) large angular distance between comparison star and the Moon. The value of E, for filter X, was determined from:

$$E = 0.15\,k_X'\,\Delta AM + 0.05\,k_X', \tag{3}$$

where k_X' is the measured primary extinction coefficient for filter X and ΔAM is the difference in air mass between the Moon and the comparison star. The $0.15\,k_X'\,\Delta AM$ term is an estimate of the uncertainty in the measured extinction coefficient while the $0.05\,k_X'$ term includes possible errors due to there being a different extinction coefficient for the Moon and the comparison star.

4. DISCUSSION

The magnitudes in Table II were normalized according to:

$$V(1,\alpha') = V - 5\log[r\,d] + 2.5\log[f], \tag{4}$$

where $V(1,\alpha')$ is the normalized V-filter magnitude at a solar phase angle of α', V is the measured magnitude, f is the fraction of the lunar disc that is illuminated as seen from the centre of the Earth, r is the observer-Moon distance and d is the Moon-Sun distance; both r and d are in AU. (The normalized magnitude is the brightness the Moon would have at full phase and at distances of 1.0 AU from the Earth and Sun.) The B-filter magnitudes were normalized in the same way as the V-filter magnitudes. The normalized magnitudes were then divided into two groups depending on whether the Moon was in a waxing or waning phase. The normalized magnitudes were plotted against α'; the resulting plots for both filters are shown in figure 1. The values of the normalized magnitudes were found to be almost linear with respect to α'. The slope of the plots in figure 1 are the solar phase angle coefficients, c_X, and the y intercepts, $X(1,0)$, are the normalized magnitudes at $\alpha' = 0°$. The solar phase angle coefficients and normalized magnitudes are listed in Table III; all points in figure 1 received equal weight. One can see that the waning phases are about 0.06–0.07 magnitude dimmer than the waxing phases; this is consistent with Harris (1961) and the measurements made by Rougier at $\alpha < 90°$ (Fessenkov 1961). Uncertainties in the normalized magnitudes and solar phase angle coefficients were calculated in the same way as is described in Schmude (1998).

TABLE III

Normalized magnitudes and solar phase angle coefficients of the Moon for the B and V filters

Filter	Moon Phase	$X(1,0)$	c_X	Number of points
B	Waxing	1.03±0.04	0.0208±0.0003	22
V	Waxing	0.16±0.03	0.0204±0.0002	22
B	Waning	1.10±0.04	0.0214±0.0003	10
V	Waning	0.22±0.03	0.0205±0.0003	12

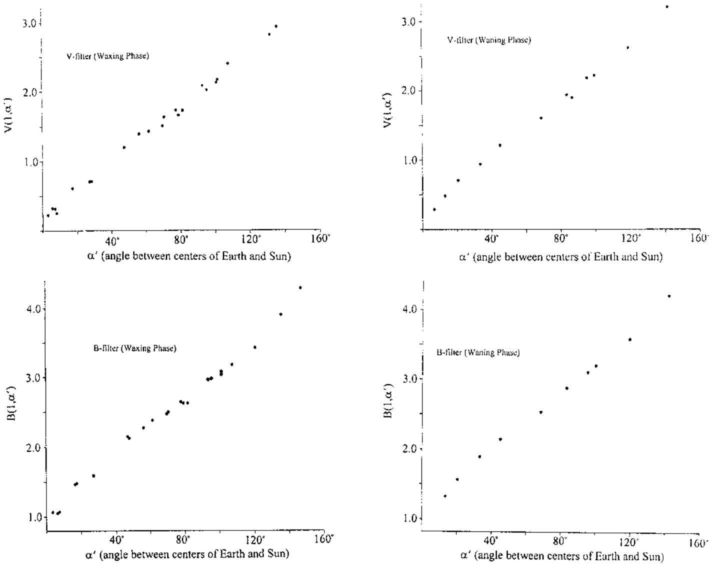

FIG. 1 — Plots of the normalized magnitudes of the Moon versus α' for both the waxing and waning phases in the B and V filters.

Harris (1961) and Lane & Irvine (1973) did not include the 2.5 log[k] term in their $X(1,\alpha)$ evaluation and so this factor became part of their solar phase angle coefficients. Lane & Irvine (1973) only used data with solar phase angles of 60° or less and they also combined waxing and waning phase data; their lunar values are: $c_B = 0.0283$, $c_V = 0.0267$, $B(1,0) = 1.08$ and $V(1,0) = 0.23$. When the data in Table II are evaluated in the same way as was done by Lane & Irvine (1973) the results are: $c_B = 0.0295$, $c_V = 0.0271$, $B(1,0) = 0.93$ and $V(1,0) = 0.12$.

One may calculate an approximate magnitude, M_{apr}, of the Moon (±0.1 magnitude) from:

$$M_{\mathrm{apr}} = 0.16 + 5\log[y\,z] - 2.5\log[f] + 0.0204\cos^{-1}[2f - 1] \text{ (waxing phase)}, \qquad (5)$$

$$M_{\mathrm{apr}} = 0.22 + 5\log[y\,z] - 2.5\log[f] + 0.0205\cos^{-1}[2f - 1] \text{ (waning phase)}, \qquad (6)$$

where y is the Earth-Moon distance in astronomical units, and z is the Earth-Sun distance in AU. Values of y, z and f can all be obtained from the *Astronomical Almanac*. It should be pointed out that y has replaced r and z has replaced d in equation (4); this will result in a maximum error of 0.04 magnitude. One should use an extrapolation procedure when computing f since the values in the *Astronomical Almanac* correspond to 0:00 U.T. for each date. Equations (5) and (6) are valid over the range of $0.99 < f < 0.08$. Equations (7) and (8) predict lunar magnitudes (M) to ±0.05 magnitude, while equations (9) and (10) predict B–V values of the Moon at different phases. One should consult the appendices to compute r and d.

$$M = 0.16 + 5\log[r\,d] - 2.5\log[f] + 0.0204\,\alpha' \text{ (waxing phase)} \qquad (7)$$

$$M = 0.22 + 5\log[r\,d] - 2.5\log[f] + 0.0204\,\alpha' \text{ (waning phase)} \qquad (8)$$

$$B\text{–}V = 0.87 + 0.0004\,\alpha' \text{ (waxing phase)} \qquad (9)$$

$$B\text{–}V = 0.88 + 0.0009\,\alpha' \text{ (waning phase)} \qquad (10)$$

The waning phases of the Moon are a little dimmer than the waxing phase. This is probably due to a larger percentage of maria region for the waning phases. According to Doggett & Schaefer (1994), the thinnest Moon seen has a solar phase angle of about 170°; the Moon is predicted to have a magnitude of ~ –4.35 which includes the brightness from the illuminated and dark sides of the Moon.

The brightness of the full Moon is dependent on the opposition surge which is a non-linear increase in brightness for solar phase angles below 4°. The brightest full Moon occurs when the solar phase angle is around 1.2°; a lunar eclipse occurs for smaller phase angles. When computing the brightness of the full Moon, one must compute the solar phase angle and the values of r and d as illustrated in Appendix I and II.

If the maximum and minimum solar phase angles of the full Moon are assumed to be 1.2° and 7° respectively then, the full Moon can range in V-filter brightness from –13.13 down to –12.46 due to the range in distances (Bishop 1999). The average full Moon will have a V-filter magnitude of –12.76 and an average eyeball magnitude of –12.58 (Stanton 1999).

Table IV

Magnitude and surface brightness of the Moon for different waxing moon phase angles. The Moon-Sun distance is 1.0 AU and the Moon-observer distance is 384,400 km.

	Bright side illuminated by the Sun		Dark side illuminated by Earthshine	
Phase Angle (degrees)	Magnitude	Surface brightness-S_i (Mag./arc-sec^2)	Magnitude	Surface brightness-S_d (Mag./arc-sec^2)
1.2	−12.91	3.18	—	—
2	−12.85	3.24	—	—
3	−12.78	3.31	—	—
4	−12.71	3.38	—	—
10	−12.58	3.51	3.99	14.78
20	−12.35	3.71	2.39	14.68
30	−12.10	3.91	1.42	14.58
40	−11.84	4.12	0.72	14.48
50	−11.56	4.32	0.16	14.38
60	−11.25	4.53	−0.31	14.28
70	−10.93	4.73	−0.71	14.17
80	−10.58	4.93	−1.05	14.08
90	−10.20	5.14	−1.36	13.98
100	−9.79	5.34	−1.63	13.88
110	−9.34	5.55	−1.88	13.78
120	−8.84	5.75	−2.10	13.68
130	−8.27	5.95	−2.30	13.58
140	−7.60	6.16	−2.48	13.48
150	−6.79	6.36	−2.64	13.38
160	−5.72	6.57	−2.78	13.28
170	−4.02	6.77	−2.90	13.18
180	—	—	−3.01	13.08

The surface brightness values of the illuminated portion of the Moon are listed in Table IV. The surface brightness, S_i, in magnitudes per square arcsecond, is computed from:

$$S_i = 2.5\log[(1865.2\text{ arcsec})^2 (f\,\pi/4)] + M, \qquad (11)$$

where 1865.2 arcsec is the angular diameter of the Moon when it is 384,400 km from the observer, $\pi = 3.1416$, and M is the magnitude of the illuminated side of the Moon. The brightness of the dark side of the Moon, caused by Earthshine (B_{ds}) is computed from:

$$B_{ds} = \{-16.81 + h\,(180° - \alpha') + 2.5\log[f']\} - M_S - 13.01, \qquad (12)$$

where f' is the fraction of Earth's disc that is illuminated as seen from the Moon and it equals $(\cos[180° - \alpha'] + 1) / 2.0$, M_S is the V-filter magnitude of the Sun (–26.81) at 1.0 AU (Harris 1961) and h is the solar phase angle coefficient of the Earth computed to be 0.01 mag/degree from equation (5) in Harris (1961). One assumption in equation (12) is that the Moon is exactly 1.0 AU from the Sun and is 384,400 km from the observer. One interesting coincidence is that the full Earth is exactly 10.00 magnitudes dimmer than the Sun as seen from the Moon. The –16.81 is the magnitude of the full Earth as seen from the Moon. The surface brightness of the dark portion of the Moon, S_d is computed from:

$$S_d = 2.5\log[1865.2\text{ arcsec})^2 (f'\,\pi/4)] + B_{ds}. \qquad (13)$$

Several people reported seeing Leonid meteors strike the dark side of the Moon on November 18, 1999; the meteors were all confirmed from video images made by Dunham (Beatty 2000). The meteors had magnitudes of +3, +3, +4, +5, +5, and +7. The data in Table IV show that it is possible to see these meteors on the dark side of the Moon and in fact, bright meteors could even be seen on the bright side of the Moon. The author feels that several other lunar meteors have been observed in the past and were classified as "lunar transient phenomena."

The average waxing and waning phase *V* magnitude of the Moon, M_V, is computed from:

$$M_V = -12.76 - 2.5\log[f] + 0.0204\,(\alpha'). \qquad (14)$$

This equation is based on data taken from $\alpha' = 6°$ up to 147° and is an average of the waxing and waning phases. For $\alpha = 1.2°$, 2° and 3°, opposition surges of −0.14, −0.10 and −0.05 magnitude must be added (Buratti *et al.* 1996). Figure 2 shows the magnitudes of the Moon given by equation (14), Harris (1961) and Lane & Irvine (1973).

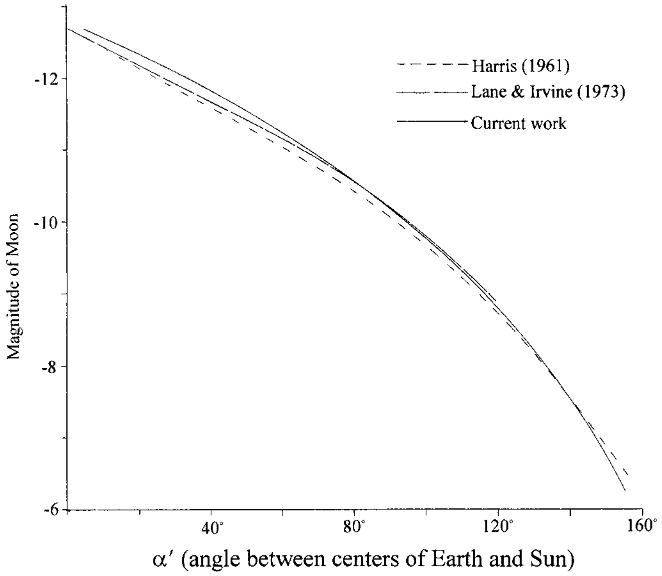

Fig. 2 — Comparison between the *V*-filter magnitudes predicted by Harris (1961) and those measured by Lane & Irvine (1973) and by the author — Equation (14).

The agreement between equation (14) and the other two studies is good except at around $20° < \alpha < 70°$ where discrepancies of ~0.2 magnitude are present.

Figure 3 is a plot of the measured minus predicted *V*-filter magnitude (vertical axis) versus the elapsed time after November 16.000, 1999 (horizontal axis). Figure 4 is a plot of the measured minus predicted *B–V* value of the Moon versus the elapsed time after November 16.000, 1999. Equations 7–10 were used in computing the predicted values for both figures. The Leonid meteor storm peaked around November 18.1, 1999, and there does not seem to be much of a change in brightness on that date. Based on figures 3 and 4, it is concluded that the Moon's *V*-filter magnitude and *B–V* value did not change by more than 0.2 magnitude.

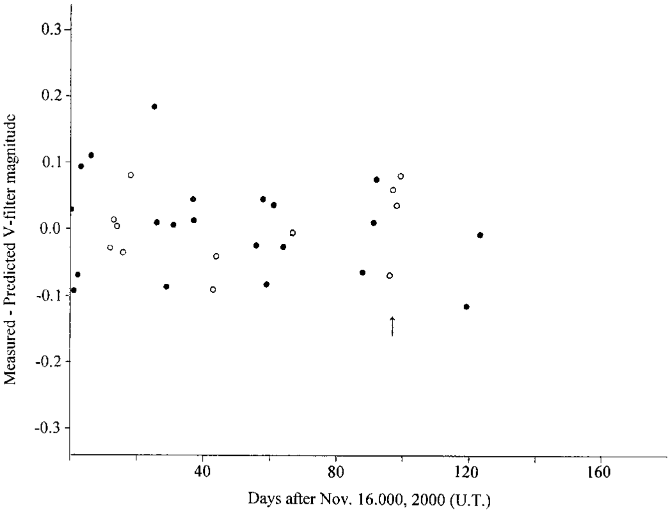

Fig. 3 — Difference between the measured *V*-filter Moon magnitudes and the predicted magnitudes. The open circles correspond to the waning phase and the solid circles correspond to the waxing phase.

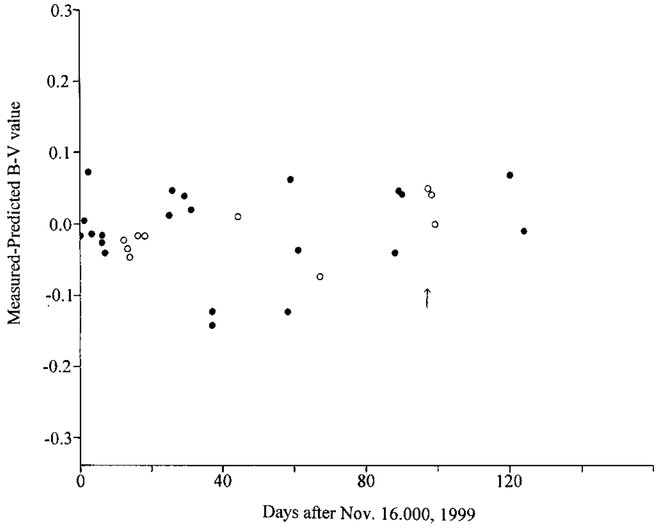

Fig. 4 — Difference between the measured *B–V* value and the predicted values. The open circles correspond to the waning phase and the solid circles correspond to the waxing phase.

On February 21, 2000 at 21:00 U.T., a burst of solar wind hit the Earth and probably the Moon (*Space Science News 2000*). February 21, 2000 is indicated by the arrows in figures 3 and 4. One can see that the brightness of the Moon did not increase as a result of the surge in solar wind.

5. Conclusions

The *B* and *V*-filter magnitudes of the Moon were measured several times in late 1999 and early 2000. In addition to the data in Table III, major conclusions are: 1) the *B–V* colour index of the Moon increases slightly with increasing solar phase angle, 2) there is an almost linear relationship between the normalized magnitude and solar phase angle as illustrated in figure 1, 3) the full Moon has an average *V*-filter magnitude of −12.76, 4) the Moon's brightness and *B–V* value did not change by more than 0.2 magnitude as a result of the Leonid meteor storm or the solar wind surge that hit the Earth on February 21, 2000.

Appendix I

CALCULATION OF THE OBSERVER-CENTRE OF MOON DISTANCE

Figure 5 illustrates the Earth-Moon-Observer geometry where the centres of the Earth and Moon are designated by E and M respectively, and the location of the observer is at point O; segment $X\,Y$ is a side view of the plane that is tangent to the Earth at point O and represents the observer's horizon. Point Z is the observer's zenith. By definition of a tangent line to a sphere, $\angle XOE = 90°$ and so one may write:

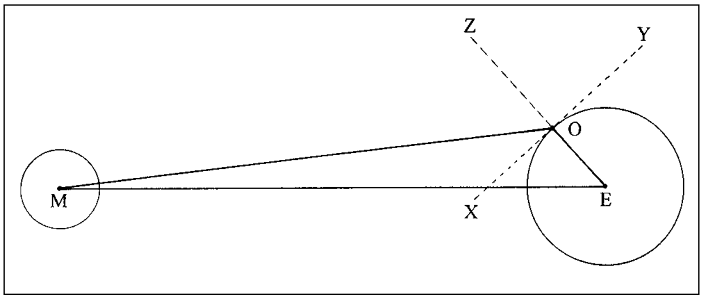

Fig. 5 — The Earth-Moon-Observer geometry. The plane of the paper is defined by points *E, M*, and *O* which are the centres of the Earth, Moon and Observer respectively.

$$\angle MOE = 90° + \angle XOM\,, \qquad \text{(A.1)}$$

where $\angle XOM$ is the altitude of the Moon as seen from the observer. The segment ME is listed in the *Astronomical Almanac* and segment OE is the radius of the Earth. The law of sines can now be used in computing $\angle OME$:

$$\sin(\angle OME) \,/\, OE = \sin(\angle MOE) \,/\, ME. \qquad \text{(A.2)}$$

One can then compute $\angle OEM$:

$$\angle OEM = 180° - \angle OME - \angle \mathrm{MOE}. \qquad \text{(A.3)}$$

Finally, one can use the law of sines to compute the Observer-Moon (OM) distance (r):

$$\sin(\angle OEM) \,/\, OM = \sin(\angle MOE) \,/\, ME. \qquad \text{(A.4)}$$

Appendix II

CALCULATION OF MOON-SUN DISTANCE AND THE APPROXIMATE SOLAR PHASE ANGLE

On page M10 of the *Astronomical Almanac* (1998), the phase angle, α, is defined as the angle measured at the centre of an illuminated body between the light source and the observer. In this paper, the approximate solar phase angle, α' will be computed which is the angle between the Sun and the centre of the Earth measured from the centre of the Moon. This approximation will result in a maximum uncertainty of about ±0.9° in the solar phase angle.

Figure 6 shows the longitude of the Sun and Moon where the plane of the paper is coplanar with the ecliptic plane. Points S, M and E are the centres of the Sun, Moon and Earth respectively. Angle δ is the longitude of the Sun and angle Θ is the longitude of the Moon. Both δ and Θ are measured in a counter clockwise direction from segments VS and $V'E$. The Earth is at the vernal equinox at point V and at this point, the Sun is at longitude 0°; similarly when the Moon is at V', it is at longitude 0°.

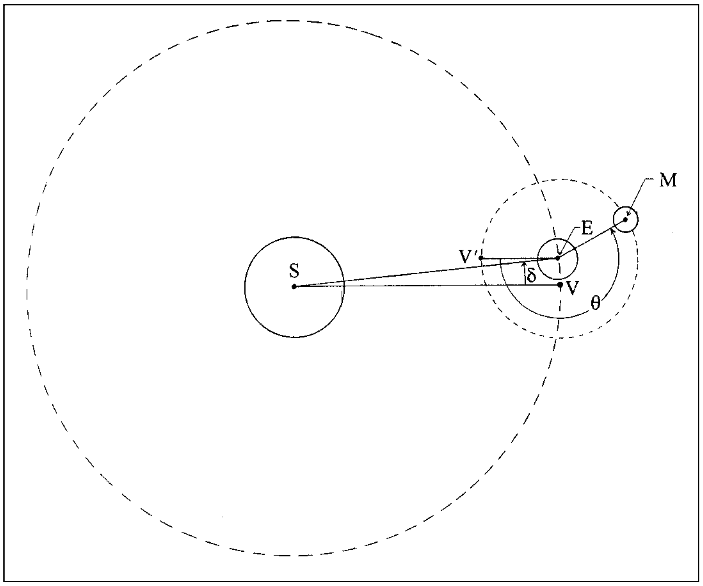

Fig. 6 — Longitudes of the Sun and Moon. The paper is coplanar with the ecliptic plane.

In defining the appropriate vectors, a coordinate system must be defined: the ecliptic plane is chosen as the X–Y plane and the Z axis is perpendicular to the X–Y plane. The origin is at the centre of the Earth. The unit vectors **i, j** and **k** lie along the X, Y and Z axes; all vectors will be in boldface type. The vectors ***ES*** and ***EM*** are defined as:

$$\boldsymbol{ES} = (ES)\cos[\delta]\,\mathbf{i} + (ES)\sin[\delta]\,\mathbf{j} + (ES)\sin[\phi]\,\mathbf{k}\,, \qquad \text{(A.5)}$$
$$\boldsymbol{EM} = (EM)\cos[\Theta]\,\mathbf{i} + (EM)\sin[\Theta]\,\mathbf{j} + (EM)\sin[\omega]\,\mathbf{k}\,, \qquad \text{(A.6)}$$

where ES and EM are the magnitudes of vectors ***ES*** and ***EM***, ϕ is the latitude of the sun and ω is the latitude of the Moon. Both ***ES*** and ***EM*** are illustrated in figure 7. One may use the vector scalar product to obtain $\angle MES$:

$$ES \cdot EM = (ES)\,(EM)\cos[\angle MES], \qquad \text{(A.7)}$$

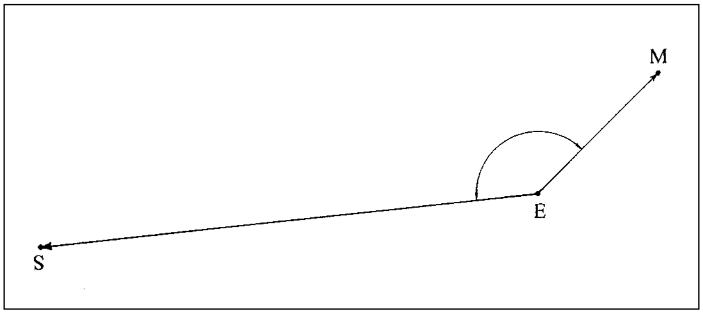

Fig. 7 — Vectors ***ES*** and ***EM***; the paper lies in the plane defined by vectors ***ES*** and ***EM***.

and once $\angle MES$ is computed, one may use the law of cosines to compute the length of segment MS which is also the Moon-Sun distance, d, in equation (4):

$$(MS)^2 = (ES)^2 + (EM)^2 - 2\,(ES)\,(EM)\cos(\angle MES). \tag{A.8}$$

The law of sines is now used in computing $\angle ESM$:

$$\sin(\angle ESM)/EM = \sin(\angle MES)\,/\,MS, \tag{A.9}$$

and finally, $\angle EMS = \alpha'$ is computed from:

$$\angle EMS = \alpha' = 180° - \angle ESM - \angle MES. \tag{A.10}$$

No attempt is made to determine the Observer-Moon-Sun angle due to the complexity of the situation.

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A RECENT FIELD CAMPAIGN TO RECOVER METEORITES DETECTED BY THE METEORITE OBSERVATION AND RECOVERY PROGRAM

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Abstract. In the fall of 1998 and spring of 1999 a team of researchers conducted systematic ground searches of predicted meteorite fall sites across Manitoba, Saskatchewan, and Alberta. The locations of the fall sites were determined from analysis of fireball events recorded by the Meteorite Observation and Recovery Project, which operated across central Canada from 1971 to 1985. The best 10 of the approximately 79 sites where meteorites are strongly suspected to have fallen were searched by ground-based teams. The two best sites were revisited in the spring of 1999. The search teams walked approximately 800 linear kilometres in total and searched nearly 4,000,000 square metres. Approximately 60 samples, which may be meteoritic, were recovered during these campaigns. Examinations of these samples suggest that they are probably not meteorites, but more detailed analysis of two candidates is ongoing.

Résumé. Durant l'automne de 1998 et le printemps de 1999 un groupe de chercheurs a entrepris une recherche systématique de terrains au Manitoba, en Saskatchewan et en Alberta sur lesquels des chutes de météorites avaient été prévues. L'emplacement de ces sites de chutes a été établi selon l'analyse des évènements de bolides enregistrés par le Meteorite Observation and Recovery Project, en opération à travers le Canada central durant les années 1971 à 1985. Les dix meilleurs sites des 79 reconnus comme étant des sites très probables de telles chutes de météorites ont été examinés à pied par des chercheurs sur le terrain. Les deux meilleurs sites ont été visités de nouveau au printemps 1999. Les groupes de chercheurs ont marché quelque 800 kilomètres linéaires en tout et ont examiné de près quelques 4 000 000 mètres carrés. Environ 60 échantillons, qui pourraient être des météorites, ont été recueillis durant ces recherches. L'analyse de ces examplaires indique qu'ils ne sont tout probablement pas des météorites, mais un examen plus détaillé de deux des échantillons se poursuit.
SEM

1. Introduction

Between 1971 and 1985 the Canadian government operated a network of 12 small observatories across western Canada (the Meteorite Observation and Recovery Project) designed to photograph bright fireballs, and from this information to determine the probable fall location and final mass of the meteorite responsible for the fireball (Halliday *et al.* 1978). Of the more than 1000 fireballs recorded by the network, 79 were expected to result in a meteorite with a mass of at least 50 grams (Halliday *et al.* 1989a). The relatively recent fall dates of these fireballs, the constraints on probable fall location (Halliday *et al.* 1989a, 1989b), and the fact that very few of these sites had been visited or searched (Brown & Zalcik 1992) increased the chance of finding a meteorite sufficiently massive to justify a systematic search campaign. The success in recovering the Innisfree meteorite on the basis of MORP observations further suggested that the chances of recovering MORP meteorites were favourable (Halliday *et al.* 1978).

The main scientific justification behind such a search is that the MORP data provide information not only on probable fall locations (generally to within a few kilometres and accounting for local meteorological conditions at the time of the fall) but also allow us to trace the orbits of these objects back into space. By recovering such objects we would be able to construct a more complete understanding of the genetic relationship between asteroids and meteorites (*e.g.*, Lipschutz *et al.* 1989; Greenberg & Nolan 1989).

In order to ensure the highest level of success, it was necessary to conduct the field campaigns during narrow windows of opportunity either before green-up of agricultural crops or after harvesting, and with no snow on the ground. A successful campaign would also rely on the participation of volunteer searchers, site conditions, and efforts to raise the level of awareness of local residents and landowners concerning the specific meteorite fall event.

2. Site Selection Criteria

Data on the 79 MORP events were analyzed, and of these, the best 10 were selected for detailed ground searches (Table I). The criteria used in the selection included a final mass of at least ~300 grams, an accessible fall location, good surface conditions in terms of dry land, low vegetation density and height, and a relatively low abundance of surface rocks. Two teams of researchers were mobilized to search these sites.

Of these sites, the Holdfast and Ridgedale events were of the highest scientific interest because of the nature of the events (Halliday *et al.* 1989a). The Holdfast meteorite is the only expected meteorite fall of a substantial mass of an Aten-type object. These are rare objects with orbits smaller than that of the Earth. The Ridgedale meteorite had orbital properties which were very similar to the recovered Innisfree meteorite, suggesting possible genetic similarities (Halliday 1987).

3. Search Strategies

Based on the past experience of field members (*e.g.*, Brown & Zalcik, 1992), it was decided that a multi-faceted field campaign would yield the best chance of success. Whenever possible and practical, each site visit involved a combination of manual field searches, with or without the participation of local residents; searches of nearby rock piles; publication of the search in the local media; information packages distributed to, and direct contact with, residents near the fall point; presentations to local schools; and "rock clinics" where residents could bring in "strange" rocks for identification.

The success of previous search campaigns has relied on factors such as large sizes of meteorites and favourable field conditions (*e.g.*, vegetation free, undisturbed land), neither of which would be relevant to the current campaign as we were committed to specific geographic localities. As a result we concentrated our efforts on enhancing our field presence. Each team was equipped with GPS receivers, flagging tape, metal detectors and off-road capable vehicles.

4. Field Campaign

The field campaign was undertaken during September 20–October 5, 1998, and April 30–May 9, 1999. The initial field campaign consisted of visits to the 10 most promising sites. The second campaign focussed on the 2 most scientifically interesting sites: Holdfast and Ridgedale. There were also additional visits to the Fork Lake site by individuals from Edmonton.

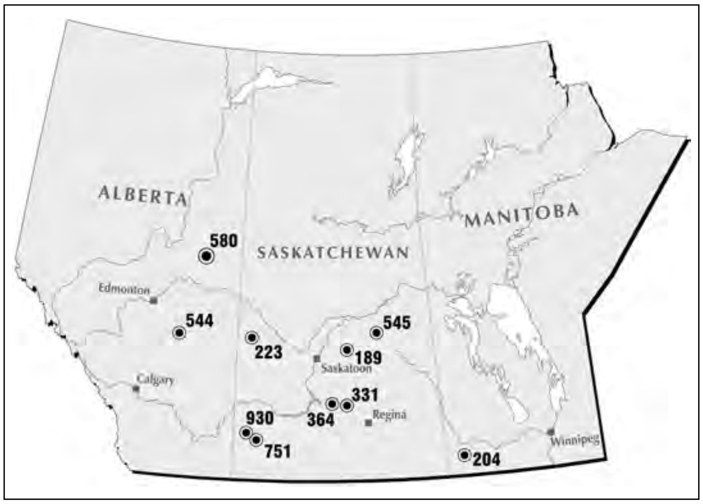

Fig. 1 — Locations of the 10 MORP events visited in 1998 and 1999. Each MORP site is identified by its MORP catalogue number.

Fork Lake Site (Sept. 20–23, 1998). The Fork Lake fall point is located in an area of mixed bush, farmland, and recently cleared pasture. The team searched the cleared areas near the fall point and along the flight path, as well as associated rock piles. The landowners around the fall site were interviewed and shown meteorite samples belonging to team members. The team also conducted an evening rock clinic in nearby Lac La Biche for residents to bring in their samples. The site was revisited by one of the team members in mid-October 1998 to conduct follow-up interviews and view additional samples acquired by local residents. Approximately 670,000 m^2 of the site were searched. A second field search was undertaken on April 3, 1999, with an additional 100,000 m^2 of ground covered, as well as new and follow-on interviews with local residents.

Edberg Site (Sept. 23–25, Oct. 3, 1998). This site had previously been searched (Brown & Zalcik 1992), and it was decided to expand the search into previously unexplored areas. The search area consists of a mixture of farmland and pasture with abundant surface rocks. Local landowners were interviewed, and a rock clinic was held in Camrose. Approximately 340,000 m^2 were searched.

Manito Lake Site (Sept. 26–28, 1998). The fall point for this event is located within a bay of Manito Lake, Saskatchewan. The site consists of a mixture of open water, pasture land, native grasses, mud flats, gravel bars, and few rocks. As water levels were low, the entire length of the shore along the bay, within 200 metres of ground zero, could be searched. Traverses along the flight path over dry land were also conducted. Approximately 300,000 m^2 were searched, and a rock clinic was held in Neilburg.

Golden Prairie Site (Sept. 29–Oct. 1, 1998). The Golden Prairie fall site is located in pasture land which appeared undisturbed, had sparse, low-lying vegetation, and few rocks. The search was concentrated along the flight line, and approximately 400,000 m^2 were searched.

Maple Creek Site (Oct. 2, 1998). This site consists largely of agricultural land covered with stubble and variable rock densities. Local landowners, originally interviewed by Brown & Zalcik (1992), were reinterviewed. Approximately 50,000 m^2 were searched.

Findlay Site (Sept. 21–23, Oct. 4, 1998). The Findlay fall point is located on agricultural land which is completely rock-free. Metal detectors were employed at the site but were found to be inefficient and slowed the search. The search team was augmented by a number of volunteers from local high schools. Local landowners were interviewed, and approximately 600,000 m^2 were searched.

Holdfast Site, Part 1 (Sept. 24–26, 1998; Apr. 30–May 4, 1999). The Holdfast fall site is located on agricultural land with variable surface rock densities. Approximately 700,000 m^2 along the flight line as well as a number of rock piles were searched, and local landowners were interviewed.

Craik Site (Sept. 27, 1998). The Craik fall site is located in communal pasture lands consisting of a mixture of swamp, low grass, and bushes. All open areas within 400 m of the fall point were searched, totalling approximately 100,000 m^2 in area.

Middle Lake Site (Sept. 28, 1998). The Middle Lake fall site is located near the shore of Middle Lake. Due to low water levels the area around ground zero was accessible. The search area consisted of scattered vegetation, mud flats, and thick algal mats in places. Approximately 250,000 m^2 of the site were searched and local landowners were interviewed.

Ridgedale Site, Part 1 (Sept. 29–Oct. 3, 1998; May 5–9, 1999). The Ridgedale fall site is located on dark soil-covered agricultural land with a very low rock density. Local landowners were interviewed, and approximately 500,000 m^2 of the site were searched.

5. Summary

A total of 10 MORP sites were searched during 1998 with return visits to the most scientifically important sites in 1999. The amount of

Table I
Characteristics of MORP sites searched during this campaign

Location	MORP No.	Latitude	Longitude	Terminal Mass (kg)
Fork Lake, Alberta	580	54° 24.9´	111° 20.2´	11.0
Edberg, Alberta	544	52° 45.0´	112° 46.6´	5.9
Manito Lake, Saskatchewan	223	52° 42.7´	109° 42.3´	3.4
Golden Prairie, Saskatchewan	930	50° 09.6´	109° 38.5´	0.52
Maple Creek, Saskatchewan	751	50° 01.1´	109° 19.0´	0.28
Findlay, Manitoba	204	49° 36.8´	100° 47.6´	3.9
Holdfast, Saskatchewan	331	50° 57.3´	105° 19.7´	1.3
Craik, Saskatchewan	364	50° 57.5´	106° 00.3´	1.4
Middle Lake, Saskatchewan	189	52° 32.2´	105° 11.7´	0.59
Ridgedale, Saskatchewan	545	53° 04.2´	104° 17.6´	1.8

Data from Halliday *et al.* (1989a).

ground that could be covered in a day depended very strongly on factors such as soil colour, surface roughness, and vegetation and rock density. In addition, searches on rainy days were slower because the rain darkened both the soils and rocks. In total, close to 4,000,000 m^2 were searched. This area translates into approximately 800 linear kilometres of searching by the teams. All of the landowners at the fall sites expressed interest in the teams' activities, and they have assured us that they will be on the lookout for meteorites on their lands. The various rock clinics and local presentations helped to raise the level of awareness of our activities in the various communities, and about meteorites in general, further enhancing the probability that any recovered meteorites will be brought to our attention.

The probability of finding a MORP meteorite declines with time. Meteorites that have fallen on farmland would be subject to breakage or burial by farm equipment, disposal in rock piles, and weathering. Searching MORP sites is also hampered by the high density of rocks at many of the sites and the dark colour of the soil, which impedes searching at low sun angles. The various impediments to finding meteorites in the Canadian prairies have also been discussed by other investigators (*e.g.*, Nininger 1972). Nevertheless, the fact that such a search was conducted is instructive in illustrating the probabilities of success (probably quite low and decreasing with decreasing meteorite size and increasing time) and in refining optimum search procedures for future campaigns.

Acknowledgements

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The 2000 Leonid Outburst
as Seen on November 17/18 from near Ottawa, Ontario

by Pierre Martin, Ottawa Centre (p.martin@mail.cyberus.ca)

I was determined to do whatever I could to catch this year's Leonids, despite the bright moonlight and generally poor November weather. This year, strong Leonid activity was possible over a period of two nights. After a washout for the first morning of November 17th, I feared the weather would again not look very promising for the following morning. A number of forecasters pointed out that all of eastern Ontario would be plagued by "Lake effect" cloud cover, resulting in overcast skies and scattered flurries. The GOES-8 satellite showed no hope whatsoever, except for a tiny sucker hole just south-west of Ottawa that would probably come and go quickly. One would have to travel deep down into the U.S. to improve the odds of clear skies.

The temperature plunged down to −3° C in mid-afternoon, and strong winds pushed the windchill factor down to −7° C. Soon after suppertime that evening, the sky outside my window was 100% overcast, without any breaks. Weather reports also had scattered snow flurries and ice pellets in some areas. I grumbled in disappointment, "Another washout."

Then I got a call from local amateur astronomer Mike Wirths, who said he currently had 90% clear skies near Perth (about 90 km south-west of Ottawa). I had doubts but decided to pack the car and head out to his place anyway. Quick glances outside the windshield along the way revealed nothing but low clouds moving fairly quickly from the west. Near 10 PM local time, as I pulled my car beside his observatory, I noticed much to my delight that the sky was crystal clear and full of stars. So I got my meteor gear together and began to set up on a flat field beside Mike's observatory. I scrambled to get my home-made observing "coffin" assembled, and added on multiple layers of winter clothing as if an ice age was upon us. Setting up in the dark was frustrating as I kept fumbling and dropping things all over the ground. Equally frustrating was not knowing how long the sucker hole would last and whether I was going through all this trouble for nothing. At least the wind died down completely — that alone made a big difference despite the freezing temperatures. I noticed one of Mike's cats jumped into my car and got all-comfortable in my meteor bag in an attempt to warm up.

A magnitude –2 Leonid between the double-cluster in Perseus and M31 in Andromeda taken from Perth, Ontario on the morning of November 18th, 2000 (photo by Pierre Martin using a 50mm f/2 lens and Fuji Superia 800 film).

I signed on to my tape-recorder just before 11 PM EST to try and catch some of the activity near the predicted 10:44 PM first peak. Several spectacular "Earthgrazers" appeared. Each one of them skimmed the upper atmosphere horizontally, resulting in very long paths across the sky. Even with the radiant only 3 degrees over the eastern horizon, it was obvious that some fairly high activity was in progress. It took only 16 minutes to see the first Leonid grazer. A second magnitude meteor shot some 40 degrees across the zenith. About 14 minutes later, a most impressive orange coloured Leonid split the sky in half — it travelled 70 degrees. However, the one that appeared shortly before midnight blew me away: a multi-coloured magnitude −2 Leonid that shot 40 degrees. It went from vivid blue to green to orange before it extinguished. A three-second train of ionized glowing material was left behind. This was definitely the most beautiful meteor of the night. Before taking a break at midnight, I saw seven more Leonids, many of which were colourful and travelled long distance.

Although the Leonids were the main attraction, I also monitored some minor showers such as Taurids and Alpha Monocerotids. A particularly nice South Taurid of magnitude −1 was seen moving down slowly in Orion. It did not have any train at all and appeared nearly pure white.

After this first successful hour, the sky was still 100% clear — so far so good. At midnight, I took a break for 30 minutes to organize my gear more properly. I also fuelled up on donuts and hot chocolate

The author's portable meteor "coffin." It is a simple design but effective for cold nights. It was built with the help of amateur astronomer Denis Legault.

and rested my voice from yelling "oooohhhh!" so much. It wasn't until I got out of my "coffin" that I realized frost was already beginning to form. My "coffin" acts as a shelter and seems to keep everything nice and dry — very helpful for cold nights. After a quick peek through Mike's 18-inch scope, I noticed Leonid activity on the rise, so I hurried back to resume observations. Mike Wirths and Attila Danko both went for a nap and would wake up to check out the predicted 2:51 EST second peak. Despite the bright Quarter Moon, I could still see nearly 6th magnitude stars under very transparent conditions. I had my field of view facing south and then to the west to avoid staring into the glare of the Moon (which was located very close to the radiant in Leo). Leonids appearing in the western sky would shoot straight down.

The second hour (12:32-1:32 AM EST) had quickly increasing Leonid rates to nearly one per minute. Many meteors were coloured blue, yellow, and orange. The brighter ones almost always left behind short-lived trains. The highlight in this hour was a nicely coloured magnitude −3 orange Leonid low in the south-east.

The third hour (1:32-2:36 AM EST) began with one or two Leonids per minute. Most meteors were now on the faint side with an occasional bright one zipping by. Leonids began increasing quickly to three per minute shortly after 2:00, and I could feel my heart pounding faster. I got my camera running and hoped some bright meteor would shoot into the frame. Sometimes a number of Leonids would appear within a very short time. At 2:02, I saw five Leonids all within 10 seconds. Another burst at 2:11 had four Leonids within only two seconds At this point, I felt we were getting close to a sharp peak that was a bit earlier than anticipated, so I began yelling, "Attila, look up! (No answer.) Attila?" Then I remembered he was probably still napping inside the observatory's heated room and couldn't hear me yelling. Around 2:30, Leonids were coming down furiously at rates of four and sometimes five per minute. There were more instances of quick bursts of activity that had me screaming out their magnitudes into my tape recorder as fast as I could. At 2:32, I recorded six Leonids all going different directions within four seconds. Even more impressive was the sight, at 2:34, of two perfectly simultaneous Leonids appearing in parallel paths. I know how rare it is to see Leonids exactly at the same time because they're so fast and brief (I think I screamed out my biggest "ooohhh" of the night).

The highest activity I saw occurred in the seven-minute period between 2:31 and 2:38, with 32 Leonids. That comes up to an uncorrected hourly rate of 272 meteors per hour. By the time Mike and Attila came out to observe the shower at 2:45, activity was already waning quickly. By 3:10, the rates were down to two meteors per minute. One Leonid was seen shooting right into the bright star Procyon. I continued observing until I was completely exhausted at 5:30 (I had had little sleep the previous night). As I got out of my coffin, I realized that everything was now covered with a thick layer of white frost. The temperature read −7° C, but it felt much warmer inside the "coffin." Mike had left the observatory door open, so I could catch some long overdue sleep in a separate heated room before heading back home.

My grand total for the night was 486 meteors (442 Leonids, eight north Taurids, four south Taurids, three Alpha Monocerotids, and 29 sporadics). Total observing time was 5.90 hours.

Was this a Leonid fireball year? I don't think so, at least not for me. Although there were many bright meteors, fireballs were not really prominent. From a total of 442 Leonids, only five could be considered fireballs (four at magnitude −3 and one of magnitude −4). My average Leonid magnitude came to +2.52.

I would like to thank Mike Wirths very much for the invitation to set up at his observatory. It stayed perfectly clear all night. Had I gone to one of the other local sites around Ottawa, I fear I might well have been staring at clouds instead. As soon as the Sun came up in the morning, clouds quickly rolled in again until it was 100% overcast. I still can't believe my luck.

Although this was nowhere near the storm activity of the 1999 Leonids I saw in Spain, it was still a fabulous shower.

Let's hope we all get a chance to see even better Leonid displays predicted for 2001.

Pierre's number one interest in astronomy is meteor observing, which was sparked at the age of 8 by a brilliant fireball observed on a clear summer evening. Since 1995, he has recorded and reported his observations to the North American Meteor Network and the International Meteor Organization. He is currently Meteor Coordinator for the Ottawa Centre. Pierre can often be found observing meteors in eastern Ontario's cold winter nights from the comfort of his portable observing "coffin."

A Memorable Mount Kobau Star Party

by Alan Whitman (awhitman@vip.net)

This year's Mount Kobau Star Party (MKSP) had the mainly clear skies which are the norm between mid-July and mid-October in the Southern Interior of British Columbia. I took my Meade 16-inch Newtonian off its observatory equatorial mount and put it on its homemade Dobsonian mount for the star party. Here is my (very subjective) report.

Saturday, July 29-30: This was perhaps the best night as both the transparency and seeing were excellent, except for some forest fire smoke on the southeast horizon from a huge 12 square-mile brush fire in Washington State about 15 miles to the south of us. With my 16-inch the globular cluster Palomar 9 (NGC 6717) immediately beside ν_2 Sgr was very easy — it was obvious at 65× and at 261× there were six resolved stars, five of about 14th magnitude and one of 15th. They appear to be cluster members as there is no similar concentration of stars in the field of view. There is an underlying glow, but the resolved stars almost obscure it. Next I star-hopped to another globular, Palomar 12. This was a tough star-hop as there are not many stars *en route*. Pal 12 was visible with only 75× when the field was put in motion. At 182× five stars were resolved, probably all of magnitude 15 to 15.5, as well as the amorphous glow of the cluster. Only two minutes of arc south-southeast of Pal 12 was a bright triangle of magnitude 11 stars, but *GUIDE 7* charting software showed only two. I thought that perhaps one was an asteroid, but Denis Boucher's sketch, provided by one of Denis' fellow Edmontonians who was at the star party, also showed this triangle of stars.

Sunday, July 30-31: The temperature was a very warm 26 degrees Celsius, a near record for the 6200-foot peak of Mt. Kobau. Those who drove down to the resort town of Osoyoos in the valley below for a swim or a steak variously reported that the temperature down there was 38 degrees or 40 degrees that day. We watched the 34-percent partial solar eclipse just before sunset with my #14 welder's filter, eclipse goggles, and a filtered Celestron-8 — casual fun. A marginal night for observing followed due to rapidly moving, forming, and dissipating altocumulus cloud, and I didn't observe anything noteworthy. My summer-weight sleeping bag sufficed all night, the first time in my 90 to 100 nights on that famously frigid peak.

Monday, July 31-Aug 1: This was another equally warm day. Howling winds on the exposed peak behind a dry evening cold front prevented use of my solid tube 16-inch, so I observed with Guy Mackie's 12.5-inch Starmaster Dobsonian. His open truss tube makes all the difference in a wind. Less stubborn or wiser observers set up a little lower on the mountain where the wind is not usually much of a problem, but I only go up on Mount Kobau for the peak's southern horizon since my backyard sky is almost as dark as Kobau's. We enjoyed a fine 88× view of southern M55, even though it culminates at an altitude of only 10 degrees. The cluster was well resolved all across it with a scattering of bright stars on faint ones. I had only my third view of the Scorpius globular cluster NGC 6453 behind the great open cluster M7, which was then only a few degrees from setting. Steve Barnes' 12-inch LX200 resolved NGC 6453 for me at Starfest's more southerly latitude in July 1999. An old favourite revisited with Guy's 12.5-inch was the Sagittarius open cluster NGC 6520 with the inky dark nebula B86 adjacent and other winding dark nebulae in nearby fields at 63×. Alert readers will note that not a single globular cluster was mentioned in the previous sentence.

Ron Scherer (past-president of the Okanagan Centre) gazing at the young crescent moon through binoculars at dusk. Needless to say, moon-gazing is a rather obscure pastime at a star party that clings ferociously to the new moon phase. If the truth be known, this photo was shamelessly contrived, but it is a single exposure. (Photo by Jim Failes).

Tuesday, Aug 1-2: Last night's and today's wind blew up the Washington State forest fire so that the transparency was poor below 15 degrees altitude, although good above. As it was again too windy for my

Owen Salava (left) describing his award-winning 12.5-inch truss Dobsonian telescope to Gary Seronik. Gary was one of the three Amateur Telescope Making judges at MKSP 2000 (Photo by Ron Scherer).

scope on the exposed peak, I observed with Lee Johnson's 17.5-inch down below, out of the wind. Lee always has something interesting that you've never heard of in his eyepiece — that night it was the galaxy cluster Pegasus 1.

There were two magnificent magnitude −8 Iridium flares on this night, the brightest that I've ever seen. The first at about 23:45 was a tremendous surprise to me; the second one at about 2:51 everybody knew was coming.

Wednesday, Aug 2-3: New arrivals observed through sucker holes; the rest of us got some much-needed sleep (in my case in my own bed at home).

Thursday, Aug 3-4: Afternoon speakers were *Sky & Telescope* associate editor Gary Seronik ("Kobau Skies This Week") and *SkyNews* and *Sky & Telescope* contributor Ken Hewitt-White ("Skywatching as a Way of Life").

The Sagittarius globular NGC 6540 at 91× in my 16-inch was an elongated bar without any visible background haze. This was my last globular of those plotted on the first edition of *Sky Atlas 2000.0* north of declination −38, because I didn't know that it was a globular until recently — Wil Tirion plotted it as an open cluster. This globular is in the same low power field as NGC 6520 and B86 — take a look.

The next star-hop was to another Sagittarius globular cluster, Palomar 8, a very easy star-hop from the tip of the Teaspoon. *En route* the 8×50 finder showed the open cluster Cr 394, which is a big bright splash in the 16-inch. Good-sized Pal 8 was instantly seen with direct vision as it was much more obvious than my previous target, the globular NGC 6540, or at least two other NGC globulars, 6749 in Aquila and 7492 in Aquarius. I saw no central condensation in Pal 8. Guy Mackie then easily found this globular cluster with his 12.5-inch.

Then, Guy Mackie made the discovery of the evening. He discovered an uncharted apparent little open cluster in the field of Pal 8, not plotted on either the *Millennium Star Atlas* or *GUIDE 7*! The apparent open cluster, about 2 arcminutes in diameter, is at (2000.0) $18^h 41^m 52^s$ −20° 03.4′. It appeared to have six or seven stars resolved at 140× in my 16-inch. Brent Archinal, a professional astronomer at the US Naval Observatory in Washington, DC and an amateur deep-sky observer on weekends, said, "I can't find any listing of this 'little open cluster' in any star cluster catalogue of which I'm aware." After studying a DSS image and saying that, without a proper motion study, it was inconclusive whether the group was a bonafide sparse open cluster or an asterism, Archinal recommended, "For future reference, I suggest a name for this group of something like Mackie 1 or Mackie J1841.9-2003." Thus Okanagan Centre member (and occasional *JRASC* deep-sky writer) Guy Mackie joins the late Father Kemble as one of the very few Canadian amateurs to have his name carried by a deep-sky object. Mackie 1 is now well known amongst Okanagan Valley observers, and it is a pleasure to introduce it to the readers of the *Journal*.

The last hour of that night was spent on tough Pal 13 in Pegasus. There was a barely perceptible smudge at the correct location, but eventually I detected a pair of magnitude 16 stars there. I may have still seen the smudge between the pair of magnitude 16 stars and the troublesomely bright magnitude 13 star, closer to the former. But I couldn't be sure as the scope was vibrating wildly in the winds of the peak with only momentary lulls every so often.

Friday, Aug 4-5: Afternoon speakers were Calgarian Tom Cameron ("The Rothney Astrophysical Observatory") and Dr. Lewis Knee ("Highlights of Recent Research at DRAO"). Edmontonian Murray Paulson did his ever-popular Binocular Star Walk with a large and enthusiastic group in the evening.

This was the only evening that the huge Prancing Horse Dark Nebula (which includes the Pipe Nebula) was a naked-eye target — the forest fire smoke over Washington State was finally gone from the south horizon. Using my 16-inch, Guy Mackie and I both decided that we could see a smudge in the right location for globular cluster Pal 10 in Sagitta. About five 16th magnitude stars were seen within the plotted location of the globular. There was an unwelcome rayed aurora in the north while we were pursuing Pal 10 in the south. We ended the night with an exceptionally crisp morning twilight view of Jupiter in Guy's 12.5-inch, which has a Zambuto mirror.

Saturday, Aug 5-6: Afternoon speakers were Ernest Pfannenschmidt ("Reminiscences on the Mt. Kobau Observatory" — great film footage from the building and site-testing days in the 1960s) and Jack Newton ("Astrophotography from Film to Infinity"). Jack and Alice Newton also hosted an open house at their nearby observatory/B&B during the star party.

I didn't make a note of the ATM and astrophotography contest winners, but

I do remember that three beautifully crafted Dobsonians won prizes: the 12.5-inch Dobsonian of distant Okanagan Centre member Owen Salava of Prince George, the 10-inch of Paul Ellard of the Okanagan Centre, and Gary Lavoie's 9.5-inch. At the closing ceremonies Gary told us that the ashes of Ernie Schmid of the Fraser Valley Amateur Astronomers had been scattered on Mt. Kobau a week or two earlier — the mountain has become a major part of the lives of so many serious western amateurs.

I repeated last night's very lengthy star-hop with the 16-inch Dobsonian to the globular Pal 6 at declination −26 degrees and this time was rewarded with a glow at the correct position at 140×. At 182× I could see sprinkles of stellar rings and it looked about twice the diameter that it is plotted as on *GUIDE 7*. Gary Seronik's 6-inch f/6 Newtonian RFT with a 2-inch 40-mm Koenig eyepiece (yielding a 3-degree field of view) and an Ultrablock filter gave a wonderful view of the North America Nebula — bright, mottled, with a very fine "Central America" and (with the filter removed) the embedded open cluster NGC 6997. Framed in the large field for contrast, the adjacent Pelican Nebula was very obvious with the Ultrablock filter — probably my best view of the Pelican. My 16-inch finished the star party chasing the Cepheus globular Pal 1. It was only occasionally suspected at 174× and 280× when the wind lightly rocked the scope and my averted vision was in the sweetest spot. It appeared fairly small. I resolved to try this one again at solar minimum as airglow always brightens MKSP skies noticeably at solar maximum.

This last morning of MKSP I was startled to see in my finder that Jupiter was surrounded by Hyades, sitting in the most distant concentration of the cluster, the northwestern band running from 50 Tau to 72 Tau. If any of the astronomy magazines mentioned this in advance, I didn't see it. Anyway, it was beautiful.

After MKSP 2000 my Palomar globular score stood at eight seen; Palomars 1, 13, and 14 suspected; and Palomars 2, 3, 4, and 15 not yet tried. Two new moons later I was able to move Pal 1 and Pal 13 from my suspected list to my observed list by using the fine 24-inch Boller and Chivens Cassegrain of Pine Mountain Observatory located in the exceptionally dark high desert of central Oregon. I find that the various observational reports about Palomar globulars that I have from the late Father Kemble, Denis Boucher, and Doug Snyder do not agree very well, probably because, firstly, detecting Palomars is so dependent on the quality of an observer's sky and, secondly, these are objects which will seldom be observed more than once or twice by each hunter.

A morning view up the Mount Kobau road before most observers are up and about, which gives a good idea of the layout of the site and the "string" of observers hugging the road all the way to the summit (Photo by Ron Scherer).

Thanks to all who made this MKSP so enjoyable: President Jim Failes, Registrar Caroline Wallace, Secretary (and brochure designer) Ron Scherer, George Loveseth (facilities manager), the other eight members of the Mount Kobau Astronomical Society, the speakers, the judges, and especially all of the many great people with whom I shared conversations on the mountain.

New moon is late next year, so the MKSP is August 18th through 26th. This means longer nights, but colder ones. Plan to bring a winter jacket, a toque, and a winter-weight sleeping bag — it can get darn cold at night at an altitude of 6200 feet at latitude 49 degrees north because of the dry semi-desert air. It is rarely colder than about 5 degrees Celsius, but you know how it is when you stand around not moving much for hours on end at night, especially if it's breezy as Kobau frequently is. Few serious observers stay down in Osoyoos because the 20 km access road has a rough surface and it would be a long haul downhill at 4AM. Osoyoos motels and lakefront campgrounds are an option for some families though, as is Jack Newton's observatory/astronomy Bed & Breakfast across the valley from Mt. Kobau. All talks and scheduled activities will be held Thursday the 23rd through Saturday the 25th. If you are flying, there is no need to bring a scope across the continent unless you wish to — there are always plenty of eyepieces available. The main thing to remember is to bring your own water as the summit is dry. It's a very casual, relaxing, and friendly star party. Attendance varies from 150 to (rarely) 275; it was 173 this year. MKSP costs only $30 all inclusive for the whole star party ($50 for a family) — just about the cheapest place in North America that you can camp for a week! The MKSP website is at: `www.bcinternet.com/~mksp`.

Alan Whitman is a full-time amateur astronomer and founder of the Mount Kobau Star Party. Alan Whitman's observatory is 18 miles from the peak of Mt. Kobau as the crow flies.

The Real Starry Sky

(Reprinted from *AstroNotes*, the newsletter of the Ottawa Centre)

by Glenn LeDrew, Ottawa Centre

When you look up on a clear night, you are seeing a very unrepresentative sample of the kinds of stars that populate our corner of the Galaxy. Because stars exhibit an incredible range of luminosities, some would be seen with the naked eye only if much closer than Alpha Centauri (the closest star system to the Sun), while others easily blaze across a considerable fraction of the Galaxy's diameter. In what follows, keep in mind that absolute magnitudes quantify the apparent brightness of an object at a standard distance of 10 parsecs, or 32.6 light-years.

The smallest viable star is about 8% of the Sun's mass and glows feebly at absolute magnitude +19. (Our Sun has an absolute of +4.8.) That is 14 magnitudes or 400,000 times dimmer than our Sun. The heaviest stars begin their lives with masses of roughly 100 times that of the Sun, and are the Galaxy's beacons at upwards of absolute magnitude −8, over 160,000 times the solar luminosity. The total range of stellar luminosities, then, occupies a range of 27 magnitudes, or a factor of 60 billion!

Nature does not like to make big stars, and those that are formed live brief lives. Star counts show that as we look to ever fainter stars, their numbers rise dramatically. For the very dimmest stars, the numbers seem to level off then decrease, but the decline may be due to the great difficulty in finding them. If the trend does persist through the lowest masses, the number of these brown dwarfs could be astounding. Contributing greatly to these rising numbers with decreasing mass and brightness is the fact that small stars live incredibly long lives. Where the most massive stars explode as supernovas after a few million years, which is only the blink of an eye in cosmic time, the smallest stars are expected to last for trillions of years, which is many times the current age of the universe.

The naked-eye sky is very strongly biased towards bright stars — mostly B- and A-type main sequence stars. Ironically, none of the most common type of star, M-type dwarfs, is visible without optical aid! We can only truly sample the fainter stellar types in the area immediately around the Sun; much farther and they fade to invisibility. To get anything like a representative sample of the brightest types, their rarity demands that we extend our net to thousands of light-years.

In Table 1, for every five absolute magnitudes, I have indicated the distance, in light-years, at which such a star would be just visible to the unaided eye. To put star counts into perspective, we need to express them in a common unit of volume. A convenient standard is 10,000 cubic parsecs, the volume occupied by a sphere just over 13 parsecs in radius. The tabulated counts are for "normal" stars (main sequence, giants, and supergiants, but not white dwarfs). The counts are presented in one magnitude bins. The first bin, labeled "−6," includes stars between absolute magnitude −6.5 and −5.5. Continuing with this line, we can see that in that magnitude range, we will find 1/10,000 of a star (a strange thing to picture) per 10,000 cubic parsecs (pc^3) or 1 star per 100 million pc^3. This small fraction of a star is still 2.6 times brighter than the Sun (the whole star would be 26,000 times brighter than our Sun), and that is with only 0.5% of the Sun's mass.

A number of interesting facts can be gleaned from a study of Table 1.

1) Look at the totals. For every 10,000 pc^3 we find 1008 stars, giving an average per pc^3 of 0.1 stars with a mass of 0.036 solar masses and producing 0.053 times the Sun's luminosity. If we include the expected number of white dwarfs, the mass goes up to 0.065 solar masses per pc^3, but the light contribution to the total would be practically negligible.

2) Most stars are intrinsically faint. The maximum numbers occur at an absolute magnitude of around +14, typically K and M dwarfs.

3) Nearly all of the light is emitted by the brightest stars, despite their rarity. Peak emission comes from stars with an absolute magnitude of +1, typically A-type dwarfs and K and M giants.

4) Most stellar mass is contributed by the vast number of dim stars. Whereas virtually all light comes from stars brighter that the Sun (near absolute magnitude +5), the mass is fairly uniformly distributed in the magnitude range from +3 to +15. The dynamics of the galaxy are clearly dominated by stars that are, at best, inconspicuous.

5) The mass-to-light ratio for stellar objects, including white dwarfs, is 1.2 solar masses per solar luminosity (654 ÷ 532 = 1.23). The ratio is greater than one because the bulk of stars are the smaller dwarfs with densities higher than that of the Sun. Density virtually always increases with decreasing luminosity. Main sequence O and M stars have, respectively, 0.03 and 10 times the Sun's density — white dwarfs have nearly a million times the Sun's density. The mass-to-light ratio derived here is surely a lower limit, as many types of objects evade detection. Many objects, (*e.g.*,

faint companions in multiple systems, dead white dwarf and neutron stars, and black holes) will contribute mass but little, if any, light.

In Table 2 we break down the number distribution of stars by spectral type and class. The row labeled "Giants" includes giants, bright giants, and supergiants. The main sequence stars dominate because that is where a star spends 90% of its lifetime, quietly burning hydrogen to helium. Additionally, no star in the universe that has about 80% or less of the Sun's mass (all K and M dwarfs) has yet evolved away from the main sequence. White dwarfs, the cores of dying stars that began their life in the range of 0.8 to about 5 solar masses, contribute significantly to the total number.

Why bother knowing this stuff? As our place in the Galaxy most probably is not unique, we should have a good idea of the overall content of the Galaxy's disk, at least at the Sun's distance from the centre. For amateur astronomers, it is always good to have a quantitative feel for the nature of what we are observing. That is especially so in this case, as the stars are the fundamental framework of what we appreciate aesthetically in our skywatching.

Glenn LeDrew has been an avid amateur astronomer since the age of thirteen. For many years of his adult life he worked for Environment Canada as a weather observer, weather station manager, and ice analyst. His astronomical travels have carried him in Australia, Baja California, and Arizona. Since 1996 he has run his own business, The Starry Room, which takes a portable Starlab planetarium around eastern Ontario. It features an artificial star projector and photographic all-sky projector, both of his own design. So far, about 25,000 people have experienced his indoor universe.

TABLE 1
General stellar luminosity function of the solar neighbourhood (per 10,000 pc^3)

Abs. Mag.	# of stars	lum. (Sun =1)	mass (Sun=1)	visibility (l.y.)
−6	0.0001	2.6	0.005	
−5	0.0006	5.1	0.02	5000
−4	0.0029	9.4	0.06	
−3	0.013	17	0.17	
−2	0.05	28	0.5	
−1	0.25	54	1.6	
0	1	96	4.0	500
1	3	111	7.4	
2	5	64	8.7	
3	12	66	17.3	
4	17	36	19.4	
5	29	25	28.1	50
6	30	10	24.7	
7	32	4	21.3	
8	33	1.8	21.8	
9	42	0.9	24.2	
10	70	0.6	35.0	5
11	90	0.3	36.0	
12	127	0.17	36.3	
13	102	0.055	20.8	
14	102	0.022	16.3	
15	127	0.011	16.3	0.5
16	102	0.0035	10.5	
17	51	0.0007	4.3	
18	22	0.0001	1.6	
19	13	0.0000	0.7	
Totals:	1008	532	356*	

* 654 including white dwarfs

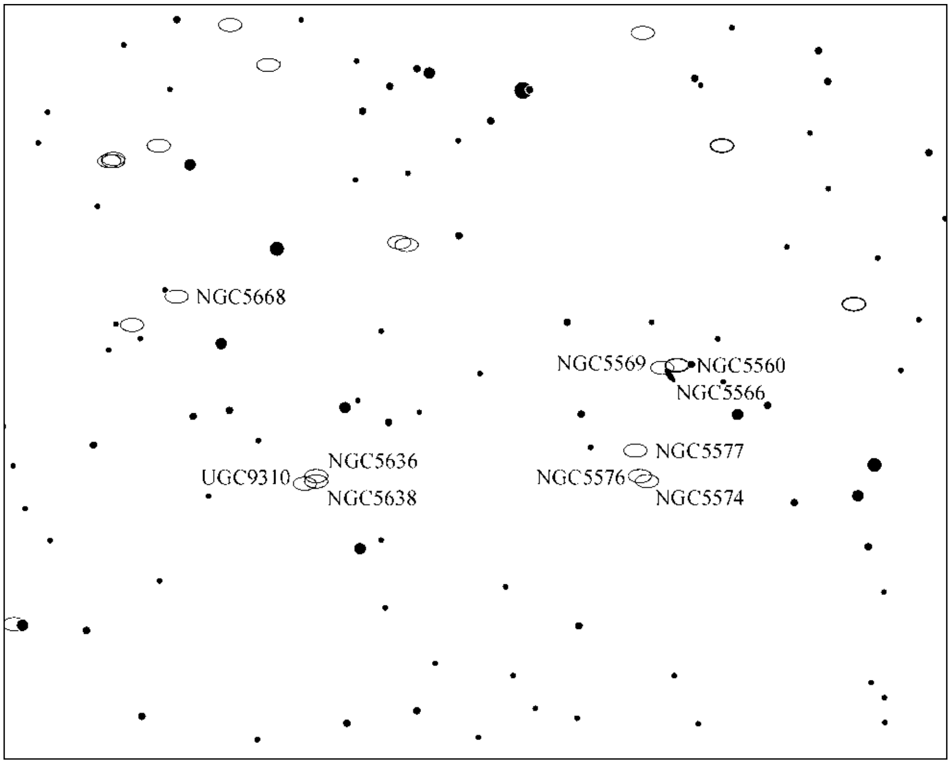
TABLE 2
Number density in the solar neighbourhood brighter than absolute magnitude +16 by spectral type and class, per 10,000 pc^3

	Spectral type							
Class	O	B	A	F	G	K	M	Totals
Giants				0.5	1.6	4	0.25	6.3
Main sequence	0.00025	1	5	25	63	100	630	800
White dwarfs		63	100	50	50	25		250

Scenic Vistas

Virgo Cluster Suburbs

by *Mark Bratton, Montreal Centre (mbratton@generation.net)*



A five-degree-high chart of many of the mentioned galaxies centred at $14^h25.5^m$ and +3° 53′ and showing stars to about 9th magnitude (ECU Chart by Dave Lane).

Examination of Chart 14 of *Sky Atlas 2000.0* places the densest concentration of the Virgo Cluster in the top right-hand corner of the page, in the area bounded by right ascensions 12^h00 and 13^h00 and by declinations 0° and +20°. Many more galaxies can be seen in an arc which curves south and east from that position, quite obviously an extension of the main cluster itself. Further to the east of the cluster's central region, however, the number of bright galaxies falls off rather quickly and only a handful of galaxies are plotted in that area. Are these galaxies truly isolated and unrelated to the Virgo cluster proper?

Not if we are to take into consideration the recessional velocities of these isolated field galaxies. Generally speaking, most Virgo cluster galaxies have recession velocities ranging from 800 to 1,200 km s^{-1}. Surprisingly, some well-accepted members of the cluster have velocities far lower than the group as a whole, including NGC 4526 (355 km s^{-1}), M91 (403 km s^{-1}), M89 (165 km s^{-1}), and M86 which is actually *approaching* our galaxy at the rate of 419 km s^{-1}. Meanwhile, the large, bright spiral galaxy M88 shows a rather high recession velocity of 1,990 km s^{-1}. Of course, one must take gravitational interaction between cluster members into consideration, as this would cause some of the galaxies to be approaching the Milky Way and appear to cancel out the general expansion of the universe.

The galaxies discussed in the present article, located well to the east of the Virgo Cluster, nevertheless show recessional velocities similar to the cluster as a whole, ranging from 1,100 to 1,700 km s^{-1}. These galaxies are likely 15 to 20 million light-years from the centre of the cluster, about the same distance that both they and the Virgo Cluster are from the Milky Way. We are, in all likelihood, seeing suburbs of Virgo's great city of galaxies.

The following observations were made in 1995 and 1997 from Sutton, Quebec, one of the darkest sites in southern Quebec that is within an easy drive of Montreal. Most of the following galaxies occur in pairs or triplets and are interesting studies in contrast. All observations were made with a 15-inch reflector using magnifications of 146× and 272×.

Working from west to east, the first targets are the two brightest members of a loose grouping of seven galaxies that all made it into the *New General Catalogue*. NGC 5363 and NGC 5364 are both brighter than magnitude 11, so they can be detected even in small telescopes. NGC 5363 is the brighter of the two, an elliptical galaxy appearing slightly elongated northwest-southeast, the outer shell being intermittently visible with averted vision. The core is bright and appears very slightly extended almost east-west. An eighth-magnitude field star is located close to the northeast. NGC 5364 is bright though quite diffuse with poorly-defined extremities, a sure tip-off that this is a spiral galaxy. The core is only slightly brighter to the middle and a faint thirteenth-magnitude star is visible to the northwest.

A very nice triplet, visible in a medium-power eyepiece, is next. NGC 5574, 5576, and 5577 show up well in a 15-inch refractor; in smaller telescopes NGC 5576 may be the only galaxy easily visible. It is the brightest, appearing quite round, sharply concentrated to a bright core. The outer edges are quite well defined and a magnitude 12 field star is visible immediately northwest. NGC 5574, located to the southwest, is the next brightest. It is a thin sliver, oriented roughly east-west with as slightly brighter core. Although fainter and quite diffuse, NGC 5577 is quite prominent in the field and appears to be the largest of the three galaxies, much elongated east-northeast/west-southwest.

Another triplet is located less than a degree to the northwest, though I was only able to note the two brightest galaxies when I observed them in 1995. NGC 5566 is an intensely bright galaxy, direct vision revealing a round, very opaque core with a bright stellar nucleus. Averted vision brings out hints of a faint, outer envelope oriented north-south. Its companion, NGC 5560 is fainter but quite prominent, a smooth elongated and fairly well-defined galaxy with a magnitude 14 star visible to the northwest. The third member of the triplet, NGC 5569, is very faint being magnitude 14.9. It is probably not visible in a 15-inch telescope under anything less than the best conditions.

Two degrees east of NGC 5574 one finds NGC 5636 and NGC 5638, a sharply contrasting pair. NGC 5638 is bright and easy in a 15-inch scope, featuring a bright, round core surrounded by a faint, secondary glow. Located 1.5 arcminutes almost due north, NGC 5636 is quite a challenge, a spiral galaxy shining feebly with a photographic magnitude of 14.6. I found it quite difficult to detect, a faint patch of light with a slightly brighter core. There is a third galaxy in the field, UGC 9310, but it is fainter than magnitude 15 and it was completely undetectable.

The last galaxy on this suburban tour is a diffuse Sc-type spiral, NGC 5668. Although moderately bright, there is little seen of the galaxy's faint, weak spiral structure. The core was quite visible, oval in shape with hints of patchy concentrations in the outer envelope. The galaxy appeared a little brighter in the southwest and a faint field star was visible in contact to the northeast.

This region of the sky, located east of central Virgo, is not often explored owing to the lack of bright field stars to help guide the way. After the crowded galaxy fields of early spring, coming to this section of the sky encourages slow and leisurely exploration and quiet contemplation of the universe beyond our Milky Way.

Mark Bratton, who is also a member of the Webb Society, has never met a deep sky object he did not like. He is one of the authors of Night Sky: An Explore Your World Handbook.

Mars 2001 *Preview*

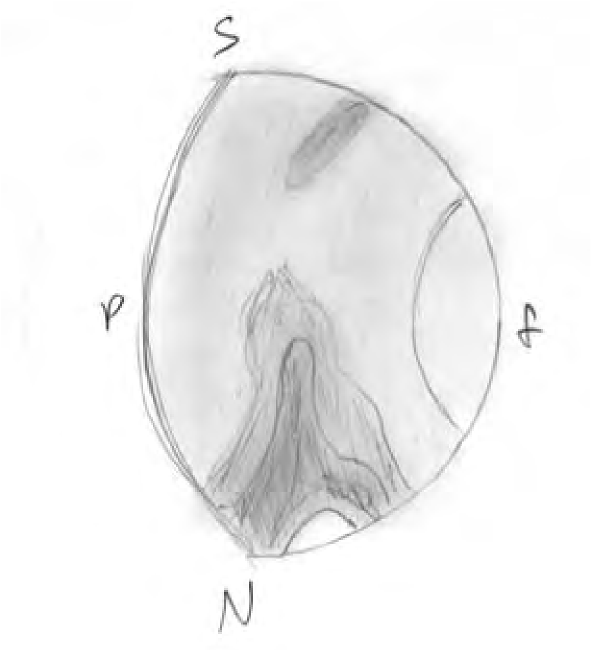
by Harry Pulley (hpulley@home.com)

Mars is arguably the most interesting planet to observe with a telescope. It is the planet that most closely resembles our own, so peering at its small disk is somewhat like looking back on our home. Of all the planets observable with a telescope, it alone offers a view of both surface features and atmospheric weather features. The surface features are what make it seem so close to our world, with dark regions appearing as though they might be continents on some long ago dried-up oceans, however wrong that impression may or may not be. Through different filters, atmospheric phenomena may be identified and categorized into fogs, frosts, and clouds. Mars rotates quickly enough that it offers a new view each night but slowly enough that there is time to make good observations and sketches of the view through several filters. For all these reasons, the planet Mars is a unique sight in our sky.

Mars is also a difficult and challenging object to observe. It offers a large apparent size only for a few months every two years. If you wait until Mars is at opposition then there is a good chance that a bad spell of weather will ruin your planned observations for the entire apparition. This short period of best observing means that there is very little time to train your observing eye, brain, and sketching hand to see and record the smaller and less obvious features displayed by the Red Planet. To someone unfamiliar with Mars observing, the disk can appear uninteresting much of the time but with practice, the more subtle features will become apparent.

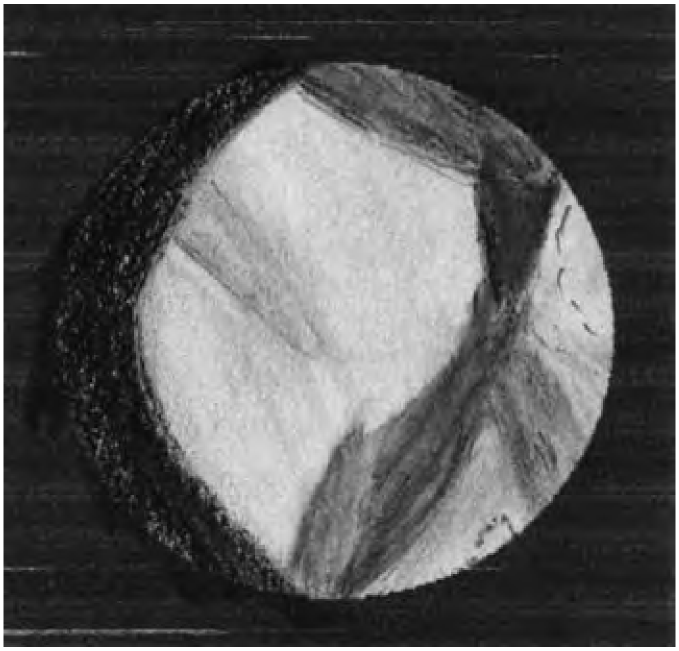
In my experience, details can be observed on Mars well when it is at an apparent diameter of six arcseconds or larger. This means February of 2001 is the month to begin observing. By this time you can already start to pick out Syrtis Major, Mare Acidalium, Mare Erythraeum, Sinus Meridiani and other large dark areas, along with large bright areas like Hellas Basin. By starting early, you can train or retrain your eye, gain or regain your Mars sketching skills, and get the kinks worked out of your imaging setup well before the planet is offering its best view.

Another reason to begin observing early is the southerly declination of Mars this apparition. At opposition, it will barely clear 20 degrees above the horizon from the southernmost locations in Canada. The seeing at this low altitude is generally poor, as observers of Venus and Mercury know well. Earlier in the year, Mars will be a bit higher in the sky during the steadier morning hours, offering a sharper view of a smaller target. In April, for example, the planet will be about 12 arcseconds in size at 25 degrees altitude, while in June it will be about 20 arcseconds across but only 20 degrees over the horizon. Five degrees doesn't sound like a lot, but it can make a big difference in the steadiness of the air. Try observing from different locations and over different surfaces to see if you can minimize local seeing factors such as heated houses, driveways, roofs, *etc.* Even though the planet will be found at a low altitude, it comes around only every two years, so it is still worthy of an observing program.



A sketch of Mars, at 215× using 23A light red filter in a 150-mm f/6.3 reflector on December 23, 1998 at 12:00 UT. Seeing was 4/10 and transparency 4/6. At only 5.9 arcseconds in diameter, Mars was already showing some detail. Note the polar cap to the north and the limb arc on the following morning limb.

Making a written record is a good way of recording both Mars itself and your progress in observing technique. Sketching Mars is made easier by prepared observing forms with circles for drawings and places to record the telescope, magnification, filter, seeing conditions, and other factors. During the early and late portions of the apparition, Mars will offer a gibbous phase; record the phase prior to making any drawing. Next record large features and place them as accurately as possible. Add fine features next, placing them in relation to the larger ones. Accompanying this article are several sketches I made during the last apparition, using an 80-mm refractor and a 150-mm reflector.



This sketch of Mars was made on February 23, 1998 from 11:50 to 12:02 UT using a 150-mm f/6.3 reflector at 151×. Seeing was 3-5/10 (poor to average). The main drawing was made with a 23A light red filter. The bright area near the limb was brightest in light yellow, while the polar region to the north (bottom) was brightest in light blue (Mars was 9.8 arcseconds in diameter).

FILTERS

More than for any other planet, Mars observation is aided greatly by the use of colour filters. The unfiltered view is enjoyable, but filters aid in both the detection and classification of features. In addition to improving the contrast of specific classes of features, filters reduce the brightness of the planet in larger telescopes. Finally, when any planet is viewed at a low altitude, the atmosphere disperses light of different wavelengths like a prism, yielding a blurry image consisting of several differently coloured sub-images. By using a filter you can select one sub-image to view at a time for a much sharper view.

Most filters are identified by the Kodak Wratten numbering scheme. I have used those numbers in the following paragraphs. The filters I mention are readily available from many vendors and manufacturers.

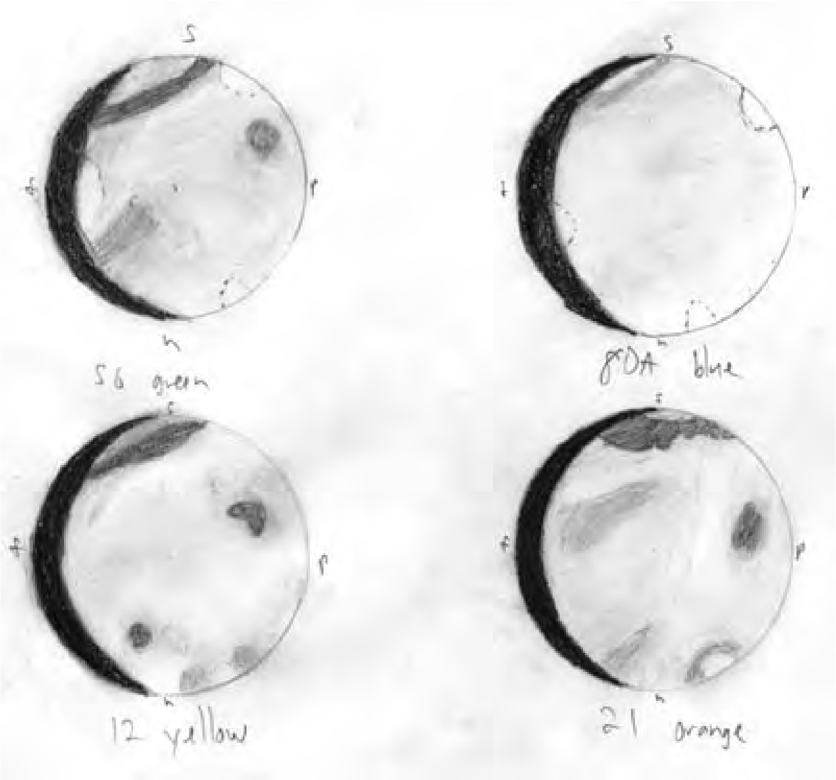
The red filter is the most important one for observations of the Red Planet. For 200-mm and larger telescopes, the 25A deep red is best, offering the highest level of contrast enhancement. Users of 150-mm scopes may prefer the lighter 23A, while those with 100-mm and smaller telescopes should use the 15 amber and 21 orange filters. Red filters are important because they greatly increase the contrast between dark and light albedo features on the planet, while suppressing the natural rust colour. Equally important, especially for this apparition, these filters will offer the steadiest view of the planet viewed in only the longer red wavelengths. As they do in aerial photography on Earth, deep red, orange and yellow wavelengths tend to punch through haze and thin cloud layers, revealing the surface topography.

Once you have completed your red-filtered sketch of basic surface features, look for any light areas on the planet. Swap in yellow 8 and 12, green 56 and 58, and blue 80A and 38A filters to determine what you are observing. If the area is brightest in yellow, it is likely a desert feature without much, if any, cloud above it. A light area brightest in green indicates frost patches and surface fogs, *i.e.*, ice and vapor close to the surface. If brightest in blue, the area contains ice and vapor higher in the atmosphere, including discrete white clouds, limb arcs, equatorial bands, and polar hoods. You can either add notes to your red sketch about the identification of lighter features or make a separate sketch with each filter, as time and enthusiasm permit.

MARS MAPS

Mars maps may be used to identify features seen through the telescope. The *Observer's Handbook* includes a good map of Mars. The 2001 edition also includes tables and calculations for determining the longitude of the central meridian on the planet. Using this central meridian, you can see which features will be displayed at a certain time. Many planetarium programs will give you this information on a globe of Mars, showing which features are currently visible and which are on the other side or are diminished by being near the limb. I strongly suggest that you do not look at maps prior to an observing session. Bring the maps or your laptop outside to check your work later but allow yourself a moment to discover the surface

This sketch of Mars was made on January 30, 1999 at 1:49 UT with a 150-mm f/6.3 reflector at 151× (seeing was 4/10 at the time). The main drawing was made with the 23A light red filter. The bright spot on the south (bottom) was brightest in yellow and green, while the other bright spots were brightest in blue. Mars was 7.9 arcseconds in diameter at the time this sketch was done.



These sketches of Mars were done with an 80-mm f/7 achromat refractor on May 28, 1999 from 1:50–2:15 UT at 140×. Mars was 14.7 arcseconds in diameter at the time.

features first, instead of trying to convince yourself that they are there. After you have seen what you can without prompting, use the map to search for things you may have missed or things that should be there but are not presently visible.

Dust Storms

Known Mars features will not always be present. Dust storms are common on the planet and will obscure even the most obvious landmarks. After making a first sketch in red, check it against your map to identify named features. If it appears that you have the correct central meridian but features are missing, note the time and the missing features. At times, most of the visible hemisphere may be covered in dust clouds, making the disk appear nearly featureless.

Final Words

The 2001 apparition of Mars will be a challenging one, but with perseverance and a red filter, you should be rewarded with satisfactory views of the Red Planet. With other filters you'll be able to follow weather patterns. By matching features to maps, you can tell if dust storms are obscuring features on the planet. A project of sketching, photographing, or taking CCD images of Mars will give you a permanent record, which you can compare with other apparitions in the future, with the work of other observers, and with reports in magazines and on the Internet.

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Harry Pulley lives in Guelph, Ontario. He is the president of the Hamilton Centre of the RASC. He is also acting coordinator of the Mercury Section of the Association of Lunar and Planetary Observers and contributes observations to other sections. He loves to observe, sketch, photograph, and take CCD images of all sorts of celestial objects, but solar system objects are his targets of long-term study.

Orbital Oddities

Lunation Rumination

by Bruce McCurdy (bmccurdy@freenet.edmonton.ab.ca)

Pop quiz: How long is a month?

This decidedly tricky question has a virtual infinitude of answers: a (western) calendar month can be anything from 28 to 31 days, menstrual cycles differ from woman to woman and from one month to the next, while the drought between pay cheques can seem to stretch on interminably.

For the purposes of this exercise, I will stick to the astronomical definition(s). The *Observer's Handbook 2001* lists no fewer than five separate periods:

Draconic month
(node to node) = 27.212 221 d

Tropical
(equinox to equinox) = 27.321 582 d

Sidereal
(fixed star to fixed star) = 27.321 662 d

Anomalistic
(perigee to perigee) = 27.554 550 d

Synodic
(New Moon to New Moon)= 29.530 589 d

The six significant digits in each case suggest that these periods are known to something like a tenth of a second; indeed, other sources list as many as nine decimal places, reducing the period in question to the nearest "nano-day." However, what is typically left unstated is that in all cases these figures are *averages* derived over very long periods. Individual months are actually like the proverbial snowflakes, no two exactly alike.

The Sun-Earth-Moon system is the classic manifestation of the three-body problem, with the tiny Moon showing the most easily measurable influences of its two larger neighbours. Add in the infinitesimal gravitational effects of the other planets, Earth's equatorial bulge, and tidal friction, and the lunar orbit is in a permanent state of evolution. Fortunately, for the purpose at hand, we need look only at the effects caused by the eccentricity of both the Moon's and Earth's orbits.

The primary focus of this rather elliptical exercise is the synodic month, also known as a lunation, defined as the interval from one New Moon to the next. Using a spreadsheet, I entered the times of all New Moons for the period 1990–2020, as listed in Jean Meeus' *Astronomical Tables of the Sun, Moon and Planets*. In the period under review, lunations varied from a minimum of 29 days 6 hours 46 minutes (May 25 to June 24, 2017) to a maximum of 29 days 19 hours 50 minutes (January 4 to February 3, 1992: more on this below). Rather than jumping about randomly, these periods followed a regular curve. Figure 1 details this curve in the short term, namely the three year period 2000–02. One can immediately see that the "long months" are grouped together, with the peaks occurring some 14 lunations apart, and the valleys of "short months" occurring at the intervals midway between the peaks.

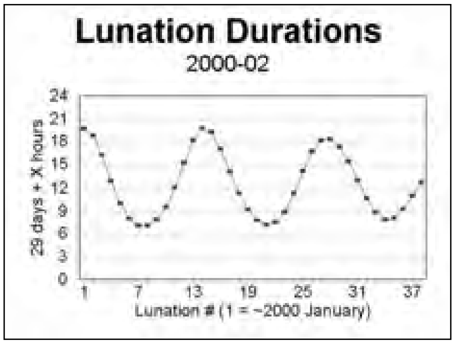

Fig. 1 — Variations in the duration of a synodic month over the period 2000-02. The effect is a rough sine curve with a wavelength of 14 months and an amplitude of about 13 hours. Bear in mind the variance appears exaggerated due to the scale of the graph; *i.e.*, the day represented here is actually the thirtieth day, so the curve should resemble a turret atop a tower 29 days high.

What's going on? I quickly determined that the primary influence is the distance of the Moon from Earth around the time of each successive New Moon. The Moon can be up to 50,000 km closer at its perigee, or closest approach to Earth, than at apogee. The Moon's orbital speed is at its fastest at perigee; also, its relative proximity to Earth effectively gives it a tighter turning radius to the Earth-Sun line, further speeding the change in phase angle. Indeed the careful naked-eye observer can actually see the Moon move further than normal from one day to the next when near perigee. As the anomalistic month from one perigee to the next is some two days shorter than the synodic, the Moon achieves perigee at an earlier phase each month. Therefore a lunation which begins near a perigee will include two "extra" days of the Moon moving at its fastest, which thus reduces the amount of time required to catch up with the Earth-Sun line. The shortest of all lunations are those that include two perigees, one just after New Moon and one just before the next. The longest lunations are those that include two apogees.

Let's do some simple math (the only kind I know how to do). The ratio of the synodic to anomalistic month is 29.530:27.554 = 1.071714. A good approximation of this is 15:14, or 1.071429. So there are almost exactly 15 anomalistic months per 14 lunations. The effect is a rotation of the major axis of the Moon's orbit, known as the line of apsides. Every 206 days this major axis is directed towards the Sun, resulting in particularly close perigees and distant apogees of the Moon. 206 days equals about seven lunations but 7.5 anomalistic months, meaning that in this period the line of apsides has completed *half* a rotation with respect to the Sun. If perigee occurs at New Moon on one occasion, 206 days later New Moon will be at apogee. This effect therefore accounts for both the peaks *and* the valleys in Figure 1.

If the Moon's orbital speed around Earth affects the duration of a lunation, so too must Earth's around the Sun. This too varies due to the ellipticity of Earth's orbit, which, while less eccentric than that of the Moon, is still significant. Earth achieves perihelion in early January each year, at which point it's about 5 million km closer to the Sun than at aphelion in early July. When Earth is moving at its fastest, it follows that the Moon will have to travel a little further to again line up with the Sun, making for a longer lunation. The reverse should hold true at aphelion. (See Figure 2 and caption.)

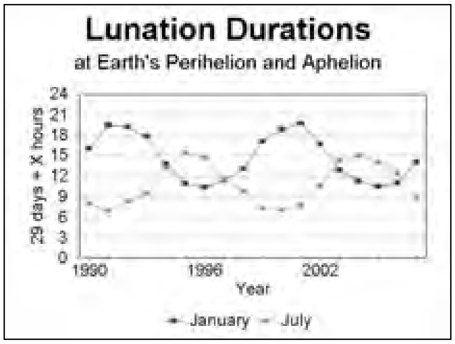

Fig. 2 — The effect of the Earth's eccentricity on lunation durations. The (usually) upper curve is comprised of the first lunation for each year from 1990-2007, the lower curve of the seventh. The two curves overlap because the effect of the Moon's own orbital eccentricity is greater than that of the Earth. Still, on average lunations are two hours longer than the mean in January and two hours shorter in July. The curves depicted here are less smooth than in the other figures because the data points are at slightly irregular intervals (either 12 or 13 lunations).

Now that we have introduced a second-order effect, it pays to look at longer-term patterns. Figure 3 graphically displays the changing durations of lunations for the period 1990–2020. The resulting curve is a fascinating representation of two separate effects gradually moving into and out of phase with each other.

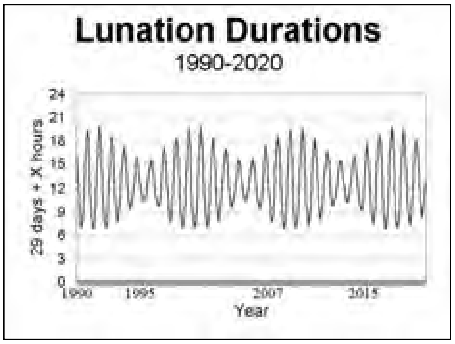

Fig. 3 — Variations in the duration of synodic months for the period 1990–2020 show a fascinating ebb and flow effect caused by the combination of the eccentricity of both the Moon's and the Earth's orbits. In general terms the Moon's distance from the Earth can affect the duration of a lunation by roughly plus five, or minus four hours, and that of the Earth from the Sun by plus or minus two. When the two effects are complementary, the amplitude of the wave is roughly 13 hours, but when they are in interference, the amplitude is reduced to about five hours.

The highest peaks occur when New Moon happens at apogee while Earth is at perihelion: the Moon's slower orbital speed in combination with Earth's greater one makes for an especially long lunation. The lowest valleys occur roughly a half-year later (or earlier) when New Moon is near perigee and Earth is at aphelion and both effects are again synchronized. However, in subsequent years the two effects gradually move out of phase and actually start to interfere with one another. Things are again back in synch after about nine years, an interval that is pleasingly consistent with the 8.85-year period known as the advance of perigee.

And if 15:14 is a good approximation of the ratio between synodic and anomalistic months, an even better one is 239:223 (1.071749), which not coincidentally is the number of each that occurs in one Saros cycle. The Saros period of 18 years plus 10 or 11 days (depending on the fall of leap years) is familiar to eclipse chasers, but it is manifest in virtually any application of lunar cycles.

In his classic work *Astronomical Algorithms*, Meeus lists the two longest lunations from 1900–2100 as follows: December 14, 1955 to January 13, 1956 (29 days 19 hours 54 minutes) and December 24, 1973 to January 23, 1974 (29 days 19 hours 55 minutes). The longest in my sample was January 4, 1992 to February 3, 1992 (29 days 19 hours 50 minutes). Note that all three occur at intervals of exactly one Saros.

In order to confirm the correctness of the mean period of a synodic month recorded in The *Observer's Handbook*, I averaged several randomly chosen samples of 14 consecutive lunations which were consistent to two decimal places *(i.e.*, 29.53 days), and a few of 223 consecutive lunations which were consistent to at least three.

Finally, for your added amusement, how long is a lunar phase? While the length of a full lunation can vary by only around 13 hours, there is a *much greater* variability in the duration of a quarter, as the same factors noted above still apply without being moderated by the rest of a full orbit. For example, have a look at the *RASC Observer's Calendar* for 2001 February, which indicates that Full Moon occurs on February 8th, Last Quarter on the 14th, and New Moon not until the 23rd, implying one phase of six days immediately followed by another of nine. While the difference is not the full three days — following the calendar's usage of Eastern Standard Time to emphasize the point in this instance — it clearly has to be greater than one. I did a quick analysis of the 2001 calendar year and found that quarters range from a maximum of 8 days 5 hours 10 minutes (New Moon on December 25, 2000 to First Quarter on January 2, 2001) to a minimum of 6 days 14 hours 24 minutes (New Moon on July 20 to First Quarter on July 27), a difference of over 38 hours (20%). Note the two extremes cited occur exactly seven lunations apart: July 27 is 206 days after January 2. In the first instance apogee occurs on December 28 and Earth is virtually at perihelion, and in the second case perigee occurs late on July 21 and Earth is still near aphelion.

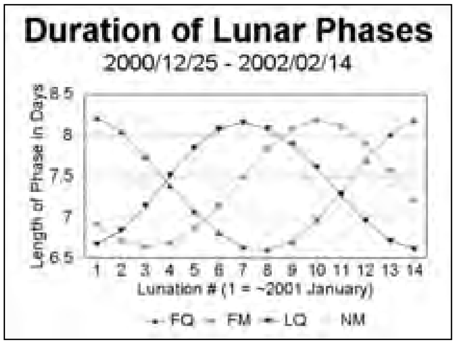

Fig. 4 — The duration of a given lunar phase, or quarter, varies dramatically due to the gravitational influences described in the text. When represented graphically, the interrelationship among them becomes obvious.

In figure 4, I have plotted the duration of all lunar phases for the 14 lunations commencing at the end of 2000. Each of the four phases follows a very similar curve, with the opposing phases (New *versus* Full, First Quarter *versus* Last) casting virtual mirror images peak-to-valley. Over the 14 lunations each of the phases averages out to about 7.38 days, each almost exactly one quarter of the synodic average of 29.53.

The intricacies of the lunar orbit can be a subject of endless fascination for those with an appreciation of nature's details and can be approached from many more angles than I have room to describe here. No doubt this topic will be raised again in this space in the future.

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A Past President of the Edmonton Centre RASC, Bruce McCurdy is also the resident "semi-pro" astronomer at the Edmonton Space & Science Centre's Public Observatory, where he has provided volunteer service for 14 years and has enjoyed paid employment for the past five summers. He has had a particular interest in the Moon since the Apollo missions and recently completed a project in which he observed every named feature on the lunar nearside. As anybody who has visited his house can attest, Bruce has a natural affinity for chaotic systems.

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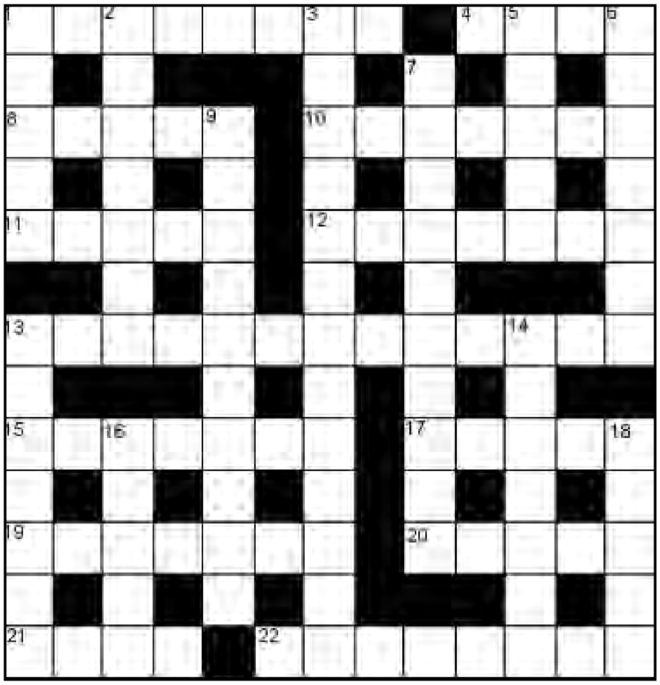
Astrocryptic #9

by Curt Nason, Moncton Centre

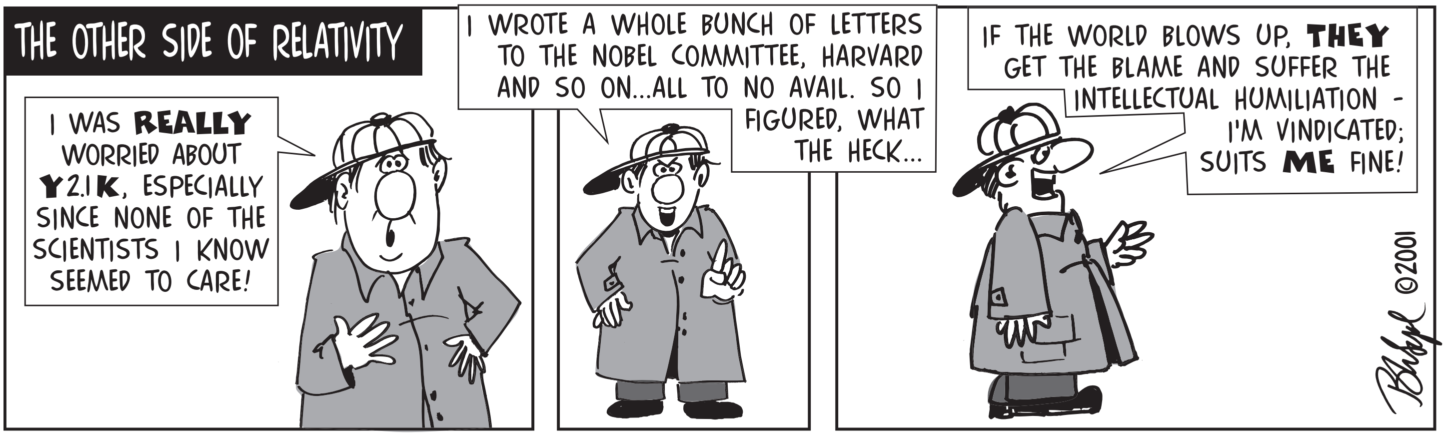


ACROSS

1. In effect, some see red when ripe junk is scattered (8)
4. RASC reorganization leaves its mark (4)
8. Southern Indian resolved from meteor train dust (5)
10. They do not shop around at the speed of light (7)
11. Jean's alignment predictions made Sky&Tel's centrefold girl return to me (5)
12. It might be an alignment phenomenon, but it isn't art somehow (7)
13. Rogue Type A red star captured on old film (13)
15. A significant fraction of #1 hydrogen alpha light filters (3-4)
17. Elizabethan author was named in the Columba constellation (5)
19. Tangible cometary train seen around Connecticut to the east (7)
20. It lies in brown haze around Saturn (5)
21. This bird can't fly around Saturn (4)
22. Isn't key C different when played on Phobos? (8)

DOWN

1. Sirius partly rises in the afternoon after a light bender (5)
2. Oddly dry mass of ice is a constant feature of H spectra (7)
3. Gribbin's planetary influence was not all it was cracked up to be (7,6)
5. Having one in each hemisphere makes one angry (5)
6. A nebula appears flipped in cassettes or in Monoceros (7)
7. Pilot or bar mix can take a satellite over the top (5,5)
9. Methodic solar one at the Index Catalogue (10)
13. Lens measurement used since the beginning of time in an uncertain period (7)
14. Peninsular home of the dinosaur killer (7)
16. Comet Kohoutek initially seen in the east northeast as a ring division (5)
18. Capella's mother or a surrogate mother (5)



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