The Journal of The Royal Astronomical Society of Canada

Journal

Le Journal de la Société royale d’astronomie du Canada

PROMOTING ASTRONOMY IN CANADA

October/octobre 2025
Volume/volume 119
Number/numéro 5 [834]

Inside this issue:

IC 1318

TOTAL SOLAR ECLIPSE
TOURS FOR 2026 AND 2027

AUGUST 2026
GREENLAND & ICELAND CRUISE

Sail deep into the Scoresby Sound fjords on Swan Hellenic's five star expedition ship, Diana.

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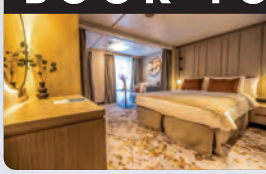

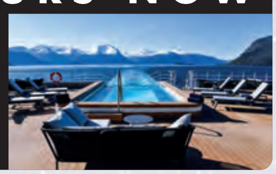

AUGUST 2026
SPANISH CASTLES

Observe the eclipse at sunset from a castle high above the pretty medieval town of Siguenza and dine in opulent surroundings. Alternatively choose the dramatic ruins of Gormaz Castle high above the plains with far reaching views towards totality.

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AUGUST 2027
NORTH AFRICA

A total solar eclipse with an extraordinary duration of over 6 minutes in Egypt will occur along the length of the North African coast. We have selected the very best locations to observe this event from, enabling you to enjoy the rich history, culture and scenery of these exotic lands.

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Tunisia: A rich Arab culture and some great antiquities and Star Wars film sets! A land where the Mediterranean Sea meets the Sahara Desert.

Siwa Oasis: Head out into the Western Deserts of Egypt and discover lush palm trees, crystal clear springs and serene salt lakes that paint a picturesque backdrop against the golden sands of the Sahara.

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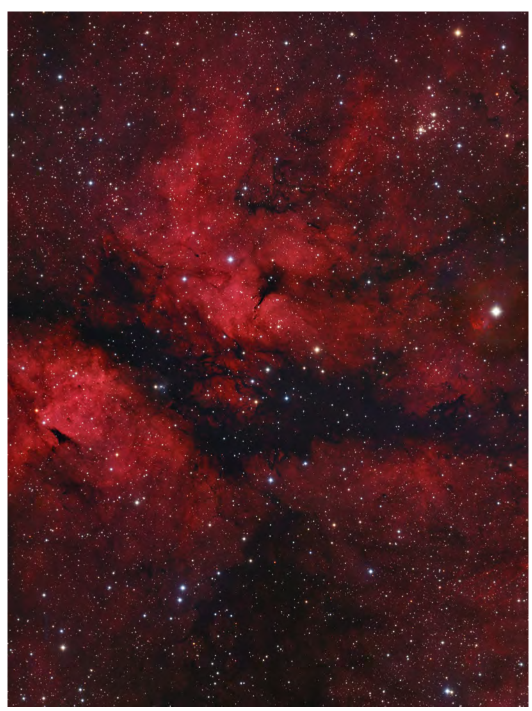
October / Octobre 2025 | Vol. 119, No. 5 | Whole Number 834

Royal Astronomical Society of Canada
Société Royale d'Astronomie du Canada

contents / table des matières



This stunning large emission nebula, IC 1318—located near Sadr in Cygnus—was imaged by Marc Ricard from his home in Ste-Lucie-des-Laurentides, Québec, in June. The final image is an integration of 164 × 180-second sub-frames captured with his QSI 683 camera and FSQ 106 EDXIII telescope through LRGB filters. "You'll find the open cluster NGC 6910 in the top left corner. The brighter portions can be seen visually under dark skies," he said.

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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President's Corner

Have you ever wondered what could be?
Have you ever been inspired?

Brendon Roy (Thunder Bay), President
novationheart@hotmail.com

They sound like simple questions—ones that invite a quick "yes" or "no." But under the dark canvas of a clear night sky, they become something more profound. At least, that's been true for me.

Those questions led me down a path of curiosity that quickly grew. I needed to seek out others who might share this sense of wonder—or even hold some of the answers. That's what brought me to The Royal Astronomical Society of Canada.

I first joined the RASC in 1993 as a youth member. Technically, it was under my father's name—I wasn't old enough to have a credit card at the time. But a little technicality like that wasn't going to stop me from learning about the night sky. I found ways to get to Centre meetings and events where I met like-minded people and learned a great deal. I've been hanging out with RASC members ever since—over 30 years now—and I wouldn't trade those experiences for anything.

Now, as President, I find myself asking a new variation of an old question(s):

> **"How can I continue to inspire *you*?"**
>
> *Or perhaps more importantly*
>
> **"What could the RASC become?"**

The answers aren't mine alone to give. This isn't *my* Society—it's *our* Society. Its progress, its accomplishments, and its future will always be the result of many individuals coming together in pursuit of a shared curiosity about our place in the Universe.

That's why I want to hear from you.
Your thoughts.
Your ideas.
Your stories.

How can we grow the RASC together? What new and exciting projects should we take on? What kind of future should we be building toward?

Of course, one of the pressing questions we face today is how we can generate the revenue needed to support our goals and aspirations. I'll be working closely with the Society's leadership to identify meaningful opportunities that align with our values and help fuel our collective mission. Current geopolitics have added an extra challenge to this process.

Even if you don't have a specific idea or project in mind, I still want to hear from you. Some of the most touching and inspiring stories I've heard over the years have come from casual conversations—little moments that might otherwise be tucked away, waiting for the "right time" to share.

If you're looking for a way to contribute, one of the simplest and most impactful is through a donation. The RASC is a national charity and can issue tax receipts for contributions. These gifts help fund our projects in the near term and sustain our long-term vision for future generations of amateur astronomers.

Behind the scenes, we're supported by an incredible team at the National Office—a hub of energy, creativity, and dedication that keeps the Society running smoothly. I rely on them, as does the rest of the leadership, to serve our members and help bring new ideas to life. You'd be amazed at the volume and variety of insights, questions, and inspiration that pass through their hands every day.

I once wondered what could be—and I was inspired by the people I met through the RASC. Thirty years later, I'm still inspired—by what the Society has done, what it continues to do, and what it *could* become.

So the next time you step outside, look up. Let yourself wonder. And know that, as a member of the RASC, when you explore the night sky—you do not do so alone. ✶

News Notes / En manchette

Compiled by Jay Anderson

A meteor shower for the ages

Asteroid 2024 YR_4 is a 16-m-diameter asteroid that at one point was thought to pose an impact risk to the Earth. Ongoing telescopic observations have refined our knowledge of its path, and now we know it will miss our planet. But currently there is still a four-percent chance that the asteroid will strike the Moon. If 2024 YR_4 strikes the Moon on 2032 December 22, it will likely be the largest impact in approximately 5000 years.

In a paper submitted in June 2025 to American Astronomical Society journals, the possibility that material ejected from the Moon by an impact is examined from the point of view of the risk it poses to Earth-orbiting satellites. If the collision does occur, the study estimated that—a few days after the impact—small-sized (0.1 to 10 mm) particles ejected from the Moon could increase the rate of meteors near the Earth by several orders of magnitude. This would produce a captivating meteor shower, though with no danger to the surface of the Earth. However, satellites in Earth orbit could face an increased risk of being hit and damaged by these particles.

Additionally, the material could affect Moon-orbiting spacecraft, including proposed systems like the *Lunar Gateway*. Much of the material lifted by the asteroid impact will fall back to the Moon, affecting surface operations of landers, rovers, and of astronauts of the *Artemis* program.

The delivery of ejecta escaping the Moon to near-Earth space is highly sensitive to the precise impact location, but the impact corridor assumed by the study allows for delivery efficiencies of up to 10 percent. This would result in particle fluxes at Earth of 10 to 1000 times the current background value, producing effective exposures equivalent to years in space over just a few days. The resulting meteor shower at Earth could be eye-catching, and possibly even unprecedented in historical time. The travel time from lunar impact to Earth is typically several days but depends on the precise location of the impact, which probably cannot be determined until the asteroid returns to visibility in 2028, when updated orbital parameters can be obtained. Material persisting in Earth orbit for times longer than those few days would present an ongoing hazard, highlighting that issues of planetary defense extend well beyond the effects of impacts on Earth's surface.

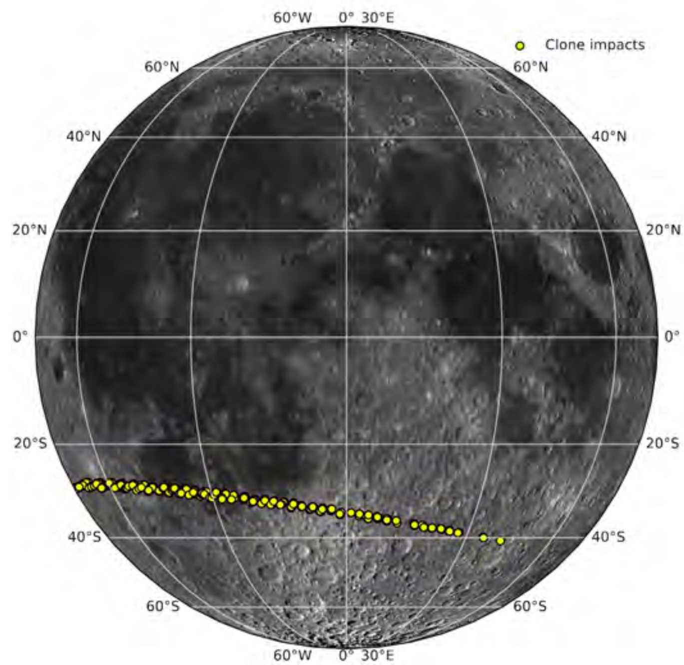


Figure 1 — The current impact corridor for 2024 YR_4 (yellow) projected on a map of the Moon's near side from Lunar Reconnaissance Orbiter *(E. J. Speyerer et al. 2011).*

Lead author, Paul Wiegert, of the University of Western Ontario, noted in an interview with the University's *Western News*, that "If YR_4 hits the Moon, it will be at about 13 kilometres per second, which is tens of thousands of kilometres per hour. At that speed, it'll make a crater and release significant amounts of ejecta. A lot of that material will fall back to the surface, which could pose dangerous risks to any astronauts nearby. This would be a particular concern given that NASA's *Artemis* program is expected to have missions on the Moon at that time."

The research team was made up of three members from the University of Western Ontario, Paul Wiegert, Peter Brown, and Jack Lopez, and one, Martin Connors, from Athabasca

University in Alberta. In their modelling of the impact consequences, they assumed a 60-m-diameter asteroid with a bulk density of 3000 kg/m³ impacting a hard-rock surface. The results estimated the formation of a crater 1.4 km in diameter; if the soil at the impact site is looser, the crater diameter would be half that size. Kilometre-sized craters are estimated to form every ~5000 years, based on earlier studies of lunar crater production statistics.

Previous work had shown that the typical ejecta from a crater impact are quite small: typically, micron- to mm-sized. The modelling showed that the impact could release 10^{11} kg of ejecta, of which 0.02 to 0.2 percent would escape lunar gravity. Though it's poorly constrained by current studies, the authors assumed that the largest ejected fragment would be about 1 metre in size.

To determine the impact probability, given the uncertain nature of 2024 YR_4's orbit, the team created 10,000 simulations (clones) of the impact, varying initial parameters for each clone. The simulations included the gravitational effects of the Sun, Moon, and planets, and the known parameters of the asteroid's orbit, up to its last observation by the JWST on 2025 May 11. Each of these resulted in a terminal position at the Moon's orbit. Of these, 410 struck the Moon, in line with current estimates (4.1 percent), and their impact positions were plotted on the lunar surface. These impact points were all in the southern hemisphere and mostly on the leading side.

The impact position has a significant effect on the amount of material ejected toward the Earth. In order for material to fall toward the Earth, its residual velocity after rising out of the Moon's gravitational field should be close to the Moon's orbital velocity and be nearly stationary with respect to the Earth. The residual velocity is very sensitive to where on the Moon the impact occurs. The authors test four locations in their model, stretching along the impact track, including one on the far side leading edge, of the lunar disk. Delivery efficiencies ranged from nearly 12 percent on the west-most trailing edge to 0.19 percent on the easternmost leading edge and to only 0.04 percent for an impact on the Moon's far side.

Impact site is also important in the time needed for particles to reach our atmosphere. Sites on the trailing side can arrive in three to five days; those on the leading side can take 80 days or more.

The visual effect of an impact by 2024 YR_4 may not be as impressive as you might think. The velocity of particles drifting in from lunar orbit is much lower than typical meteor shower speeds, greatly reducing the heating and ablation that give rise to a typical shooting star. Even so, it will be a spectacular show.

The impacts may be most strongly felt by the constellations of satellites in orbit, which have a velocity of their own—about 7.5 km/s—to add to that of the infalling lunar debris. Wiegert and his colleagues speculate that the flux of meteor particles could rise to 10 to 1000 times the background flux. It is possible that hundreds to thousands of impacts could be spread across the satellite fleet.

Fortunately, the *James Webb Space Telescope*, at the Lagrangian point, is largely immune from a lunar impact.

Compiled in part with material provided by the University of Western Ontario.

An old friend finds a partner

Betelgeuse, the tenth-brightest star and the closest red supergiant to Earth, has an enormous volume, spanning a radius around 700 times that of the Sun. Despite only being ten million years old, which is considered young by astronomy standards, it's late in its life. Located in the shoulder of the constellation Orion, Betelgeuse has played an important part in stellar lore for millennia. In 1836, Sir John Herschel noted that the star changes in brightness over time, though this may have been known by aboriginal groups in Australia for a much longer time. At its brightest, Betelgeuse outshines nearby Rigel, making brightness changes more apparent to knowledgeable observers. In modern times, astronomers have established that Betelgeuse has a main period of variability of around 400 days and a puzzling, more extended secondary period of around 6 years.

In 2019 and 2020, there was a steep decrease in Betelgeuse's brightness—an event referred to as the "Great Dimming." The event led some to believe that a supernova death was quickly approaching, but scientists were able to determine the dimming was actually caused by a large cloud of dust ejected from the star. Observations of Betelgeuse at the time were not able to detect a companion, a consequence of the very small separation of the two stars at the time and the large amount of dust in the vicinity.

The Great Dimming sparked a renewed interest in studying Betelgeuse, which brought about new analyses of archival data on the star. One analysis led scientists to propose that the cause of Betelgeuse's six-year variability is the presence of a companion star, but when the *Hubble Space Telescope* and the *Chandra X-Ray*

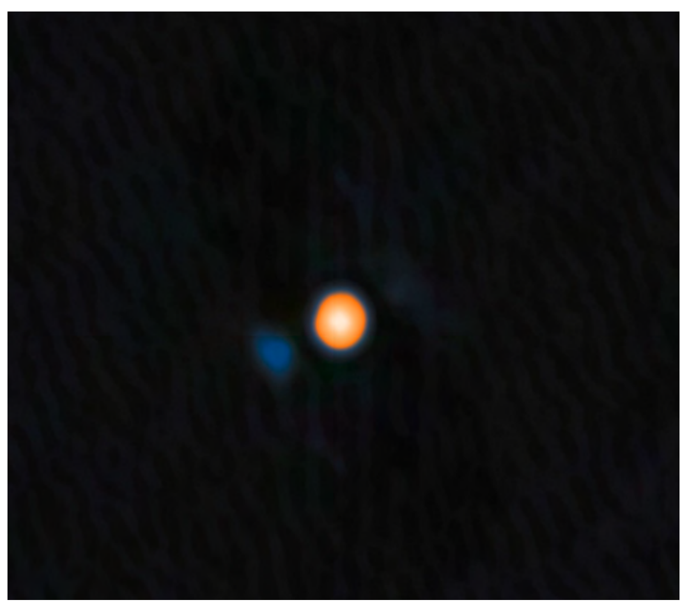


Figure 2 — An image of Betelgeuse, the yellow-red star, and the signature of its close companion, the faint blue object. Data: NASA/JPL/NOIRLab. Visualization: NOIRLab.

Observatory searched for this companion, no detections were made. A companion was expected, as recent modelling had finally attributed the 6-year brightness variations to a second, closely orbiting star and had determined a provisional orbit.

The companion star has now likely been detected for the first time by a team of astrophysicists led by Steve Howell, senior research scientist at NASA Ames Research Center and lead author of the paper reporting the discovery. They observed Betelgeuse by using a speckle imager called ʻAlopeke. ʻAlopeke, which means "fox" in Hawaiian, is mounted on the Gemini North telescope on Mauna Kea, Hawai'i, one half of the International Gemini Observatory. To improve their odds of discovery, the research team searched when the star's predicted orbit placed it at its greatest distance from Betelgeuse.

Speckle imaging is an astronomical imaging technique that uses very short exposure times to freeze out the distortions in images caused by Earth's atmosphere. Individual images are then aligned, averaged, and stacked, a process familiar to amateur astronomers. This technique enables high resolution, which, when combined with the light collecting power of Gemini North's 8.1-metre mirror, allows for Betelgeuse's faint companion to be directly detected.

The discovery image showed the companion as a small, blue-white smear alongside the much larger and brighter orange glow of Betelgeuse, a detection that was thought to be impossible because of the small separation of the two stars and the overwhelming glow of Betelgeuse. Even so, the discovery is right at the limit of detection because of the very short exposures required for speckle imaging.

Analysis of the companion star's light allowed Howell and his team to determine that the companion star is six magnitudes fainter than Betelgeuse in the optical wavelength range, has an estimated mass of around 1.5 times that of the Sun, and appears to be an A- or B-type pre-main-sequence star: a hot, young, blue-white star that has not yet initiated hydrogen burning in its core. The star was very close to the position predicted from the orbit model.

The companion is at a relatively close distance from Betelgeuse—about four times the distance between the Earth and the Sun. This discovery is the first time a close-in stellar companion has been detected orbiting a supergiant star. Even more intriguing—the companion orbits well within Betelgeuse's extended atmosphere.

"Gemini North's ability to obtain high angular resolutions and sharp contrasts allowed the companion of Betelgeuse to be directly detected," says Howell. Furthermore, he explains that ʻAlopeke did what no other telescope has done before: "Papers that predicted Betelgeuse's companion believed that no one would likely ever be able to image it."

This discovery provides a clearer picture of this red supergiant's life and future death. Betelgeuse and its companion star were likely born at the same time. However, the companion star will have a shortened lifespan as strong tidal forces will cause it to spiral into Betelgeuse and meet its demise, which scientists estimate will occur within the next 10,000 years. That event may help push Betelgeuse into a supernova explosion if it hasn't already occurred.

The discovery also helps to explain why similar red supergiant stars might undergo periodic changes in their brightness on the scale of many years. Howell shares his hope for further studies in this area: "This detection was at the very extremes of what can be accomplished with Gemini in terms of high-angular resolution imaging, and it worked. This now opens the door for other observational pursuits of a similar nature."

Martin Still, NSF program director for the International Gemini Observatory adds: "The speckle capabilities provided by the International Gemini Observatory continue to be a spectacular tool, open to all astronomers for a wide range of astronomy applications. Delivering the solution to the Betelgeuse problem that has stood for hundreds of years will stand as an evocative highlight achievement."

Another opportunity to study Betelgeuse's stellar companion will occur in November 2027, when it returns to its furthest separation from Betelgeuse, and thus easiest to detect. Scientists will use that opportunity to refine the companion's mass, orbit, temperature, and chemical composition, but are especially eager to measure how the stars interact dynamically and whether any signs of mass transfer are visible.

Composed in part with material provided by NASA

Long-distance repair at Jupiter

The mission team of NASA's Jupiter-orbiting *Juno* spacecraft executed a deep-space move in December 2023 to repair its

JunoCam imager to capture photos of the Jovian moon Io. Results from the long-distance save were presented during a technical session on July 16 at the Institute of Electrical and Electronics Engineers Nuclear & Space Radiation Effects Conference in Nashville.

JunoCam is a colour, visible-light camera. The optical unit for the camera is located outside a titanium radiation vault; camera electronics are contained within the vault, which has one-centimetre-thick walls.

Juno's highly elliptical orbit carries it through the most intense planetary radiation fields in the Solar System. While mission designers were confident JunoCam could operate through the first eight orbits of Jupiter, no one knew how long the instrument would last after that. Throughout *Juno*'s first 34 orbits (its prime mission), JunoCam operated normally, returning images the team routinely incorporated into the mission's science papers. Then, during its 47th orbit, the imager began showing hints of radiation damage. By orbit 56, nearly all the images were corrupted.

While the team knew the issue may be tied to radiation, pinpointing what, specifically, was damaged within JunoCam was difficult from hundreds of millions of miles away. Clues pointed to a damaged voltage regulator that is vital to JunoCam's power supply. With few options for recovery, the team turned to a process called annealing, where a material is heated for a specified period before slowly cooling. Although the process is not well understood, the idea is that the heating can reduce defects in the material.

"We knew annealing can sometimes alter a material like silicon at a microscopic level but didn't know if this would fix the damage," said JunoCam imaging engineer Jacob Schaffner of Malin Space Science Systems in San Diego, which designed and developed JunoCam and is part of the team that operates it. "We commanded JunoCam's one heater to raise the camera's temperature to 77 degrees Fahrenheit—much warmer than typical for JunoCam—and waited with bated breath to see the results."

Soon after the annealing process finished, JunoCam began cranking out crisp images for the next several orbits. But *Juno* was flying deeper and deeper into the heart of Jupiter's radiation fields with each pass.

"After orbit 55, our images were full of streaks and noise," said JunoCam instrument lead Michael Ravine of Malin Space Science Systems. "We tried different schemes for processing the images to improve the quality, but nothing worked. With the close encounter of Io bearing down on us in a few weeks, it was Hail Mary time: The only thing left we hadn't tried was to crank JunoCam's heater all the way up and see if more extreme annealing would save us."

Test images sent back to Earth during the annealing showed little improvement the first week. Then, with the close approach of Io only days away, the images began to improve dramatically. By the time *Juno* came within 1,500 kilometres of the volcanic moon's surface on 2023 December 30, the images were almost as good as the day the camera launched, capturing detailed views of Io's north polar region that revealed mountain blocks covered in sulfur dioxide frosts rising sharply from the plains and previously uncharted volcanos with extensive flow fields of lava.

Figure 3 — The graininess and horizontal lines seen in this JunoCam image show evidence that the camera aboard NASAs Juno *mission suffered radiation damage. The image was taken 2023 November 22. Credit: NASA/JPL-Caltech/SwRI/MSSS*

Recently, the image noise returned during *Juno*'s 74th orbit. Another attempt at annealing may again temporarily repair the damage, but *Juno* is scheduled to end its mission in September, eventually burning up in Jupiter's atmosphere.

Since first experimenting with JunoCam, the *Juno* team has applied derivations of this annealing technique on several *Juno* instruments and engineering subsystems.

"*Juno* is teaching us how to create and maintain spacecraft tolerant to radiation, providing insights that will benefit satellites in orbit around Earth," said Scott Bolton, *Juno*'s principal investigator from the Southwest Research Institute in San Antonio. "I expect the lessons learned from *Juno* will be applicable to both defense and commercial satellites as well as other NASA missions."

Composed with material provided by NASA

Scattered light changes planets' sizes

In new research, University of California, Irvine astronomers describe how more than 200 known exoplanets are likely significantly larger than previously thought. It's a finding that could change which distant worlds researchers consider potential harbours for extraterrestrial life.

"We found that hundreds of exoplanets are larger than they appear, and that shifts our understanding of exoplanets on a large scale," said Te Han, a doctoral student at UC Irvine and lead author of the study. "This means we may have actually found fewer Earth-like planets so far than we thought."

Astronomers can't observe exoplanets directly. They have to wait for a planet to pass in front of its host star, and then they measure the very subtle drop in light emanating from a star. "We're basically measuring the shadow of the planet," said Paul Robertson, UC Irvine professor of astronomy and study co-author.

Han's team studied observations of hundreds of exoplanets observed by NASA's *Transiting Exoplanet Survey Satellite* (TESS), which uses an array of wide-field cameras to survey the sky. The researchers found that, because of TESS's wide field and low resolution, the light from a star hosting a transiting exoplanet can be blended with the light from stars in the background field. If not fully corrected, this extra light can dilute the transit signal and result in a smaller measured planet radius because smaller planets block less light than bigger planets. The low angular resolution of TESS means that background stars at several pixels away (about 1 arcminute) can contaminate measurement of the exoplanet host. As a result, blending in TESS exists for almost all stars.

Han assembled hundreds of studies describing exoplanets discovered by the TESS mission, and sorted the planets according to how various research teams measured their radii. From these, he could estimate, with the help of a computer model, the degree to which those measurements were biased by light contamination. The team used observations from another satellite mission called *Gaia* to help them estimate just how much light contamination is affecting TESS's observations. Han and his group found that exoplanet radii for 228 planets was underestimated by ~6 percent, leading to a ~20 percent overestimate of planet density.

"TESS data are contaminated, which Te's custom model corrects better than anyone else in the field," said Robertson. "What we find in this study is that these planets may systematically be larger than we initially thought. It raises the question: Just how common are Earth-sized planets?"

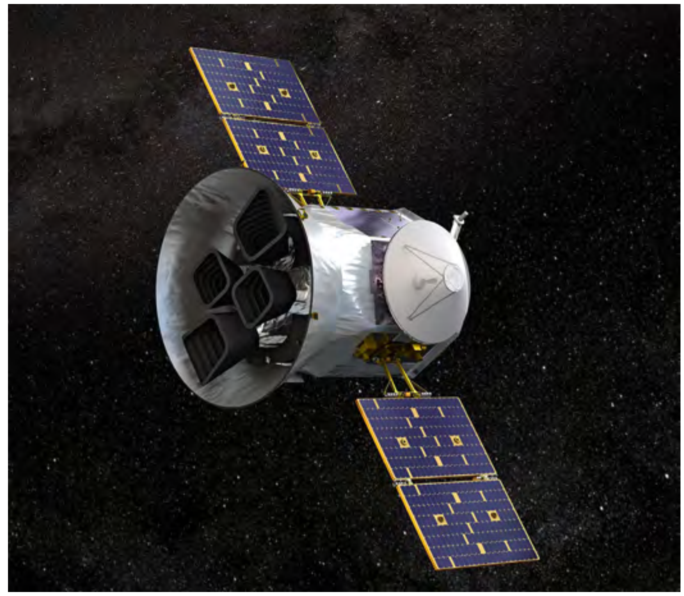


Figure 4 — Illustration of the TESS (Transiting Exoplanet Survey satellite). *Credit: NASA/GSFC*

The number of exoplanets thought to be similar in size to Earth was already small. "Of the single-planet systems discovered by TESS so far, only three were thought to be similar to Earth in their composition," said Han. "With this new finding, all of them are actually bigger than we thought."

That means that, rather than being rocky planets like Earth, the planets are more likely so-called "water worlds," planets covered by one giant ocean that tend to be larger than Earth—or even larger, gaseous planets like Uranus or Neptune. This could impact the search for life on distant planets, because while water worlds may harbour life, they may also lack the same kinds of features that help life flourish on planets like Earth.

"This has important implications for our understanding of exoplanets, including among other things prioritization for follow-up observations with the *James Webb Space Telescope*, and the controversial existence of a galactic population of water worlds," said Roberston.

The biases in the literature have found their way into the understanding of the exoplanet population. Correcting the biases will refine the exoplanet mass-radius relation, reshape our understanding of exoplanet atmospheric and bulk composition, and potentially affect prevailing planet formation theories.

Next, Han and his team plan to use the new data to start re-examining planets previously thought uninhabitable due to their size and to also let other researchers know to exercise caution when interpreting data from satellites like TESS. ✶

Composed with material provided by the University of California, Irvine.

Featured Article / Article de Fond

Seeking a Record of the Crab Nebula Supernova Reveals Doodles in the Capitulary of St. Gallen Abbey

by Jayanne English, University of Manitoba; visiting University of Zurich 2018
Jayanne.English@UManitoba.ca
Miroslav Filipović, Western Sydney University

Abstract

While searching for a European record of supernova SN 1054, the explosion that created the famous Crab Nebula, sketches of a dog and manicule (pointing hand) have been discovered in digital photographs of an apparently blank page in the Capitulary of St. Gallen Abbey. The animal shows similarities to ninth-century figures used for outlining constellations of dogs or wolves, initially suggesting to the investigators that the page could contain a star chart. However, the creature is most similar to dogs in watermarks that were embedded in manufactured writing surfaces in the 1300s and later. Rather than pinpointing the occurrence of the supernova, this dog and manicule seem to be more examples of the numerous, and common, "doodles" made by monks.

Keywords: supernovae: individual: Crab Nebula, SN 1054; History and philosophy of astronomy: St. Gallen Abbey, doodles.

Introduction

The monks of St. Gallen Abbey, Switzerland, recorded an important event per year in annals contained in a capitulary begun in the 9th century CE. Although many such codices, i.e. manuscripts in book form, from other religious sites have been dispersed or destroyed, St. Gallen's resides at its Stiftsbibliothek; its shelfmark being Cod. Sang 915[1]. Its significance for astronomers is that Page 234's seemingly blank upper region could have contained an entry about the supernova explosion that produced the renowned Crab Supernova Remnant (SNR); see Figure 1. Observations of the "guest star" were recorded in 1054 by the Chinese and there has been an unsuccessful quest for a textual European record of this consequential event to date.

Various approaches have been used to establish the date of the SN explosion. Astronomy analyses employing the expansion rate of the SNR nebula can produce uncertainties of several decades for the date, yet that of Rudie, Fesen and Yamada

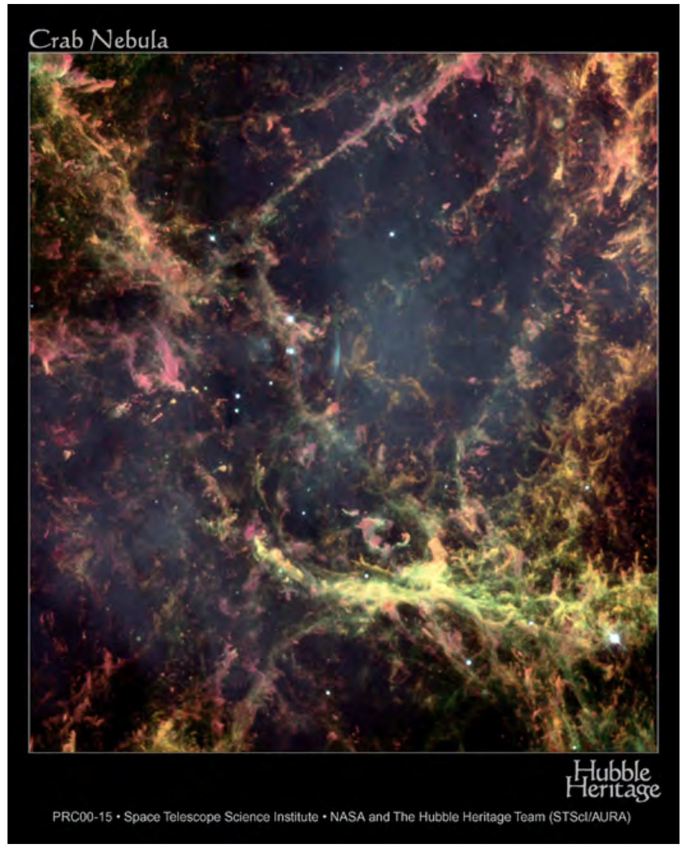


Figure 1 — The Crab Supernova Remnant

This Hubble Space Telescope *image zooms in on the neutron star, which is the core that remains when a star explodes. It is the bottom bright point in the centre of the image. The supernova remnant, consisting of filaments of heated gas, was created in the explosion.*

(2008) agrees with 1054 CE with an uncertainty of roughly 24 years. The uncertainty for 1054 CE based on the Chinese reports of the guest star's appearance is only a matter of a few months (see Filipović et al. (2021a) and Table 2 in Filipović et al. (2022)). We began by reviewing the pages in the capitulary that encompass the broader time period.

Each page in the annals section of the capitulary consists of an itemized list of dates in Roman Numerals scripted in red ink. Text entries occur on Page 232 up to the date of 1044 CE The portion of this page reserved for 1045 CE is blank. The next page, Page 233, only contains a woodblock bookplate with a coat of arms indicating that the book belongs to the St. Gallen library. The page we focus on, Page 234, lacks a list of years except for the single entry at the bottom, which is for 1056 CE The translated Latin text reads "General Henry has died. He was succeeded by his son, Henry". The following page, Page 235, lists in red ink the years 1057 to 1068. However, there are no text entries for this decade. Since pages 232, 233 and 235 list dates that are outside the range of the expected SN explosion, only Page 234 was examined for faded ink or grooves from a stylus.

Results and Technique

The digital images presented here were obtained on 2018 June 1, by Jayanne English (University of Manitoba, visiting University of Zurich). The Fujifilm X-E1 digital camera settings were ISO 6400, *f*/4, speed 1/60 and 55.00 mm zoom. Figure 2a shows a digital photograph of page p. 234 of the annals, Cod. Sang 915, under uniform lighting, the even illumination being created by two lamps. Figure 2b shows a zoomed-in region of this page with grazing incident light created using only one lamp; the light grazes the page at an angle of incidence that reveals indentations. Figure 2c is the photograph in Figure 2b with an image manipulation technique, called "masking," applied to enhance grooves that are considered by visual inspection (by J. English) to be produced by a dry-point stylus. A digital tracing was made of these lines. Using the GNU Image Manipulation Package (GIMP) and its "layer masking" schema, this tracing was applied to the digital photograph such that it improved the contrast between the indentations caused by degradation of the parchment and the putative stylus grooves. The fainter, fuzzier "strokes" delineate grooves that were less deep and harder to distinguish from the surface texture of the parchment.

Assessment of the Iconography

Inspired by the similarity of the sketched animal with dog and wolf figures on The Earth and Heaven Globe in the St. Gallen library[2] English examined several sources of constellation maps (e.g. The Aratea of the University of Leiden, Klosterneuburg Stiftsbibliotek, St. Gallen Stiftsbibliotek, etc[3]; the al-Sufi Almagest[4]; woodcuts by Albrecht Dürer[5]). It was found that the animal is similar to the dogs Canis Major and Canis Minor, in the years around the 800s[6], but also to the wolf (or fox) Lupus, particularly after the late 1300s. In general, it is difficult to distinguish between wolves and dogs in both constellations and bestiaries (White 2010).

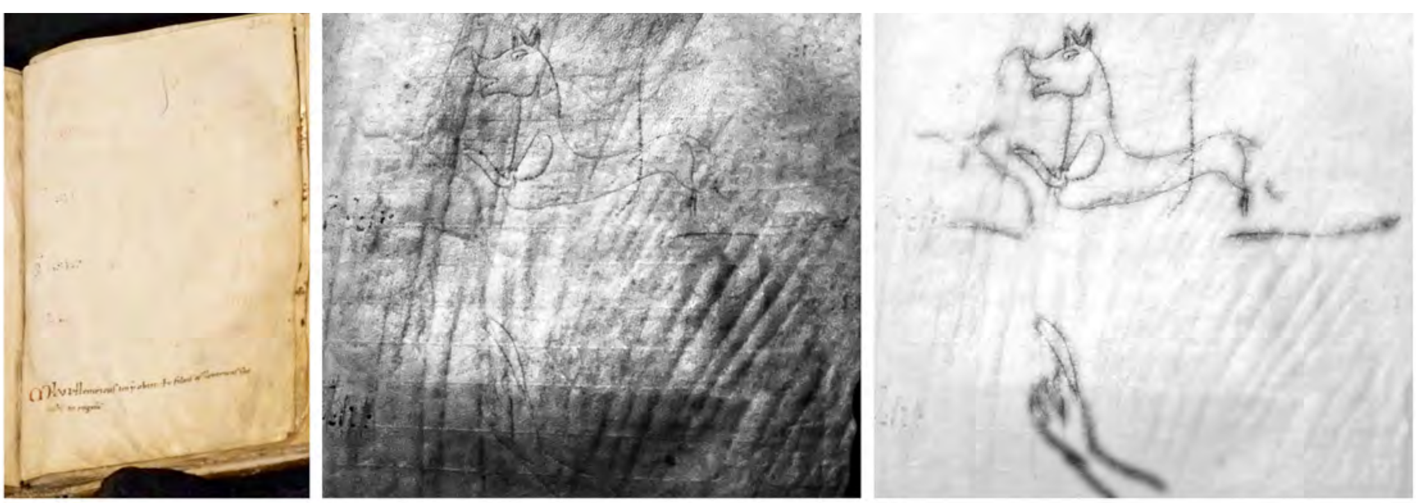
It is notable that the dog of Toggenburg was absorbed into the Heraldry of the Abbey of St. Gallen in 1400s and appears in Coat of Arms book of the St. Gallen abbot Ulrich Rösch (1463-1491)[7]. Although the figure could have been drawn on p. 234 of the annals during any era that used a stylus, including the 1400s, the Toggenburg dog has a collar and a different stance from the sketched animal. Members of the Swiss Heraldry Society (Furrer & Kälin 2019) confirm that the annals drawing is unrelated to St. Gallen heraldry.

In terms of iconography as well as crudeness, watermarks embedded in paper present figures that are most similar to the drawing in the annals. Catalogues contain both the animal and manicule. Some Italian examples (1300 to 1400s) of leaping "chien" with open mouths and perky ears, as in Figure 3, indicate that the animal should be classified as a dog. (The main reference, by Briquet (1968), does not have the categories of "loup" and "reynard"; however, the leaping fox in Heawood[8] does not have a hound ribcage. In the drawing of the hand, the segment that appears to be pointing could be the amalgamation of two fingers, in which case it is similar to "Main; bénissant, du serment ou de la foi" ("Hand; blessing, oath or faith"; 1400-1500s).

Also, Filipović et al. (2021b; e.g. their Figure 3) found in nearby Balkan regions this common drawing of animals on a large number of tombstones dated back to XI century and that could be connected with the SN 1054 event. However, we don't suggest any connection with the St. Gallen Capitulary drawings.

Discussion and Summary

Our attempt to reveal a European text record in the St. Gallen Capitulary of the stellar explosion that created the renowned



2a 2b 2c

Figure 2 — Page 234 of Cod. Sang 915, "Capitulary" of St. Gallen Abbey
2a: Evenly applied illumination. 2b: Grazing incident illumination. 2c: Masking applied to 2b. See Section "Results and Technique" for a description.

Crab Nebula was in part motivated by the superb description in this codex of SN 1006 as a new unusual-looking star, positioned outside of known constellations, that appeared for three months, and was at times terrifyingly bright.

Instead of text, our examination of the *St. Gallen Capitulary* for a record of the stellar explosion of SN 1054, that produced the Crab Nebula, revealed representational graphic figures. Our initial speculation was that the two drawings in Figure 2 could form a sky chart relevant to the supernova. However, that event occurred in a horn of Taurus the Bull, while the animal detected in the St. Gallen codex is reminiscent of a horse, dog, wolf, or fox. Examining a popular planetarium app, Stellarium, suggested that the figures could be one of the dog constellations plus Columba, a bird constellation devised in the 1500s. However, our masking technique substantiated that the bird interpretation would be incorrect and the figures' relative positions did not match distances between Columba and any of the dog-like constellations: Canis Major (Figure 4), Canis Minor, or Lupus.

Since the drawings did not compose a star chart, the iconographies presented in bestiaries and heraldry were examined. Figures in these are ambiguous, especially in early eras when strict rules did not exist to constrain graphic symbolism. However, figures of watermarks more convincingly indicate that the animal is a dog (Figure 3), as well as suggest that the drawing toward the bottom of the page represents a hand symbol, likely of the kind that is delivering a religious blessing. Scribes use such "pointers" in the margins of manuscripts to indicate notable text.

The unrelatedness of the symbols suggests that the stylus sketches are simply part of the practice of monks to "doodle" on blank pages (Nievergelt 2013) to improve their skills for drawing icons found in various religious sources, including codices in the St. Gallen collection. Indeed, this Capitulary dog (Figure 2 imaging of Cod. Sang. 915 page 234[1]) shows some similarity to the dog head in Biblia latina Vet. et Novi Testamenti (Cod. Sang. 72, page 202[9]).

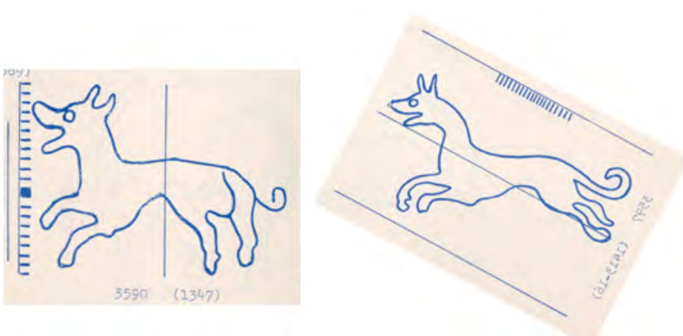


Figure 3 — Graphic drawings in the category of "chien''

Chien from Briquet's catalogue of historic watermarks (1968 facsimile of 1907).

Figure 4 — Figure 1c overlaying the putative dog on a plot from Stellarium planetarium software

Since the lower graphic does not coincide with any constellation positions for any rotation of the detected figures, this group of two objects does not appear to form a star chart.

Using Reflectance Transformation Imaging and 3-D laser scanners (e.g. Lucida by Manuel Franquelo and Factum Arte) in the future, to reveal stylus lines missed by our masking technique, could produce more accurate diagrams and thus improve such assessments. Nievergelt (2013) reveals how common the practice of surrounding text with doodles is in St. Gallen manuscripts. The use of art conservation imaging techniques could contribute to such studies by exposing faded glosses and doodles that are not currently visible in the optical regime.

Other authors speculate on a variety of intriguing reasons for the absence of a European record of SN 1054 (e.g. Filipović et al. 2021a, 2021b, and 2022). Since an earlier generation of St. Gallen monks were clearly interested in accurately recording supernovae in their annals, and since the guest star was visible in the night sky for roughly two years, it is perplexing that they did not describe this unusual phenomenon. On the other hand, they did not use the annals for noting events for years on either side of the explosion date. If only 1054 CE were blank, then one might consider the Great Schism between the Roman Catholic and Eastern Orthodox churches as a potential explanation for not describing a celestial portent. However, except for the 1056 entry for the death of General Henry, there are no entries from 1045 to 1080. It seems likely that the monks simply lost interest in keeping records in this codex a decade before the star exploded in the constellation Taurus. ✶

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Endnotes

1 A digital version of the codex exists at https://www.e-codices.unifr.ch/en/csg/0915/ and the page of interest is available at www.e-codices.unifr.ch/en/csg/0915/234.

2 A description for the public is available in "Presentation Red- und Himmels - Globus", 2009 Aug 22–Sept 13 produced by the Stiftsbibliothek St. Gallen.

3 The Aratea are available at the Warburg Institute Iconographic Database. This example is from Magic & Science: iconographic.warburg.sas.ac.uk/object-wpc-wid-afud

4 The Almagest is available, for example, at the Library of Congress: www.loc.gov/item/2021667391/

5 Southern hemisphere woodcut at the Warburg Institute Iconographic iconographic.warburg.sas.ac.uk/object-wpc-wid-aaad

6 Leiden, Universiteitsbibliotheek Voss. lat. Q. 79, fol. 78v, circa 816.

7 Cod. Sang. 1084, binding. www.e-codices.unifr.ch/en/csg/1084/bindingE

8 E.M. Heawood. Available at the Thomas Fisher Rare Book Library, University of Toronto.

9 See the bottom margin at www.e-codices.unifr.ch/en/csg/0075/202.

Acknowledgements

Our gratitude to the Stiftsbibliothek St. Gallen Abbey Librarian Cornel Dora for his guidance and hospitality, as well as to his staff for their assistance. Thanks also to librarians Timothy Perry and David Fernandez at the Thomas Fisher Rare Book Library, University of Toronto, Canada, for recommending the catalogues of watermarks. Olivier Furrer and Rolf Kälin of the Swiss Heraldry Society were generous with their time. Thank you to Haida Liang (Nottingham Trent University) for including J. English in her imaging study team. We are grateful to Prasenjit Saha (UZH) for supporting this imaging study.

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Research Article / Articles de recherche

Observation of some intense knots of Herbig-Haro 39, which is associated with the star R Monocerotis and the variable nebula NGC 2261

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Abstract

HH 39 and NGC 2261

Many people are already familiar with the variable nebula NGC 2261 in the constellation of Monoceros. This nebula is associated with the star R Mon, a young binary star whose main component is of the Herbig Ae/Be type (intermediate mass star) and the redder secondary is of the T Tauri type. They are located ~2500 ly away and are associated with the nebula NGC 2261 which has a span of about one ly, [1.2] and [1.3]. Many are familiar with the variable appearance of the small, comet-shaped nebula NGC 2261.

This new paper focuses on the detection of the Herbig-Haro 39 (HH 39) object. It is known that its components are observable in part thanks to the light emitted by certain chemical elements such as hydrogen (Hα) light at 656.3nm. The most intense components of HH 39 are in the form of a few small luminous emission knots, detectable north of the main nebula NGC 2261, at ~7.5 arcmin, north of the star R Monoceros (R of the Unicorn) according to Walsh and Malin (1985), see our Figure 4.5. Our observations allow us, among other things, to note certain grouping in the angles of tangential displacements of the main knots of HH 39. It can be seen from the literature that the knots all have a common displacement toward the north of the nebula NGC2261, but that these seem to move at quite varied angles, ranging from NW to NE. In addition, Hα structures have been detected south of HH 39—rarely seen, these structures seem to confirm a relationship between the nebula NGC 2261 and HH 39.

Résumé

NGC 2261 et HH 39

Plusieurs connaissent déjà la nébuleuse variable NGC 2261 dans la constellation de la Licorne. Cette nébuleuse est associée à la l'étoile R Mon, une étoile binaire jeune dont la composante principale est de type *Ae*/*B*e de Herbig (*étoile de masse intermédiaire*) et la secondaire plus rouge de type T Tauri. Elles sont situées à ~2500 al et sont associées à la nébuleuse NGC 2261 qui a une envergure qui s'étend sur à peu près une année lumière, [1.2] et [1.3]. Plusieurs sont familier avec l'aspect variable de la petite nébuleuse de forme cométaire NGC 2261.

Ce nouveau document s'oriente sur la détection de l'objet Herbig-Haro 39 (HH 39). On sait que les composantes de celui-ci sont observables en partie grâce à la lumière émise par certains éléments chimiques dont la lumière émise par l'hydrogène (Hα) à 656.3nm. Les composantes les plus intenses de HH39 sont sous forme de quelques noeuds lumineux en émission, détectables au nord de la nébuleuse principale NGC 2261, à ~7.5 arcmin, au nord de l'étoile R Monoceros (R de la Licorne) selon Walsh and Malin (1985), voir notre Figure 4.5. Nos observations permettent entre autres

Figure 1 – Epoch 2024, from J-G Moreau, this picture shows the difficulty in detecting these knots of HH 39, they are very small and very dim at ~7.5 arcmin north of the star R Mon [2.5].

de constater certaines asymétries dans les angles de déplacements tangentiels (sur le ciel) des principaux nœuds de HH 39. On peut constater dans la littérature que les nœuds ont tous un déplacement commun vers le nord de la nébuleuse NGC2261, mais que ceux-ci semblent se déplacer sur des angles assez variés, allant du N-O au N-E. En plus on a détecté des structures Hα rarement vues au sud de HH 39 qui semblent pouvoir confirmer la relation entre HH 39 et l'étoile R Mon.

According to Jones and Herbig (1982) [2.8]. Using images taken before 1982, they determined that the luminous knots of object HH 39 appear to be moving north.

Walsh and Malin (1985) [2.5], have also estimated the displacement of the knots of HH 39, their results are in agreement with the general shift northward measured by Jone & Herbig [2.8].

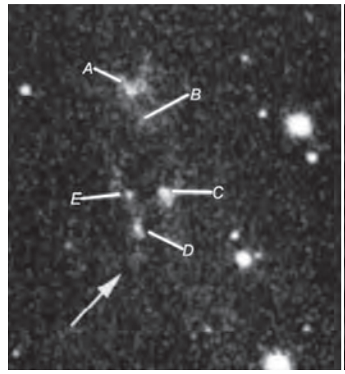
We built Table-1, to compare the results (PA°) of the movement of knots on the sky. In column 2, we present the (PA° of the velocity vector) by Walsh and Malin (1985), and in column 3 our results 40 years later (2024), by estimating the PA° of the tangential displacement of certain knots in HH 39.

Knots Jones et Herbig (1982) & Walsh et Malin (1985)	(P.A.°) Velocity vector Walsh et Malin (1985)	(P.A.°) Tangential Displacement St-Onge et al (2024)	(Δ P.A.°) 1985 / 2024
HH-39A	/	355°	W ←1°
HH-39A′	/	320°	
HH-39B	355°	~12°	17°→ E
HH-39C	340°	350°	10°→ E
HH-39D	330°	/	/
HH-39E	340°	355°	15°→ E
HH-39G	350°	~12°	22°→ E
HH-39H′	/	~310°	
1	2	3	4

Table 1 – We compare the results (PA°) of the moving knots. (Position angle of the knots movement, with respect to the north, measured eastward from north).

It is clear that our observations have highlighted a northward shift of the knots of HH 39. This corresponds to a recession of HH 39 from the star R Monocerotis position, which is in agreement with Jones and Herbig (1982) and Walsh and Malin (1985).

Some knots associated with HH 39 are observed at ~7.5 arcmin north of the star R Mon [2.5], north of the main nebula of NGC 2261. The motion toward the north at angles mainly between "P.A. ≈ 330° and P.A. ≈ 355°" according to Walsh and Malin (1985) [11], Table-1 column 2. Our results are in column 3. Column 4 presents an eastward shift compared to the (PA°) measures of Walsh et Malin (1985). Only HH-39A is similar to the results of Jones and Herbig (1982), we see a difference of 1° west for this one.



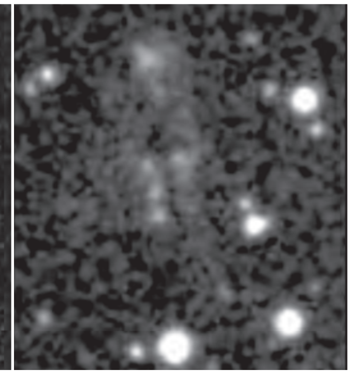


Figure 2 – (left) A representation of some knots identified by Jones and Herbig (1982) [2.8], [4].

Figure 3 – (right) Same region as in Figure 2. This image is a slice centred on HH 39, which comes from the DSS. Image taken on 1989 November 7 at 09:63:00 UT, POSS-II red, IIIaF plate with RG610 filter (POSS-II F). 70.0 minutes exposure. Sampling 1.01 arcseconds per pixel [6].

Summary of Figures 2 and 3

Images from different epochs allow the detection of obvious movements (tangential movement), and monitoring changes in knot morphology. In Figure 3, we can see that the D and E knots of Jones and Herbig are followed by a strong third knot observed to the south under the D knot. In Figure 2, at the time of Jones and Herbig (1982), the arrow indicates a pale mass aligned just below the D knot.

In the 1989 image (DSS) Figure 3, what appears to be an intense knot in this region is observed, it may be the G knot described by Walsh and Malin (1985) [2.5]. Knot C seems to have changed in intensity between the two epochs (Figures 2 and 3), there are some luminous structures that may be new knots aligned in the southern section of HH 39 in 1989. The knot B is still very pale in 1989. It should be considered that detection technologies and filters have evolved significantly between these two periods, moving from silver imaging to CCD imaging.

These images (Figures 2 and 3) allowed us to observe the movement of the knots between these two periods. Since Figure 2 is of lower quality, the resulting data is not very precise, but it allows us to see that all the measurable knots seem to have a (tangential) displacement, toward the north, but with various angles, and that some knots seem to have different tangential velocities from one to the other.

Using one of our modern images (2024) with Figure 3 (1989), the average tangential movement is observed by these knots. Figure 4, is the DSS image of November 1989, and Figure 4.1, is an image by J-G Moreau on March 2024. These two images allowed us to detect northward movement of the knots of HH 39, refer to Figure 4.2 and 4.3, to see that the knots move northward, over a period of just over 35 years.

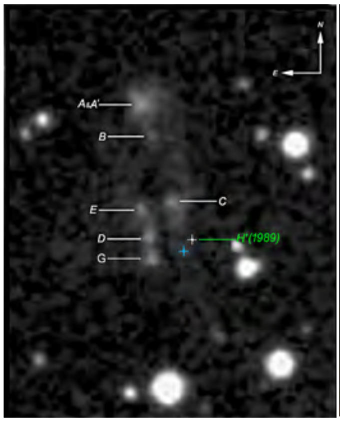


Figure 4 – 1989 (DSS)

Figure 4.1 – 2024 J.G. Moreau

Figure 4, we can observe what seems to be the evolution of a knot that becomes important in 1989 under the D knot. Probably the G knot mentioned by Walsh and Malin (1985). (Possibly detected in Figure 2, the arrow, which is from before 1982).

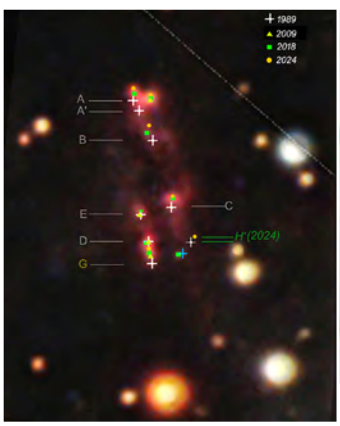


Figure 4.2 (left)

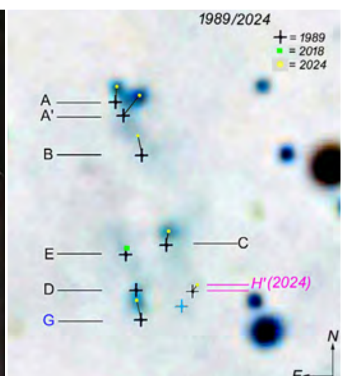


Figure 4.3 – (right) This figure allows us to observe the total displacement of the knots toward the north between 1989 and 2024.

Figure 4.2: Is an overlay of four pictures.

The white crosses are the positions of the knots on 1989 November 07 (DSS).

The yellow triangles are the 2009 positions of the knots (poor seeing); we can only identify four knots, (A′, E, D, and G), by J-G Moreau from 2009 (Québec, Canada).

The green rectangles are an image of 2018 by Mark Hanson (New Mexico).

The orange circles are from an image by J-G Moreau from 2024 (Québec, Canada).

Between 1989 and 2024, we see that the knots move northward (north is at the top).

We used several images over four periods, namely 1989, 2009, 2018, and 2024. By superimposing them in (blink image comparison) routines, this allowed us to better control the identification of each knot for each epoch and to ensure that their movement was monitored as well as possible.

Discussion Figure 4.2

Points 1 and 2 below are consistent with what has been described by Jones and Herbig (1982) and by Walsh and Malin (1985).

1) We can see that the knots have tangential displacement angles that are spread at different angles.

2) The tangential velocity of the knots is also a component that differs from one knot to another.

3) The morphology of these knots changes over time, some change in size, intensity, appearance; some disappear, maybe they can merge with another knot, or more.

4) Knot D is not detectable in 2024; if it had followed the northward path at a comparable velocity to the others, it should be observed just south of the position of the 1989 knot E. In 2018, a presumed knot is detected just a little east of the 1989 knot D position, but still near the 1989 position of knot D? (Either it has disappeared in the 2024 picture, or if it moved south, it could have merged with knot G, which became very intense in 2024)?

Description of the tangential displacements

Of the knots over four image periods, totalling approximately 35 years of evolution. (Refer to Figure 4.3)

We therefore have created an animation of four images: one from 1989 (DSS), a second one by J-G Moreau 2009, a third from 2018 by Mark Hanson, and a fourth one from 2024, also by J-G Moreau. In these images we can detect from north to south, the knots A, A′, B, C, E, D, G, and H′;

Using two images, from 1989 and 2024, we can infer an approximate mean tangential motion of the knots over ~35 years. Some knots may have changed velocities and directions over time, so this is an "approximate" average. Furthermore, we did not have access to HH 39 spectra, so we have no integration of "RV" (radial velocity) measurements for this period of these knots; we only measured the average apparent displacement for the corresponding time period.

For each knot, a summary of what we detect of its movement and a projection of it in time.

#A and A′, to the north are moving toward the northwest, at (PA°) of A ~355 and (PA°) of A′ ~320.

#B, follow, moving toward the northeast, at (PA°) of ~12 (between 1989 and 2024).

Not sure if it's the same knot in 2018, it is a little shifted to the east but well detected.

#C, much lower to the south of HH 39, is moving toward the northwest, at (PA°) of ~350.

#E, moves toward the northwest, at (PA°) of ~355 between 1989 and 2018. (Not detected in 2024)

#D, appears stable in place, or descends slightly southward from 1989 to 2018 (undetectable in 2024).

#G, very intense in 1989, becoming more diffuse in 2018 and then very intense again in 2024, we can assume that it is possible it merged with knot D. G is moving rapidly toward the NE, at (PA°) of ~12.

#H′, rather faint in 1989, pale but detected in 2024, moves toward the NW at (PA°) of ~310.

Figure 4.4 resume

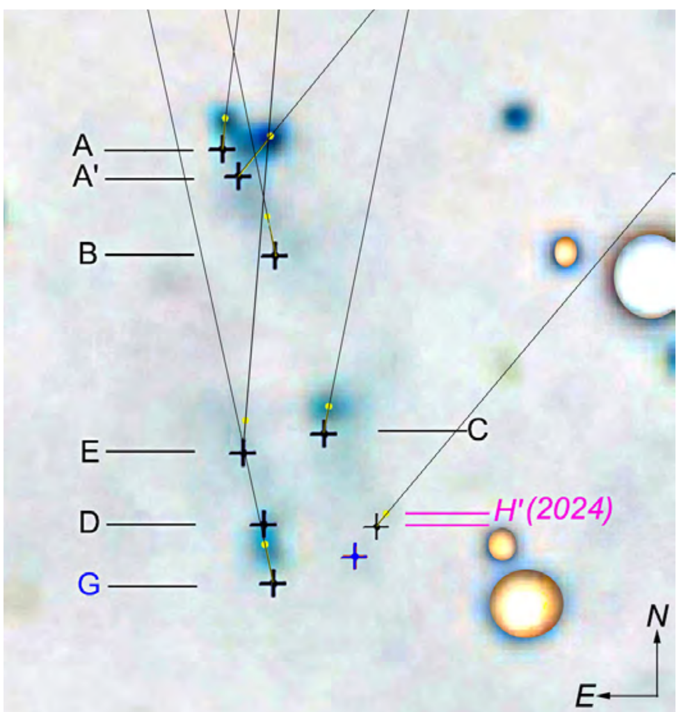


Figure 4.4

The "+" is an intense source in 1989, this may be the source identified as H by Walsh and Malin (1985). The latter presents a different displacement from the others, we can guess a slight displacement toward the east, between the periods of 1989 and 2024? Assuming that it is the same source, this source is paler in 2024 than in 1989, it seems to be of rather variable intensity.

Summary of Figure 4.4

Three major groups dominating the displacement of the knots of HH 39 are traced in this figure.

1) G and B knots, move toward the NE at an angle of ~12°
2) A, E, and C knots, move toward the NW at ~355°
3) A′ and H′ knots, move at much steeper angles toward the NW, at ~320°

Groups 1 to 3 appear to be randomly distributed from north to south in HH 39, there does not appear to be any consistency at first glance in the position of these knots by groups.

The (tangential) displacement angles of the knots that we measured seem to agree with the wide dispersion obtained by Walsh and Malin (1985), who estimated angles between 330° and 355° at the time.

Our 2024 estimates of tangential displacement are also spread over a large area to the "north/northwest" of the nebula NGC 2261; they are observed between PA° ~320° and PA° ~12°.

This wide distribution of the tangential trajectories of the knots across the sky raises some questions:

Can these structures be related to the environment of the star R Monocerotis only?

Or is there a precession (curved movement) in the trajectory of these knots?

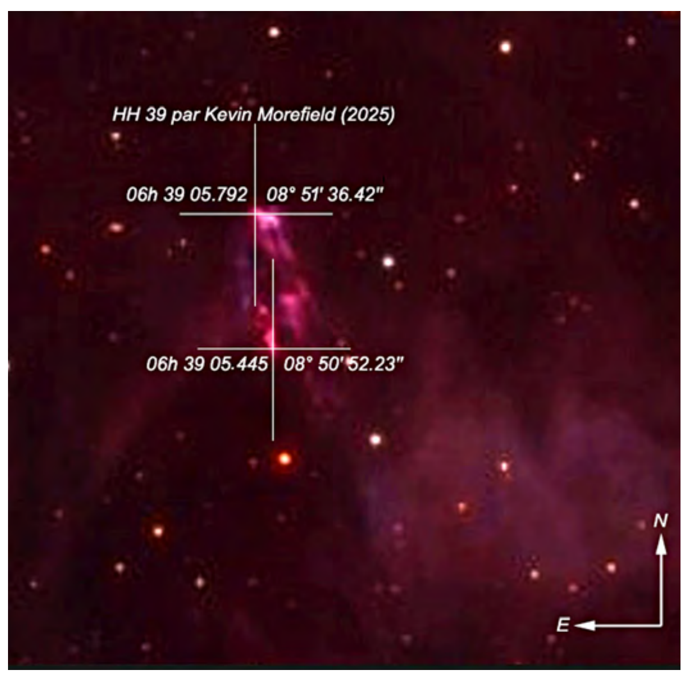


Figure 4.5

Continues on page 190

Pen & Pixel

Figure 1 — Shelley Jackson took this beautiful image of the Milky Way from the North Frontenac dark-sky viewing area in eastern Ontario. Though the night was forecast to be clear, there were some clouds on the horizon, but as she said, "I decided to shoot anyway, as we drove two hours to get there, and I kind of like the effect." She used a Nikon D5500 with 14 mm ƒ/2.8 Rokinon lens on a Sky-Watcher Star Adventurer mini. She shot two-minute tracked exposures at ISO 1600, and stacked three images using Sequator, then used PixInsight to complete the editing. "I hope to get many more images of the Milky Way from various locations," Shelley said. "We have so many pretty locations here in Eastern Ontario."

Figure 2 — Stefan Jackson imaged both the Lunar X and Lunar V on February 16, 2024 from the Jackson Observatory, Athens, Ontario. The image is a stack of the best 100 luminance images from a 1,000 image video, shot with a Stellarvue 105 with 0.8 reducer on AZEQ6 and an ASI1600 mono camera. Shot with Sharpcap, processed in AutoStakkert, Imppg, Gimp and PixInsight to highlight the lunar X and lunar V.

Continues on page 187

What's Up in the Sky?

October/November 2025

Compiled by James Edgar

October Skies

The Moon begins the month having just passed first quarter. Its first encounter is with Saturn on the 5th, when the Ringed Planet is passed 4 degrees to the south. On the 10th, the Moon is 0.9 degrees north of The Pleiades (M45). By the 13th, Jupiter is 4 degrees south, plus the Beehive Cluster (M44) is in close vicinity later the same day. This will be a good time to check out Jupiter's double shadow events–see below. On the 16th, Regulus is 1.2 degrees south of the Moon, an occultation for extreme northern Canada. Venus is 4 degrees north of the thin sliver of the Moon on the 19th. The Moon is new on the 21st. The 23rd sees Mars and Mercury sharing the sky with our satellite–the former is 5 degrees north; the latter is 2 degrees north. On the 24th, Antares is 0.5 degrees north of the waxing crescent Moon.

Mercury appears in the western evening sky early in the month, providing the best evening view of 2025 for Southern Hemisphere observers. The speedy planet slowly separates from the Sun, achieving greatest elongation east on the 29th. It remains brighter than magnitude 0.0 all month long. It's within 2 degrees of Mars on October 20–21 and about the same distance from the 2-day-old Moon on the 23rd.

Venus, shining brightly, rises in the eastern sky before twilight. Catch it before sunrise, or even after the Sun is in the sky.

Mars is difficult to locate in early evening twilight as it gets closer to the Sun during the month. The Red Planet is in conjunction with Mercury on the 20th–21st, with Mars appearing the smaller and fainter of the two.

Jupiter rises around midnight; the last-quarter Moon passes by on the 13th. The giant planet has numerous double-shadow transit events this month, involving various combinations of all four Galilean satellites–about every two or three days.

Saturn is in good position all through the night. Watch as the month progresses to see the ring tilt decrease to almost face on. The Moon passes by on the 5th.

Uranus crosses the sky for most of the night as it approaches its November 21 opposition. It's slowly retrograding in the constellation Taurus, The Bull.

Neptune is in Pisces, hanging out with The Fishes.

The large Minor Planet Ceres is at opposition on October 2–something worth looking for.

The zodiacal light is visible before eastern morning twilight for the last two weeks of October. The Orionid meteors peak on October 21.

October 20 *sees Jupiter rising in the east among the stars of Gemini, with Orion to the west. Sirius is just breaking the horizon, while Uranus is up near the Pleiades.*

Image courtesy of Starry Night Pro Plus

Continues on page 186

The Sky October/November 2025

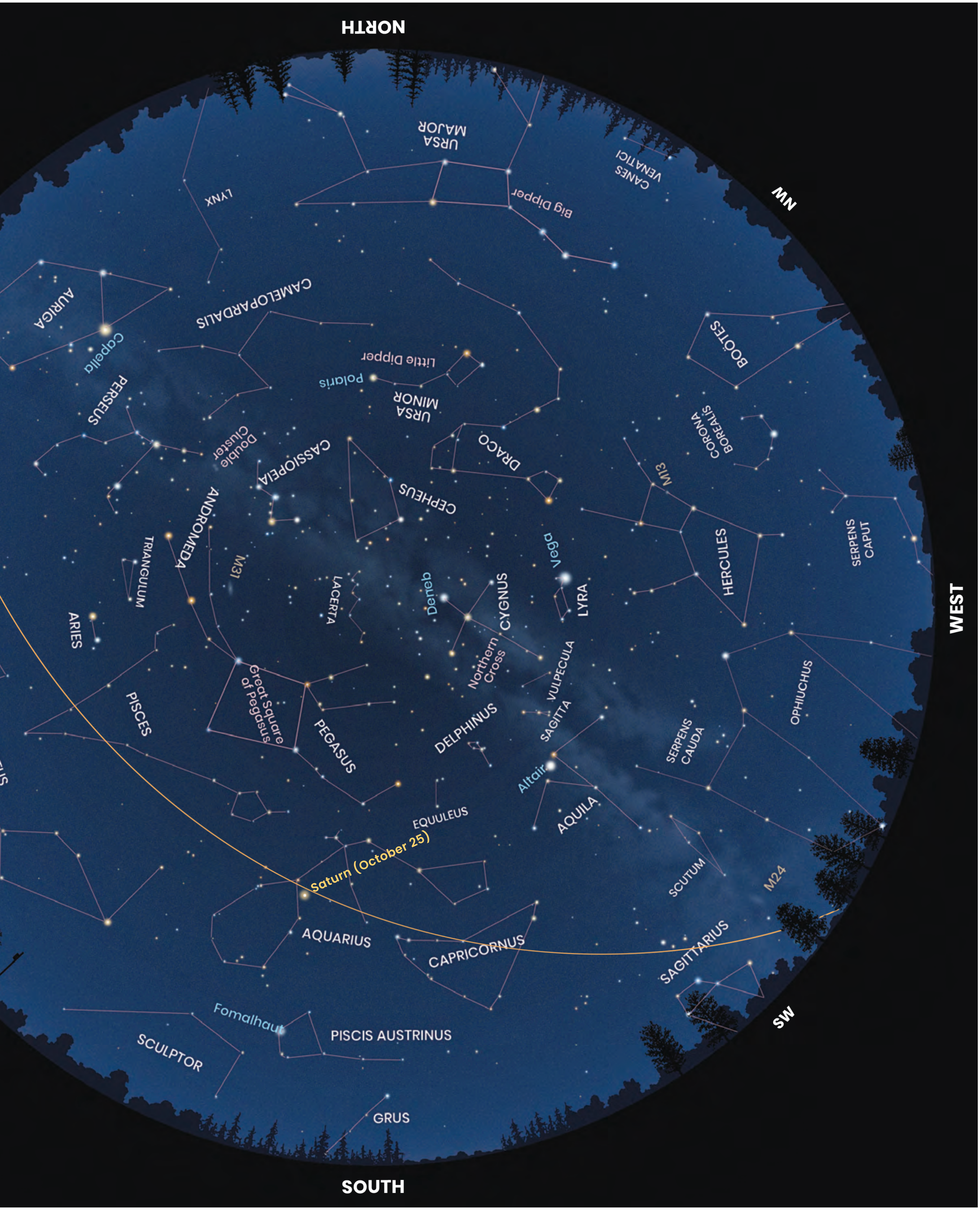
Compiled by James Edgar with cartography by Glenn LeDrew

Oct. 2 Ceres at opposition
Oct. 4 double shadows on Jupiter
Oct. 6 double shadows on Jupiter
Oct. 7 full Moon at 11:48 p.m. EDT
Oct. 7 double shadows on Jupiter
Oct. 8 Moon at perigee (359,819 km)
Oct. 10 crescent Moon 0.9° north of Pleiades (M45)
Oct. 11 double shadows on Jupiter
Oct. 13 double shadows on Jupiter
Oct. 13 Moon at last quarter
Oct. 13 Jupiter 4° south of waning gibbous Moon
Oct. 14 double shadows on Jupiter
Oct. 15 Moon 1.9° north of Beehive Cluster (M44)
Oct. 16 Regulus 1.2° south of waning crescent Moon
Oct. 18 double shadows on Jupiter
Oct. 19 Venus 4° north of thin waning crescent Moon
Oct. 20 double shadows on Jupiter
Oct. 21 Mercury 2° south of Mars
Oct. 21 new Moon (lunation 1272)
Oct. 22 double shadows on Jupiter
Oct. 23 Mars 5° north of new Moon
Oct. 23 Mercury 2° north of new Moon
Oct. 25 Antares 0.5° north of thin crescent Moon
Oct. 25 double shadows on Jupiter
Oct. 29 double shadows on Jupiter
Oct. 29 Moon at first quarter

Nov. 1 double shadows on Jupiter
Nov. 2 Daylight Saving Time ends
Nov. 2 Saturn 4° south of waxing gibbous Moon
Nov. 2 Neptune 3° south of waxing gibbous Moon
Nov. 5 Double Shadows on Jupiter
Nov. 5 south Taurid meteors peak
Nov. 5 full Moon at 9:19 a.m. EST (largest in 2025)
Nov. 5 Moon at perigee (356,833 km) Large tides
Nov. 6 Moon 0.8° north of Pleiades (M45)
Nov. 10 Jupiter 4° south of waning gibbous Moon
Nov. 11 Moon 1.7° north of Beehive Cluster (M44)
Nov. 12 Moon at last quarter
Nov. 12 north Taurid meteors peak
Nov. 12 Mercury 1.3° south of Mars
Nov. 12 Regulus 1.0° south of last quarter Moon
Nov. 17 Spica 1.2° N of Moon, occultation2
Nov. 17 Leonid meteors peak
Nov. 20 Moon at apogee (406,691 km)
Nov. 20 new Moon (lunation 1273)
Nov. 21 Double Shadows on Jupiter
Nov. 28 Moon at first quarter
Nov. 29 Saturn 4° south of first-quarter Moon
Nov. 30 Neptune 3° south of waxing gibbous Moon

Planets at a Glance

	DATE	MAGNITUDE	DIAMETER (″)	CONSTELLATION	VISABILITY
Mercury	Oct. 1	—	4.9	Virgo	—
	Nov. 1	0.2	6.9	Scorpius	Evening
	Oct. 1	–3.9	12.2	Libra	Evening
Venus	Oct. 1	–3.9	11.1	Leo	Morning
	Nov. 1	–3.9	10.3	Virgo	Morning
	Nov. 1	0.1	9.2	Cancer	Evening
Mars	Oct. 1	1.6	4.0	Virgo	Evening
	Nov. 1	1.5	3.9	Libra	Evening
	Oct. 1	0.6	19.0	Aquarius	Evening
Jupiter	Oct. 1	–2.1	37.0	Gemini	Evening
	Nov. 1	–2.3	40.6	Gemini	Evening
	Nov. 1	5.6	3.8	Taurus	Evening
Saturn	Oct. 1	0.6	19.4	Aquarius	Evening
	Nov. 1	0.9	18.9	Aquarius	Evening
Uranus	Oct. 1	5.6	3.7	Taurus	Evening
	Nov. 1	5.6	3.8	Taurus	Evening
Neptune	Oct. 1	7.8	2.4	Pisces	Evening
	Nov. 1	7.8	2.3	Pisces	Evening


NORTH
URSA MAJOR
CANES VENATICI
NW
LYNX
Big Dipper
AURIGA
CAMELOPARDALIS
Capella
Little Dipper
Polaris
URSA MINOR
BOÖTES
PERSEUS
Double Cluster
CORONA BOREALIS
CASSIOPEIA
DRACO
CEPHEUS
M13
ANDROMEDA
TRIANGULUM
M31
Vega
HERCULES
SERPENS CAPUT
LACERTA
Deneb
CYGNUS
LYRA
WEST
ARIES
Northern Cross
VULPECULA
Great Square of Pegasus
PISCES
OPHIUCHUS
PEGASUS
DELPHINUS
SAGITTA
SERPENS CAUDA
Altair
AQUILA
EQUULEUS
Saturn (October 25)
SCUTUM
M24
AQUARIUS
CAPRICORNUS
SAGITTARIUS
SW
Fomalhaut
PISCIS AUSTRINUS
SCULPTOR
GRUS
SOUTH

Continued from page 183

November Skies

The Moon is approaching full phase as the month begins, but before that, on the 2nd, Saturn and Neptune are 4 and 3 degrees south, respectively. The Moon is at perigee on the 5th, making for the largest full Moon of 2025. A few hours later, on the 6th, the Moon is 0.8 degrees north of the Pleiades (M45). Then on the 10th, Jupiter is 4 degrees south of the Moon, and on the 11th, Luna is 1.7 degrees north of the Beehive Cluster (M44). The 12th sees an occultation of Regulus in the far north, just missing North America. For local viewers, it's a close approach of less than a degree. On the 17th, Spica, the bright star in Virgo, The Maiden, snuggles up to the very thin crescent of the waning Moon. The phase new Moon is on the 20th, and first quarter is on the 28th. Then, on the 29th, Saturn and Neptune join the Moon to reprise their trio from the first of the month, 4 and 3 degrees south, respectively.

Mercury is in its best evening apparition of 2025 for Southern Hemisphere observers. On the 12, the speedy planet joins up with the Red Planet, Mars, 15 degrees east of the Sun on the 12th, when the two rocky planets, separated by 1.3 degrees. Mercury achieves inferior conjunction on the 20th, returning to the morning sky in November's final days.

Venus is visible during the first few days of the month, in the early morning dawn. By the end of November, it's too close to the Sun to be observed.

Mars can be found with difficulty early in the month before becoming too close to the Sun to be seen.

Jupiter rises in the evening, reaching its first stationary point on the 11th–it appears to stop moving against the starry background. It then begins retrograde motion for the next four months, apparently moving westward along the ecliptic in the constellation Gemini the whole time. The waning gibbous Moon passes 4 degrees to Jupiter's north on the 10th.

Saturn, in Aquarius, shows less and less of its rings–they almost become invisible. This phenomenon presents a good time for telescope users to hunt for Saturn's moons, as they orbit within and outside the ring system. The waxing-gibbous Moon passes nearby on the 2nd and again on the 29th.

Uranus is in opposition on the 21st, providing a good time for viewing high above the murky horizon. The blue-green planet is so far away from Earth that its reflected sunlight takes 2.6 hours to reach us.

Neptune is in Pisces, alongside Saturn, as mentioned above in the Moon section. The two of them have close encounters on the 2nd and 29th.

Daylight Saving Time ends on Sunday, the 2nd; the south Taurid meteors peak on the 5th.

The north Taurid meteor shower peaks on the 12th. ✶

November 5 *has Uranus in Taurus, where it remains for months. The full Moon is on high in the southwest, while Neptune and Saturn hover above the horizon on the border of Pisces and Aquarius.*

Saturn's rings are nearly edge-on.

Image courtesy of Starry Night Pro Plus

Continued from page 182

Figure 3 — Stephen Tate imaged NGC 1272 from the North York Astronomical Association's annual star party, Starfest, in August. He used an Askar 151PHQ with a ZWO2600mm on a Losmandy G11 mount. Total image integration was 5 hours of RGB at 120 seconds.

Figure 4 — The Milky Way rises over a small islet off Mackenzie Beach in Tofino, British Columbia. Rob Lyons made this image in the early hours of 2025 July 28, with his Sony A7SIII and Sigma 14mm ƒ/1.4 lens. He shot 20 × 13-second images and stacked them for the sky, and then shot a single 180-second image for the foreground.

Continued from page 183

In Figure 4.5

The HH 39 image of 2025, coordinates (J2000).

The northernmost (highest) section of HH 39 is near; (j2000) 06^h 39^m 05.79^s +08° 51′ 36.42″ [3.1]

The southernmost (lowest) section of HH 39 is near; (j2000) 06^h 39^m 05.44^s +08° 50′ 52.23″ [3.1]

Image HH 39 at Figures 4.5 and 4.6 / Courtesy of Kevin Morefield, El Sauce Observatory, from Chile.

Instruments; Telescope Planewave CDK17, mont Planewave L-600, camera ATIK APX60, Chroma LRGB filters.

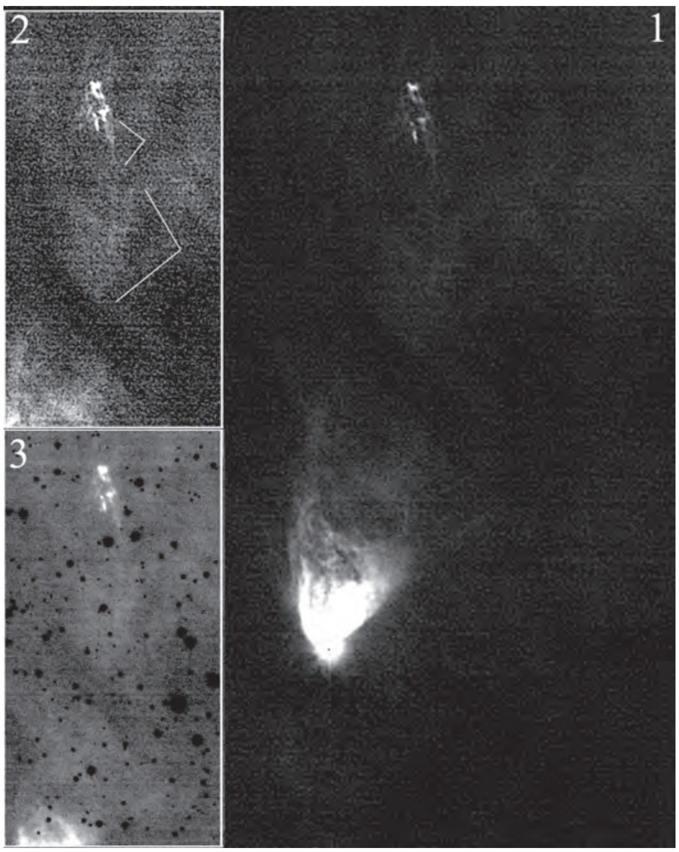


Figure 4.6-1, 4.6-2, 4.6-3

Figure 4.6 Summary

The figure above (Figure 4.6-1) is an image in the Hα domain from which the stars have been removed as well as the continuum leaving only the maximum of the Hα emission.

We tried to detect on Figure 4.6 traces of Hα structures between HH 39 and NGC 2261.

The main image (Figure 4.6-1) clearly shows the gap between the nebula NGC 2261 to the south and HH 39 at ~7.5 arcmin to the north. We can clearly see the morphology of the main knots of HH 39. Then just below the H′ knot to the south, we detect a bright extension in Hα of which the surface extends toward the south. A little farther there seems to continue a thinner and fainter structure in two parallel segments that can be observed for a few arcminutes farther toward the south. They curve toward the main nebula of NGC 2261.

The boxed section in the upper left of (Figure 4.6-2), shows between the lines the two regions of the Hα emission extending southward toward the main nebula of NGC 2261. This inset image has been enhanced to better highlight these extensions, which range from HH 39 toward the nebula to the south. We can see that the two parallel bright Hα segments are located in a large and dark region when viewed in visible light (RGB), as in Figure 4.5. And that these two segments disappear further south in a dark region in the Hα image, detected on the (Figure 4.6-2 and -3). These two structures are well curved and not aligned with the main axis of the nebula NGC 2261, but are shifted toward the west. R Mon is known to have at least one stellar companion; some may argue that this has affected the trajectory of the curved structures mentioned south of HH 39. On the other hand, observations of another star, RY Tauri, showed us that the direction of the "jet and counterjet" may be quite constant over more than at least 700y if not affected by the orbital motion of a close-in binary companion, according to St-Onge & Bastien (2008) [6.5].

HH 39 has knots very far from its presumed source star, at ~7.5 arcmin to the north. This is a bit curious, since a large number of young stars have configuration of the knots of the ionized jets, which are observed rather in the youngest section of the jets, that is, closer to the source star. Further from the star, these are the bow shocks that can be detected if there are any. In this case, no knots are detected closer to the star R Mon, nor any trace of the jet itself. For many young stars, from which we were able to access images who allowed us to see that a significant number of them have knots closer to the star, well aligned one behind the other on the major axis of the jet, but in the case of HH 39, they are rather grouped into two small segments side by side very far north of the star. Perhaps regions of significant dust are hiding the jet and the knots nearer to the star R Mon? Or we can consider that R Mon is an exception to the more general rule.

Either way, the Knots of HH 39 are still active, all the observations over time made it possible to note that certain knots have undergone changes, (some appear, others disappear, and some change intensity and even shape). So the knots have a lifespan that is limited in time, can we think that there can be more than one source responsible for these? According to Walsh and Malin, it is indeed the star R Mon that is the origin of the knots of HH 39, and Walsh J.R. (2017) [13]. Furthermore, our observations in Figure 4.6 reveal the elongation across the sky toward the NGC 2261 nebula further south of bright Hα structures that may connect HH 39 to NGC 2261 and therefore to the star R Mon. This is in agreement with Walsh and Malin.

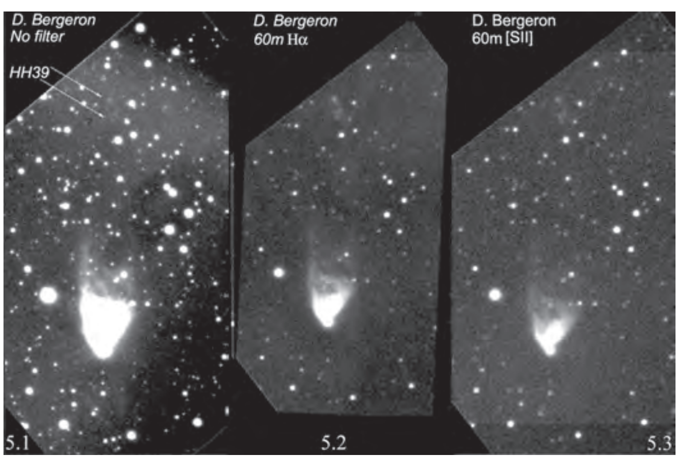
Some of our usual group of observers

Can amateur images be of sufficient quality to draw conclusions regarding the HH39 case?

To check this claim, we called on a few amateurs, some of whom were well accustomed to the challenges presented by the urban sky. Our sky imagers are Denis Bergeron, who captured images from his home in Val-des-Bois under observing conditions much better than Montréal, Denis St-Gelais of Mexico, under a fairly good quality sky, Yves Tremblay, west of Montréal, in a very polluted suburban sky, J-G Moreau under a good quality sky, and the contribution of Mark Hanson (New Mexico) and Kevin Morefield, El Sauce Observatory, from Chile, these two under excellent observing conditions.

Images by Denis Bergeron

Figure 5: These images were taken from Val-des-Bois, on 2012 February 3, with a 305-mm Meade RCX telescope with a focal length of 2712 mm, at ~*f*/8.8. The images were taken in bin2 with an ST10 XME CCD camera from Santa Barbara Instrument Group (SBIG); Images consisted of 10-minute exposures. Only dark frames have been removed. In the images of Denis Bergeron, we can identify several of the knots of object HH 39: A, C, D, and E. The knot A is very intense in Hα; it is the northernmost, at the top of the image. Knots C, D, and E are further south and form a small luminous triangle, very pale.



Figures 5.1, 5.2, 5.3 – 5.1: no filter, 5.2: with Hα filter, 5.3: with SII filter. Images by Denis Bergeron.

Image 5.1, on the left, without using a filter, allows us to detect the four knots mentioned (A, C, D, and E), the contrasts are very accentuated on the images.

Images by Denis St-Gelais

His images were taken from Queretaro in Mexico, under a medium-quality sky, at an altitude of 2012 metres, between December 2011 and February 2012. Denis used a Meade LX200 Classic telescope, 254-mm diameter, equipped with a large format SBIG STL 1001e CCD camera, with pixels of 24 μ by 24 μ. For his images he used RGB filters and luminance exposures, his images are composites of seven exposures of 600 s in luminance, 3 exposures of 936 s in red, 3 exposures of 1002 s in green, and 3 exposures of 1248 s in blue.

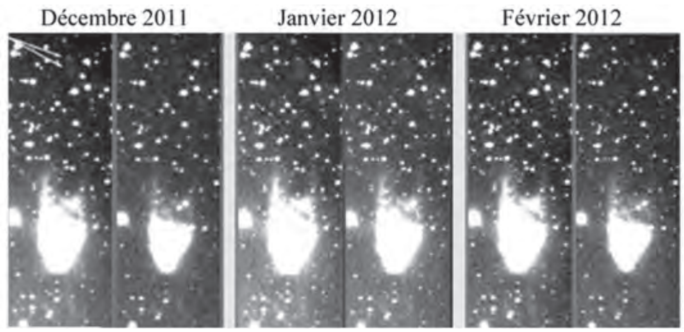


Figure 6

Figure 6 summary

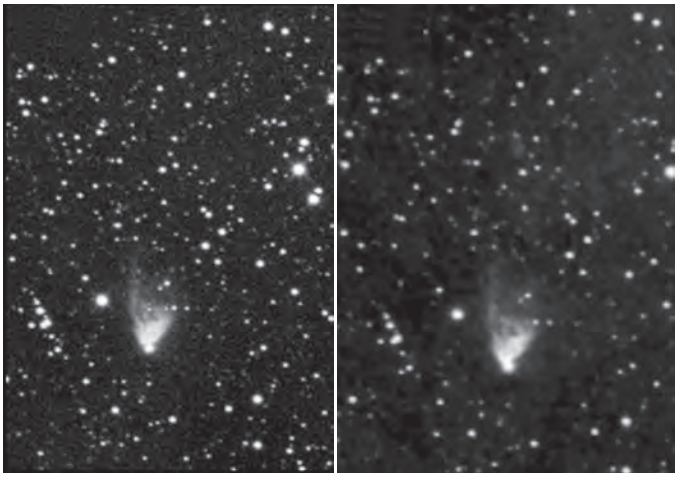
Denis St-Gelais's images also show knots of HH 39; some show well the four knots mentioned and observed on the images by Denis Bergeron. The best images are from December 2011 (first) and February 2012 (second to last). These images, which have been accentuated in contrast, also detect the faint thin and elongated luminous nebula that extends south of NGC 2261 (jet-like structure). Special attention has been focused on this structure since the beginning of the 2020s, St-Onge et al. [10]. On the old images it can be seen more easily on higher-resolution images, such as those by David Malin of the Anglo-Australian Observatory [3.3].

The images of Yves Tremblay

From Vaudreuil-Dorion in the western suburbs of Montréal, under a sky rather polluted by the light of the big city. He used for this occasion his AstroTech ATRC8 telescope of 200 mm at *f*/5,2 (focal reducer: AstroPhysics). The camera is a QHY9 with 5.4μ per pixel, and the filters used are Baader. He captured 12 times 600 s exposures in bin2 for Hα, and 13 times 180 s exposures in bin1 for luminance.

The image in Figure 7 shows that, with a cumulative unfiltered image, resulting from the combination of 13 180-second exposures, no significant trace of HH 39 knots can be seen in the sky over the western suburbs of Montréal. However, in Figure 8, with the use of a Hα filter for 12 exposures of 600 seconds, we see some pale compact structures that can be associated with HH 39.

We have therefore tried to isolate the sector of HH 39 by differential image reductions. Using the image taken in luminance Figure 7, from which the continuum was isolated, we therefore subtracted this continuum image from the Hα image in Figure 8. The result allows to isolate as much as possible the sources of HH 39, which are mainly intense in Hα emissions. The result is the image in Figures 9a and 9b.



Figures 7 and 8 – Figure 7, left,, in luminance (without filter), 13 exposures of 180 seconds each. Figure 8, right, in Hα, 12 exposures of 600 seconds each.

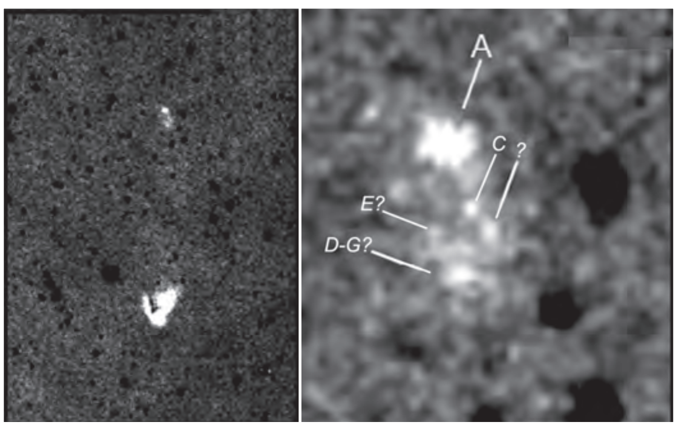


Figure 9a, 9b – 9a: Differential reduction of images by Yves Tremblay, (Hα – (continuum)). 9b: An enlarged section showing the various knots visible after this reduction.

Figures 9a and 9b

The result of (Hα minus continuum) allows us to see that some intense regions become visible in the region occupied by the knots. We have identified some knots, "A, C, E?" and "D-G?". Some other bright spots may also be knots belonging to HH 39, including an important region that is detected just south of knots C, "?" maybe it's a new one.

We know that knots can change their morphology over time in addition to moving at speeds that can be changing. For some, we could observe variations in intensity and shape. Some seemed, also, to merge together. Most of them change shape and morphology after a while, some may even disappear and others appear.

Conclusion

Comparing the results of Jones and Herbig (1982) and 1989 (DSS), we observe that the knots present general tangential displacements toward the north but at varied angles and with different tangential velocities for some of the knots.

Jones and Herbig (1982), noted that certain knots of HH 39 have movements from 320° to 12°. And Walsh and Malin (1985) estimated the knots at angles of 330° to 355°.

Some 40 years later, our conclusions (Figure 4.4) are that these knots have tangential movements that are quite well aligned in the same large region , between ~350°(W) and ~12°(E) for five of them. Only two (A′ and H′) show a much more westerly displacement, at ~320°. Our estimates cover a long period, and surprisingly, our results are close to those of Jones and Herbig (1982) who estimated angles of (PA°) displacements from 320° to 12°. Our results are not so far from Walsh and Malin (1985), who presented ~40 years ago displacements concentrated between 330° and 355°.

Our observations also seem to indicate grouped tangential displacements of the knots of HH 39; they are found in three groups and on three distinct angles, as mentioned in Figure 4.4:

1) G and B knots move toward the NE at an angle of ~12°
2) A, E, and C knots, move toward the NW at ~355°
3) A′ and H′ knots move at much steeper angles toward the NW at ~320°

Our observations also revealed some detectable Hα structures south of the HH 39 knots, which may be ionized Hα materials, which can be the signature of a jet that comes from the environment of the star R Mon, from which the HH 39 knots originated. Figures 4.6-2 and 4.6-3 clearly show the structures south of HH 39, which are in the direction of the nebula NGC 2261 and the star R Mon. Rarely detected, these structures seem to confirm that there is indeed a relationship between the nebula NGC 2261 and the HH 39 knots, in agreement with Walsh and Malin (1985).

Our 2024 observations force us to ask some questions as mentioned in Figures 4.4, 4.5, and 4.6.

Could there be more than one source (stars) from which the knots of HH 39 originate?

Or is there a precession (curved movement) in the trajectory of these knots?

* Thanks to Kevin Morefield, El Sauce Observatory, from Chile, whose images enabled these detections, refer to Figures 4.5 and 4.6.

Our objectives are met

Our work confirms that it is possible with modern amateur instruments to detect certain components of the Herbig-Haro 39 object and follow their progress with a certain precision. This, even under a sky polluted by urban light as in the suburbs of Montréal. In better observation conditions, we can even determine on the image certain parameters of the tangential movements of the knots, such as the angles (PA°) of movement and probably determine, with a certain precision, an average velocity of the knots over long periods of several decades.

Figures 10

In addition, the use of narrow-band filters such as Hα and SII improve the detection of HH 39 components, mainly if a filter is also used for the continuum and applied in differential imaging to narrow-band images as shown in Figures 9a and 9b.

Amateur observations in a high-quality sky even allow the detection of very pale structures of some nebulae surrounding the knots of object HH 39. As shown on J-G Moreau's 2024 image, in Figure 10. There is a large loop extending away from HH 39 over to the SE. ✶

* This loop is reported by, J.R. Walsh & D.F. Malin (European Southern Observatory) 1985 in their paper *Faint structures in the NGC 2261 – HH 39 region* [2.5]. They show a pale structure (loop) that extends across the sky, from non-stellar objects formed by the knots of HH 39. They observe it from the position of HH 39 and it bends away, curved to the southeast.

We express thanks to Gerald MacKenzie and Dominique Tessier MacKenzie (RASC Montréal Centre) for reviewing the translation.

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* **For this report, we used images made by some of our collaborators in the extensive monitoring of NGC2261**

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Mostly Variable Stars

Tales of the North Star

by Hilding Neilson
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I think we take the North Star for granted. I mean, it is there every night with the northern circumpolar stars moving around it as we look for more exciting night sky phenomena that we haven't already observed for centuries. After a couple of centuries of observations, how much is there really to learn?

Well, what we've learned is that Polaris is just weird. Polaris is the nearest classical Cepheid to us, which you might think would make Polaris one of the most important anchors for the standard candle distance ladder and calibrating the Leavitt Law (Period-Luminosity relation). But, it's not. Polaris is considered a low-amplitude pulsating Cepheid and is likely pulsating in the first overtone mode instead of the fundamental mode like most Cepheids. The pulsation mode could be managed but Polaris has a long history of its pulsation changing. In 1993, Don Fernie from the University of Toronto and the Dunlap Observatory published with co-authors (including an undergraduate Sara Seager) a paper called "Goodbye to Polaris the Cepheid" (Fernie et al. 1993). They presented radial velocity and photometry measurements and showed that both the visual and radial velocity pulsation amplitudes were decreasing and by the turn of the millennium Polaris might cease to be a Cepheid.

Kamper & Fernie (1998) presented a follow-up article "Polaris Revisited" where they acknowledged a significant mistake in their 1993 paper and, instead of ceasing being a Cepheid, found that Polaris was stabilizing as a low-amplitude Cepheid with a V-band amplitude of only 0.03 magnitudes. Typical Cepheid amplitudes can range between 0.1–1.5 magnitudes. Bruntt et al. (2009), concluded the trilogy with the paper "Welcome back Polaris the Cepheid" as a response, where the authors presented observations of Polaris using the WIRE satellite and the *Coriolis* satellite from 2003–2006 and found that the amplitude of Polaris was increasing again, to about 0.12 mags in 2006. While this might sound like a settled case, Anderson (2019) conducted a detailed analysis of past data along with new high-resolution spectroscopy and found that the radial velocity amplitude for Polaris has been stable in the 2010s, and furthermore that there are issues with the analysis from Bruntt et al. (2009) suggesting that the visual amplitude might not be increasing after all.

It is surprising that, in 30 years of measurements, astronomers cannot clearly delineate the evolution of pulsation amplitude of the nearest classical Cepheid. At least, we can be certain about the pulsation period, right? Well yes and no. We are fortunate to have over two centuries of observations of Polaris and its variability. In a work from over a decade ago (Neilson et al. 2012) I worked with colleagues to measure how much the pulsation period is changing using about 200 years' worth of observations In Figure 1, I show the O-C diagram for Polaris where the parabolic shape tells us that the period has been growing longer for centuries at a rate of about 4.5 seconds every year. However, in that plot we computed two best fits because in the mid-1960s there appears to be a glitch in the data where there may have been a small shift in pulsation period. On the other hand, the glitch may be a data artifact, we just don't know.

Polaris is an important calibrator because it is the nearest Cepheid to us. Unfortunately, the distance to Polaris has also been a problem. You might think that we would have a strong parallax measurement of the star. van Leeuwen et al. (2007) measured the distance to be about 130 pc (425 ly) using the *HIPPARCOS* parallax. However, Turner et al. (2013) questioned that result and suggested that Polaris was actually about 100 pc (325 ly) away, assuming that Polaris is a part of a sparse stellar cluster. Bond et al. (2018) measured the parallax using the Fine Guidance Sensor on the *Hubble Space Telescope* and found a distance of 158 pc (515 ly). Finally, a distance of 137 pc (447 ly) was measured using parallax from the exceptional *Gaia* satellite mission (Gaia Collaboration et al. 2023). While the ranges of distances might not seem like much in a field where uncertainties can be of an order-of-magnitude, the differences can have significant impacts on theoretical models, especially when we also want to know how massive Polaris is.

That is the third challenge for understanding the North Star. Polaris is a lone star, nor is it a binary, it is a trinary system. Better yet, Polaris is a spectroscopic and an astrometric binary. We can observe the companion orbiting Polaris, assuming you have about 30 years of free time. Evans et al. (2008) presented one of the first estimates of the binary orbit to measure the mass of Polaris to be about 4.5+2.2–1.4 solar masses. Evans et al. (2018) followed that a decade later with a new mass measurement 3.45±0.75 solar masses. Most recently, Evans et al. (2024) compiled new observations and measured the mass of Polaris to be 5.13±0.28 solar masses. Again, we see a significant amount of variation in the measurements. In this case, the mass determination is dependent on the assumed distance to the system along with greater sampling of measurements of the binary orbit.

Altogether, we have a number of mysteries for understanding what is happening with Polaris. I found that Polaris's rate of period change was inconsistent with the stellar evolution models. We know that the pulsation period of a Cepheid is a function of the mean density of a star, in a way analogous to how we talk about strings and standing waves in a first-year

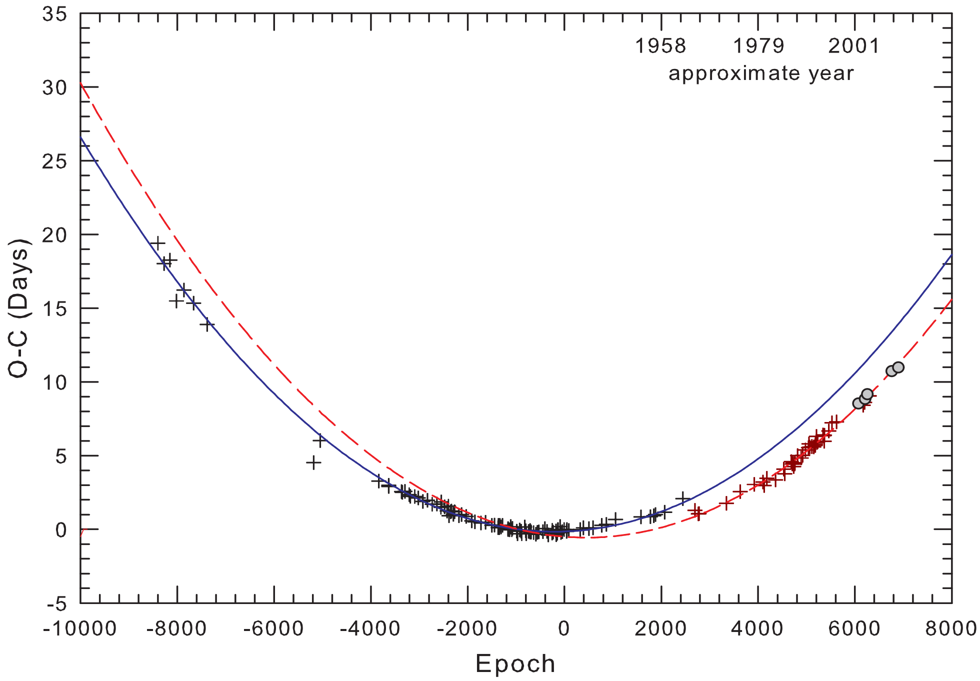

Figure 1 — O – C data from 1844/5–2011, from both radial velocity and photometry measures, are shown for the Cepheid Polaris. For the purposes of fitting, the data were divided into two sets (pre-1963 and post-1965) because of the apparent discontinuity in the O – C curve around 1963–1966 (epoch 2400–2600). The weighted, least-squares quadratic fits to the data sets are also shown, where the blue solid line is the fit to the earlier data set and the red dashed line is the fit to the later. The crosses represent data from Turner et al. (2005) and circles represent our data. The early data show a period increase of 4.44 ± 0.19 s yr^{-1} and the later data show a period increase of 4.50 ± 1.45 s yr^{-1}.

physics class. So, when the star is evolving as a Cepheid, then a change of pulsation period tells us about a change in the mean density of the star, most likely to a change in the radius of the star. But, the change in period for Polaris is too rapid given its luminosity in the stellar evolution models I used in 2012. I suggested that Polaris must have some kind of enhanced stellar wind to explain the distance. Furthermore, Evans et al. (2024) also found that their measured mass for Polaris was inconsistent with the luminosity of Polaris when modelling its evolution. The star is more luminous than expected for stellar evolution models for five-solar-mass stars.

We've had a roller coaster of measurements of the distance and mass to Polaris. It is likely that we have settled on the mass and distance to the Polaris system, but it continues to challenge stellar evolution models. That is not necessarily a new problem. Cox (1980) wrote a review about how Cepheid masses from stellar pulsation calculations tended to be smaller than masses estimated using stellar evolution models fit to observation of luminosity and stellar effective temperatures. This was called the Cepheid mass discrepancy and is still a problem today. There are a number of possible fixes, from winds, rotation, etc., but we still don't know yet which will work best, though it will likely be a combination of solutions, not just one.

Thanks to different observations over the past two centuries, we know a lot about Polaris, we might even just have too much information for our models to work. But, I'll add one more tidbit; Polaris has a magnetic field. Barron et al. (2022) did a survey of nearby classical Cepheids searching for the presence of magnetic fields and Polaris was the only one to present a complex magnetic field that is also perplexing.

So, given all of these issues, what next? Well, as much as I hate to write it, we need more observations. As the brightest Cepheid, about 2nd magnitude, Polaris is very difficult to observe professionally. So this is a great target for enthusiasts to observe and add to the vast number of observations and maybe we can take steps forward in understanding this fixture in the night sky and Cepheids in general. ✶

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Keep Calm and Orbit On

Ten Times the Fun!

By Samantha Lawler, Regina Centre
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There's a new trans-Neptunian Object (TNO) in the outer Solar System, and it's 10 times the fun of Neptune! Whereby "fun" actually means "orbital period."

2020 VN$_{40}$ is the official designation of this new TNO, discovered as part of the Large Inclination Distant Object (L*i*DO) Survey.[1] In this survey, my team and I used the Canada-France-Hawaii Telescope (CFHT) between 2020–2023 to discover new, highly tilted TNOs that travel far above and below the plane of the Solar System. 2020 VN$_{40}$ is tilted more than 33° to Earth's orbit. For reference, Pluto, everyone's favourite former planet, is only tilted by 17°.

We measure the orbits of distant TNOs by watching their position change against background stars. The motion over a few months shows us their current distance, mostly due to Earth's motion around the Sun causing parallax. But over the course of one or more years, the TNO's own very slow orbital motion can be measured.

2020 VN$_{40}$ was the largest orbit we discovered in the L*i*DO survey: it orbits the Sun at an average distance of 140 au (1 astronomical unit, or au, is the average Earth-Sun distance). For comparison, Neptune, the farthest planet from the Sun, orbits at 30 au.

But what's really special about this orbit is its perfect relationship with Neptune's orbit, and we can use Kepler's 3rd Law to see why.

One of my old professors used to always say that Kepler's 3rd Law is the astronomer's password, and all astronomers should be able to rattle this off:

"***P*** squared is ***a*** cubed."

P is the orbital period of an object around the Sun, in years, and ***a*** is the semimajor axis, or average distance from the Sun, of the object in au. Written as an equation it looks like this:

$$P^2 = a^3$$

Using this equation, we can calculate the orbital period of Neptune using its 30 au semimajor axis: 165 years. 2020 VN$_{40}$, with its 140 au orbit, takes 1,650 years to orbit the Sun, exactly 10 times longer than Neptune.

When two bodies have orbital periods that are a small integer ratio of each other, they are often in what's called a mean-motion resonance (MMR). We talk about these MMRs in terms of the orbital period ratios. Because 2020 VN$_{40}$ takes 10 times longer to orbit the Sun than Neptune, we say it is in the 10:1 MMR (pronounced "ten to one").

When we first discovered 2020 VN$_{40}$, it was close to the 10:1 MMR, but with very large error bars on the semimajor axis. This is normal: it takes years to measure precise orbits. In order to make those orbital uncertainties smaller and learn whether it was inside the 10:1 resonance or simply orbiting right next door, we needed a longer observation arc. First, we obtained extra time on Gemini North to observe it one more time, extending the observation arc from 3 years to 4. That made the error bars a little smaller, but not quite small enough to know for sure if it is in the 10:1 MMR. We needed more arc, and being impatient astronomers, the only way to do that without waiting was to go back in time.

In my last column, I talked about the power of public astronomy data archives like the Canadian Astronomy Data Centre (CADC). We made use of the CADC's powerful public "Solar System Object Image Search"[2] to look back in time and find images that may have contained 2020 VN$_{40}$ where it was not yet discovered. We found nearly decade-old images from Subaru that contained 2020 VN$_{40}$ in a Planet 9 search[3]! With the observation arc extended from four years to well over a decade, the error bars shrank to within the parameter space that guarantee this little TNO is in Neptune's 10:1 MMR.

MMRs are extremely important in the outer Solar System. Out of the 141 TNOs discovered in the LIDO Survey, for example, 55 of them are definitely in MMRs with Neptune. Pluto, the original TNO, is in the 3:2 MMR with Neptune. This special orbit is what has allowed Pluto's orbit to cross Neptune's for billions of years without a collision: Pluto and

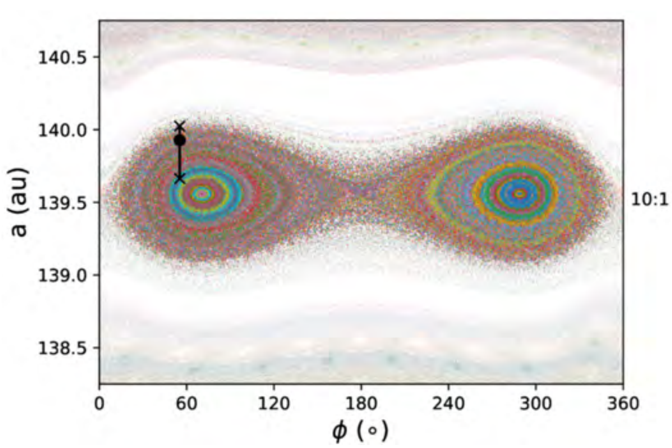

Figure 1 — A Poincaré map of the 10:1 MMR with Neptune. The colourful concentric teardrops show the parameter space of the 10:1, and the black dot shows the location of 2020 VN$_{40}$ in this map as well as the uncertainty on its orbit, which is fully inside the 10:1 MMR. Credit: Pike et al. 2025.

Neptune are protected from crashing by the MMR, because every time Pluto crosses Neptune's orbit, Neptune is far away.

MMRs also tell us that there is a gravitational connection between two bodies. Whenever 2020 VN_{40} has its closest approach to Neptune (every 10 Neptune orbits), it gets a gravitational kick from Neptune. Two objects that are not in an MMR will give each other gravitational kicks at random places in the orbit. But the MMR forces the close encounter to always occur at the same spot in the orbit, like pushing a kid on a swing. So even though 2020 VN_{40} never gets closer than several au from Neptune, it's strongly tied to Neptune's orbit by the MMR.

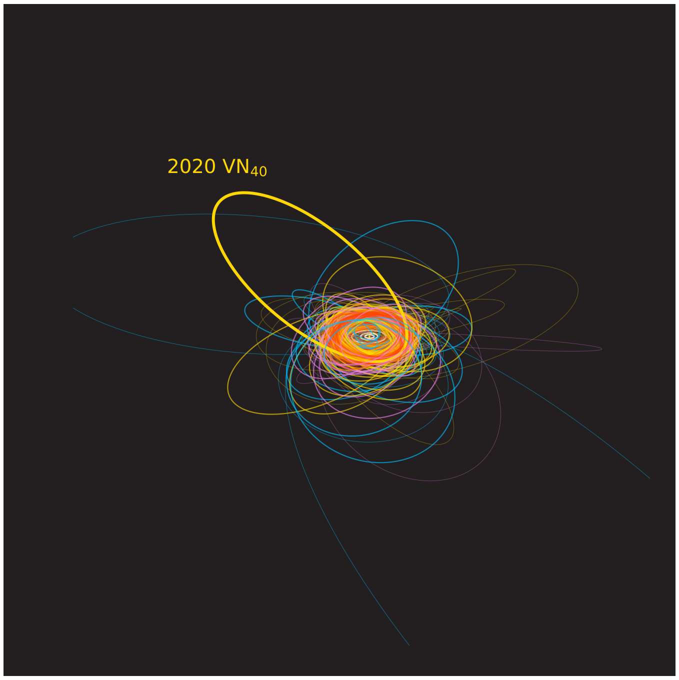

Figure 2 — The orbit of 2020 VN_{40} relative to a bunch of known distant TNOs, showing its highly tilted, very large orbit. Credit: Pike et al. 2025 paper press release.

There's a famous quote (possibly mis-)attributed to Isaac Asimov: "The most exciting phrase to hear in science, the one that heralds new discoveries, is not 'Eureka!' but 'That's funny…'" We definitely had a lot of "Huh, that's funny" moments while discussing and analyzing this discovery. The very high orbital tilt makes certain aspects of the MMR behave differently, because Neptune's gravitational-kid-on-a-swing pushes happen at a different point in the orbit than for less-tilted orbits. Instead of its closest point to Neptune being near pericentre, the TNO's closest approach to the Sun, it's actually closest almost 90 degrees from its pericentre. This was not expected and shows a lot more ways for TNO orbits to exist in MMRs in the distant Solar System than we previously thought.

The fact that MMRs are important and common at such very large distances from Neptune has interesting implications for what we expect to find in the distant Solar System. One particular question that has been hotly debated recently is whether or not there is an additional, undiscovered, massive planet at 500 au (sometimes called "Planet 9"[4]). If MMRs are demonstrated to be important at 140 au, why wouldn't they be important at 500 au? And more importantly, how would MMRs with hypothetical Planet 9 change where we expect to find distant resonant TNOs like 2020 VN_{40}?

But we'll talk about the Planet 9 theory a bit more in a future article.

The orbits of distant TNOs trace out gorgeous celestial spirograph patterns over millions of years and give us clues about processes in the distant past, like planet migration and tidal forces from the galaxy, as well as what may or may not exist beyond the edge of current discoveries. The Vera Rubin Observatory, now taking data, will discover thousands of new TNOs[5], and give us many more clues to piece together the story of why we're here today on this pale blue dot. ✶

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John Percy's Universe

Canada's Astronomical Heritage

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A decade ago, I wrote a column about Toronto's astronomical heritage, motivated by my interest in heritage and outreach and communication, and by some of my International Year of Astronomy heritage projects (Percy 2014). This follow-up column was prompted by an informal online brainstorming session of the Heritage Committee of CASCA, the Canadian Astronomical Society[1], organized by CASCA VP Erik Rosolowsky. I am a member of that committee.

What is heritage? It's related to history, but is more. Its various definitions reflect the variety of its contexts and meanings. Most deal with inheritance, buildings, culture, or language, but the Heritage Council of Ireland's definition is relevant here: "heritage is what we have inherited from the past, to value and enjoy in the present, and to preserve and pass on to future generations." The first of the CASCA Heritage Committee's terms of reference is similar: "Work on behalf of the CASCA Board to help ensure that cultural properties and artifacts significant in the development of Canadian astronomy, together with the intangible heritage of astronomy, are brought to the attention of proper authorities for their protection." I would add "... brought to the attention of the Canadian people" as well.

In fact, the 13 members of the committee, ably chaired for many years by Dr. Elizabeth Griffin (DAO), work on our own heritage projects as well. We are rarely asked by the CASCA Board to work on specific projects. We did prepare short obituaries of deceased founding members on the occasion of CASCA's 50th birthday in 2021. Thus, we are less of a committee, and more of a working group. And we do work; you can read our reports here![2]

There is much to preserve and protect, including science itself. Anti-science is prevalent in some places—I will not say more. Occasionally there have been calls to reduce astronomy in the provincial school science curricula, on the grounds that it has little or no practical value. This is where public outreach and communication, by professional and amateur astronomers, journalists, and other writers can really help.

The definitive account of astronomy in Canada is Richard Jarrell's (1988) *The Cold Light of Dawn.* But it is several decades old. An update or sequel would be appropriate and welcome, but unfortunately Jarrell passed away in 2013.

Colonial astronomy, of the practical kind, dates back 500 years in Canada. In the 19th century, small observatories sprang up in a few cities and towns across the country, mostly for practical astronomy. There was first the Castle Frederick Observatory (1765) in Nova Scotia (Bishop, 2012), the William Brydone Jack Observatory (1851) at the University of New Brunswick, and the Québec City Observatory (1850) on the Plains of Abraham, among others (Jarrell 1988, page 191. Some of them remain. In the early 20th century, the government observatory (1855) on the University of Toronto campus was threatened with demolition when the university expanded. It was saved by the lateral thinking of surveying instructor L.B. Stewart; the observatory was disassembled, stone by stone, and reassembled in a safer spot. It has been used for a variety of purposes since then, and still exists today (Percy 2014).

The first half of the 20th century brought great progress in astronomy instrumentation, research, and education in Canada. As well as the national Dominion Observatory (1902–1970) in Ottawa, there was the Dominion Astrophysical Observatory (1918) in Victoria, and the David Dunlap Observatory (1935) in Toronto. In 1935, DAO and DDO boasted two of the three largest telescopes in the world! DAO is well-described in Peter Broughton's (2018) award-winning biography of John S. Plaskett, its long-time director.

As Peter notes in his book, Plaskett was himself heavily committed to proactive public outreach and education. He started regular Saturday night public open houses that continue to this day.

To improve the quality of visitor experiences, a purpose-built (and heated!) education facility, *The Centre of the Universe*[3], was developed by then DAO Director (1986–2014) Jim Hesser. It opened in 2001 and was operated by NRC through 2013. In 2015, the not-for-profit community group Friends of the DAO took over operations, and draw heavily upon the enthusiastic expertise of members of the RASC Victoria Centre.

The story of the rise, fall, and resurrection of DDO is a more complicated story, and deserves an in-depth scholarly article, or book. There was strong—but fragmented—community support. Happily, DDO is now thriving as a municipal education facility[4], and the proceeds from the sale of the lands around DDO have been used to endow a new Dunlap Institute[5] at the University of Toronto, thus preserving the name of the original donors of DDO—the Dunlap family.

The mid-20th century brought a new technology—radio astronomy—with the Algonquin Radio Observatory (1959) in Algonquin Park, and the Dominion Radio Astrophysical Observatory (1960) in Penticton. Richard Jarrell began to write a history of radio astronomy in Canada, but it was incomplete at the time of his death in 2013. Happily, the book has now been completed and was published by Jasper Wall and Elizabeth Griffin (Wall et al. 2024).

Government activity in astronomy and astrophysics was brought under the umbrella of the new Herzberg Institute of Astrophysics (1975), named after Canadian Nobel laureate Gerhard Herzberg. The later 20th century also brought major government-funded international partnerships such as the Canada-France-Hawaii observatory (1979) and others in Hawaii and Chile, and in space.

There were other initiatives, such as the Canadian Institute for Theoretical Astrophysics (1984), a national institute hosted by the University of Toronto, and institutes at other Canadian universities. CASCA was born in 1971. Canada also became involved in a number of space astronomy projects (Percy 2025). Canadian astronomers such as Richard Bond, Art MacDonald, and Vicki Kaspi have achieved international recognition and renown, as did astronomers such as Plaskett, Peter Millman, and C.S. Beals in the 20th century.

Canada has also achieved excellence in some areas related to "practical" astronomy, such as geophysics, and upper atmospheric phenomena (aurorae, meteors, impact craters).

Figure 1 — The Dominion Astrophysical Observatory (1918), in Saanich, outside Victoria, B.C. Its heritage has been preserved, thanks to inspired leadership by Dr. Jim Hesser, by the attached education facility **Centre of the Universe**, *and by strong community support. Source: National Research Council of Canada.*

All this deserves serious scholarly research and writing, before the major players in the game pass away. We must remember that astronomy is done by people, not by books and journals! These "major players" are the ones who made 21st-century astronomy in Canada possible, but biographical information is sometimes scarce or scattered. There is Peter Broughton's (2018) award-winning biography of Plaskett. At least one Canadian astronomer—MIT professor and RASC Honorary President Sara Seager (2020)—has written an award-winning memoir, which I highly recommend. My department has engaged a part-time historian-in-residence, Dr. Victoria Fisher, to write short (six pages in my case) biographies of its emeritus professors. I hope that other such biographies are produced and preserved.

In the past two centuries, libraries, museums, universities, and scientific and community organizations such as the so-called Mechanics' Institutes have helped to create, preserve, and promote astronomical heritage. Ingenium, our national museum of science and technology, plays an important role. But the closing of Toronto's McLaughlin Planetarium in 1995, and the neglect and temporary (we hope) closing of the Ontario Science Centre in 2024 remind us that science and education exist at the whim of the governments that are supposed to support them. Philanthropy can help, as it did with DDO.

Science journalists, such as Nicole Mortillaro (CBC, author, and editor of this *Journal*) and Ivan Semeniuk (*Globe and Mail*) have the skills and experience to do in-depth research and writing about the complexities of science in Canada—past and present. Other writers, such as the late Terence Dickinson and Helen Sawyer Hogg, have generated cross-country public interest, understanding, and support for Canadian astronomy. And the outreach done by amateur and professional astronomers is widespread and significant.

Students can help, too. At the University of Toronto, graduate students at the Institute for the History and Philosophy of Science and Technology created the University of Toronto Scientific Instrument Collection[6] "to gather, safeguard, research, catalogue, and interpret the material heritage of science (including astronomy) at the University of Toronto" and make it available as a virtual museum.

The RASC has done an exemplary job of preserving its heritage. Peter Broughton (1994) has published a comprehensive and fascinating history of the RASC. It is now out of print but is freely available on the RASC website[7]. RASC has published this *Journal* since 1907. It contains reports of the Society and its Centres, scholarly articles on the Society's history, and reports on almost every advance in Canadian astronomy. It's indexed in NASA's Astrophysics Data System[8].

Peter Broughton's book covers the RASC Centres as well as the national society. Ideally, every Centre should have a designated historian, to identify, preserve, and promote aspects of the Centre's history and heritage. It would make sense to partner with local heritage organizations. At the least, they can produce and display plaques to mark significant structures, people, and achievements.

Much archival material is available at the National Office, though it would be desirable to digitize this material as soon as possible. The Dorner Telescope Museum, also housed at National Office, is a unique collection of instruments that amateur astronomers have used for research, outreach, and recreation. Randall Rosenfeld, a leading figure in the promotion and preservation of Canadian astronomy history and heritage today, is the director and curator.

As you can see from this very brief overview, there is much to be proud of, and much to be done. We need in-depth articles, and ideally a book or two. We need a formal inventory of the history and culture of Canadian astronomy, including astronomical knowledge, organizations, facilities, and people, and a bibliography summarizing what is known about them.

How about starting with an informal inventory: a suitably referenced popular book of one-or-two page thumbnail sketches of Canada's most notable astronomers, both professional and amateur, observatories and planetaria, and notable Canadian astronomical developments and discoveries? If I were a decade younger, I might take this on!

Acknowledgement. I thank Dr. Jim Hesser for reading and commenting on a draft of this column, and for his leadership in so many aspects of astronomy in Canada. ✶

Endnotes

1 CASCA Heritage Committee: casca.ca/?page_id=18675
2 CASCA Heritage Committee Reports: casca.ca/?page_id=18690
3 Centre of the Universe, Victoria BC: centreoftheuniverse.org
4 David Dunlap Observatory (DDO): www.richmondhill.ca/en/learn-more/ddo-programs.aspx
5 Dunlap Institute of Astronomy & Astrophysics: dunlap.utoronto.ca
6 University of Toronto Scientific Instrument Collection: utsic.utoronto.ca
7 Looking Up: A History of the RASC: rasc.ca/looking
8 NASA Astrophysics Data System: ui.adsabs.harvard.edu

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Blast from the Past!

Compiled by James Edgar
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Magnetic Disturbances Recorded at the Agincourt Observatory.

By R. F. Stupart

A SERIES of magnetic disturbances were recorded at the Agincourt Magnetic Observatory February 6-9, 1907, during which period the sun showed remarkable disturbances as evidenced by spots, and some very beautiful aurorae were observed in various parts of the Dominion.

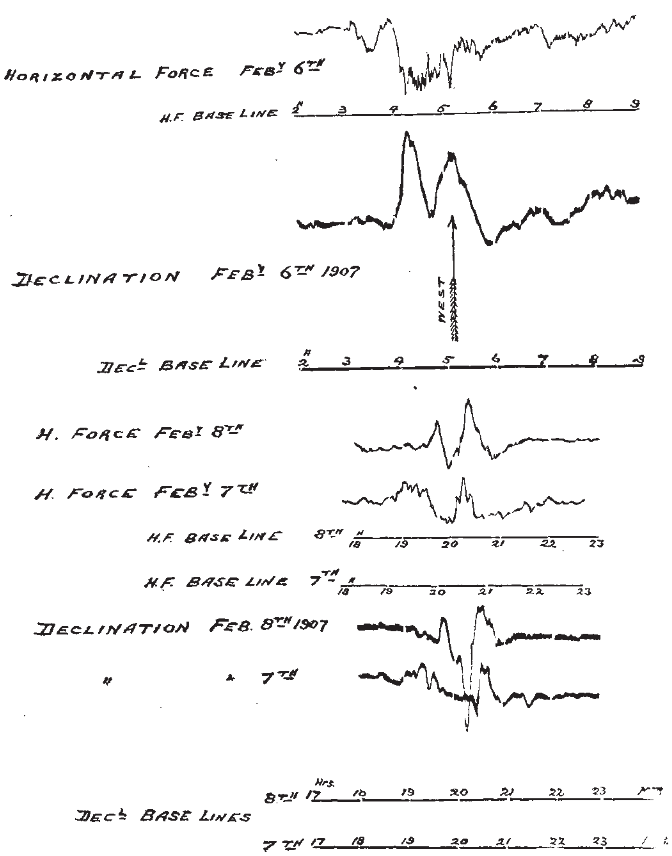
The magnets were somewhat disturbed after 21h February 6, and small movements continued during the night. At $3^h\ 56^m$ on the 7th the declination needle began a westerly movement, and in 21 minutes had passed through an arc of 45′.2. A sharp return movement followed lasting for 29 minutes, when another abrupt westerly movement occurred through an arc of 28′, and then a somewhat slower easterly movement, which by $4^h\ 43^m$ gave a declination 10′ east of that recorded at $3^h\ 56^m$. By $9^h\ 30^m$ the magnet was steady at a nearly normal position.

The movements registered on the evenings of the 7th and 8th were quite remarkable. They had somewhat similar characteristic features, and occurred at approximately the same hour on consecutive days. On the 7th the extreme easterly reading was reached at $20^h\ 29^m$ and the extreme westerly at $20^h\ 35^m\ 7^s$, and on the following day the extreme easterly at $20^h\ 14.4^m$ and westerly at $20^h\ 30^m$, a change of 56′ occurring in 14.5 minutes. Several irregular movements of both the declination and the horizontal force magnets occurred during the early hours of the 9th, and then suddenly at $9^h\ 10.5^m$ a disturbance of large dimensions set in. Until about 14^h the force was below its normal value and afterward generally above for seven hours, during which interval the bifilar magnet made some eight large excursions, and in five instances the record was beyond the limit of the paper. The largest movement in declination occurred between $20^h\ 43.6^m$ and $21^h\ 0^m$, when a change of 1° 4′ was recorded.

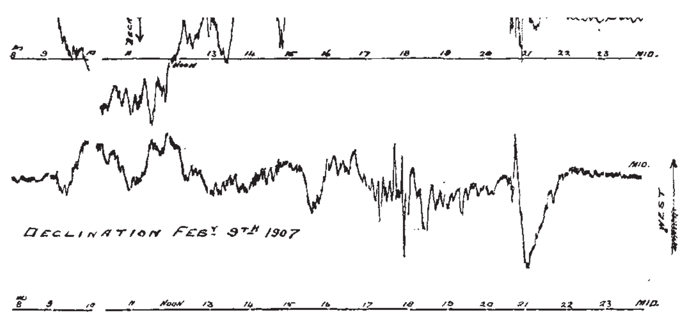
The changes above described are shown by the accompanying diagrams. ✶

[Editor's Note: ROBERT FREDERIC STUPART (1857–1940) joined the permanent staff of the Canadian Meteorological Service as a map-drawer when he was only 15.

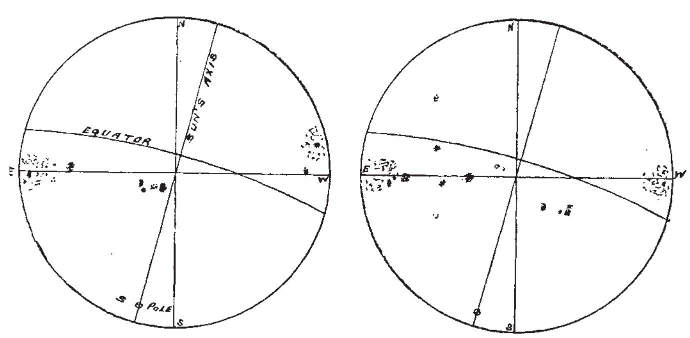
He was Director of the Toronto Observatory, Superintendent of the Dominion Meteorological Service (1894–1929), and President of the RASC (1902–03). He was knighted in 1916. www.rasc.ca/robert-stupart]



Disturbed Magnetic Curves, February 6, 7, 8, 1907.
Agincourt Station of Toronto Observatory.



Horizontal Force and Declination Curves for February 9, 1907.
Scale for H. F., 1 mm. = 0·000207 dyne;
for Decl., 1 mm. = 5′·88.



Feb. 6, 1907, 12 h 15m. Feb. 8, 12 h 40m, E.S.T.

The Sun's disc as sketched with the 6-inch refractor of the Toronto Observatory.

Dish on the Cosmos

Radio Astronomers Strike a CHORD with New Telescope

by Pamela Freeman
(pamela.freeman@ucalgary.ca)

In a recent issue, I mentioned the expansion of the Canadian Hydrogen Intensity Mapping Experiment (CHIME), a radio telescope hosted at the Dominion Radio Astrophysical Observatory (DRAO) in British Columbia on the traditional unceded territory of the Syilx people, with outrigger stations in California and West Virginia, USA. This placement of smaller versions of CHIME at distant locations will allow for the localization of fast radio bursts (FRBs)—an important step in solving the mystery of where, and from what, these energetic bursts come. These outriggers are not the only instruments in development: a successor telescope to CHIME, the Canadian Hydrogen Observatory and Radio-transient Detector (CHORD), is well underway. It will be an array of 512 six-metre dishes situated beside CHIME at the DRAO site (see the whole instrument set up in Figure 1), and the first collection of dishes is set to be up and working near the end of this year.

As the name suggests, CHORD will continue the world-class research conducted with CHIME: mapping atomic hydrogen across the Universe and detecting radio transient events, such as FRBs—the difference in the development of CHIME and CHORD is that FRB research was then unexpected for CHIME. Similar to CHIME, CHORD will scan overhead as the Earth rotates, observing the sky above it 24 hours a day, 7 days a week.

CHIME was initially constructed to map neutral hydrogen in the distant Universe to study how it expanded (see *JRASC*, April 2016). Over a frequency range of 400–800 MHz, neutral hydrogen maps the large-scale structure of matter—the intergalactic structure, not resolving individual galaxies—over a period of billions of years, when the Universe was less than half its current age.

CHORD will expand that frequency range to 300–1500 MHz, reaching both closer and further back in time and covering a greater period of expansion. It will be the largest 3-D image of the cosmos yet. The map of hydrogen shows the flow in between galaxies, how matter builds up to the distinct structures we see today (the structures we see through telescopes and deep data analysis). In the earlier Universe, this will be a collective signal from many galaxies. Closer to us, CHORD will be able to distinguish individual galaxies—up to 10^7 galaxies are estimated to be detected.

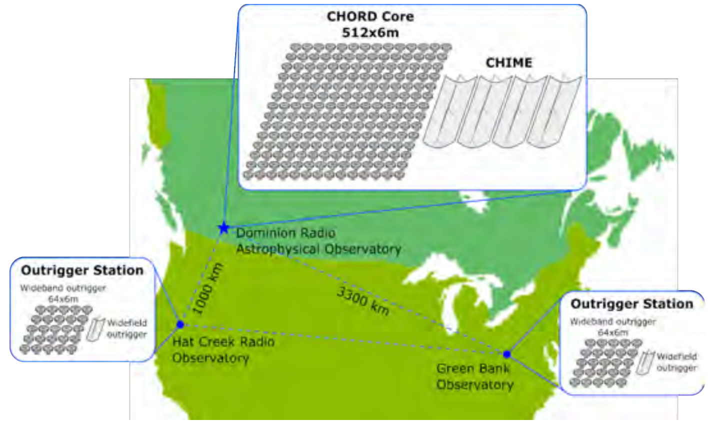


Figure 1 — The arrays for CHIME and CHORD spread out across North America. Image credit CHORD collaboration.

The expanded frequency range benefits FRB research, as well. CHIME detects FRBs across its band, as broad signals; prior to CHIME, FRBs were detected around 1400 MHz. A broader frequency range, then, indicates a greater ability to capture FRBs. Along with the ability to localize the FRBs with the outrigger stations (*JRASC*, April 2025), it's only a matter of time before their origin is uncovered. In addition, knowing where in the Universe these come from will provide a new probe of the intervening intergalactic medium. If that's not enough transient astronomy, CHORD also aims to detect new pulsars and follow up on gravitational wave events.

Given the past exploration of the science on CHIME, I want to use the rest of this column to showcase how CHORD will achieve these science goals. CHIME only came online in 2017, and the technology advancements since then will propel CHORD into the next generation of cosmological research. These advancements in radio instrumentation and analysis are led by Canadian researchers.

The CHORD telescope is classified as "large N, small D," indicating a large (512) number of dishes of small (6 metre) diameter making up the main array. The distance between the antennae dictates the resolution of the telescope, as it acts as a virtual dish the size of the distance between those antennae. Here, the distances will be short, six to eight metres, in relation to other well-known interferometric arrays, which use large distances in between dishes to obtain high resolution. The short baselines, however, allow astronomers to resolve extended sources in the sky, such as the large-scale structure that connects galaxies in our cosmos.

The distant hydrogen emission CHORD observes is incredibly faint. In the design of radio telescopes, caution is taken to ensure the instruments themselves will produce as little radio noise as possible. The telescope's sensitivity to these faint signals is reliant on reducing this noise, and CHORD is testing those limits.

The dishes themselves (Figure 2), developed by the National Research Council, have a precise surface made from fibreglass and a metal mesh. They are deep to shield the antenna from unnecessary signals—the NRC have learned, from CHIME, that the horizon is especially noisy. The short distances between dishes is also a concern for noise, as it increases "crosstalk," or the undesired coupling between different elements in the array.

For the instrumentation, researchers at the University of Toronto developed custom feeds—the piece of the telescope that guides the signal to the receiver—with the requirements of being low cost, low complexity, compact, and able to work over a wide range of frequencies. Researchers at the University of Calgary developed a low-noise amplifier—a key part of the system that boosts the incoming signal strength while adding minimal noise.

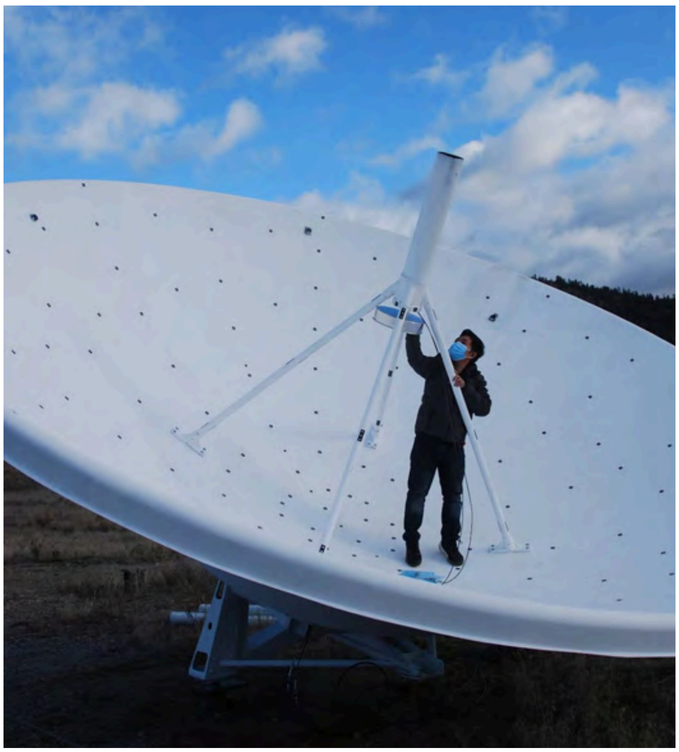


Figure 2 — A CHORD collaboration member working on the instrumentation in one of the dishes. Image credit CHORD collaboration.

The heart of an interferometric telescope is its correlator. CHIME, and now CHORD, have a robust muscle here. The correlator is designed to digitize the data and separate it into channels in one engine, then correlate the data in a second engine. It is the processor that combines the signals coming into the different antennae in order to create a comprehensible image, while allowing easy filtering and sorting. This, as you may imagine, requires a lot of computing power.

The CHIME team benefitted from computing power catching up to their scientific ambitions. The vast amount of data that comes into these telescopes, observing passively, is immense—one researcher estimated that CHORD will collect the same amount of data as the entire mobile network traffic of North America each day. Thanks, in part, to developments in video game hardware, the technology to handle this data was available for CHIME and has only improved until today. These telescopes use consumer-grade graphics processing units, which makes it cost-accessible and adaptable for different purposes (my Master's thesis, in fact, used this correlator design for the Synthesis Telescope at the DRAO).

That is not where the innovation ends. It is an exciting, if slightly daunting, task to develop ways to transport, store, share, and use the wealth of data that will come in. The team, across many institutions, are developing sophisticated software to process the data so it can be used for commensal projects.

There are many ways to categorize a telescope's capabilities. For CHORD, the team uses the combination of bandwidth, field of view, and sensitivity, to assert that it is an "order of magnitude more powerful" than CHIME. The expertise being developed in Canada is in demand internationally, with technology being shared with the Square Kilometre Array Mid in South Africa, and with the upgrade for the Atacama Large Millimetre/submillimetre Array in Chile.

CHORD is a testament to the innovation of radio astronomy in Canada. For many years, researchers here have shown resourcefulness and ingenuity in this realm. Feats in this space include the first Very Long Baseline Interferometry measurement in 1967 between two antennas at the Algonquin Radio Observatory in Ontario and the DRAO, a distance of 3,074 kilometres. Their limited budget led them to procure surplus video recorders from the Canadian Broadcasting Corporation—a serendipitous event as the CBC was moving to colour broadcasting and had no use for their old recorders, which still boasted a long recording time and wide bandwidth.

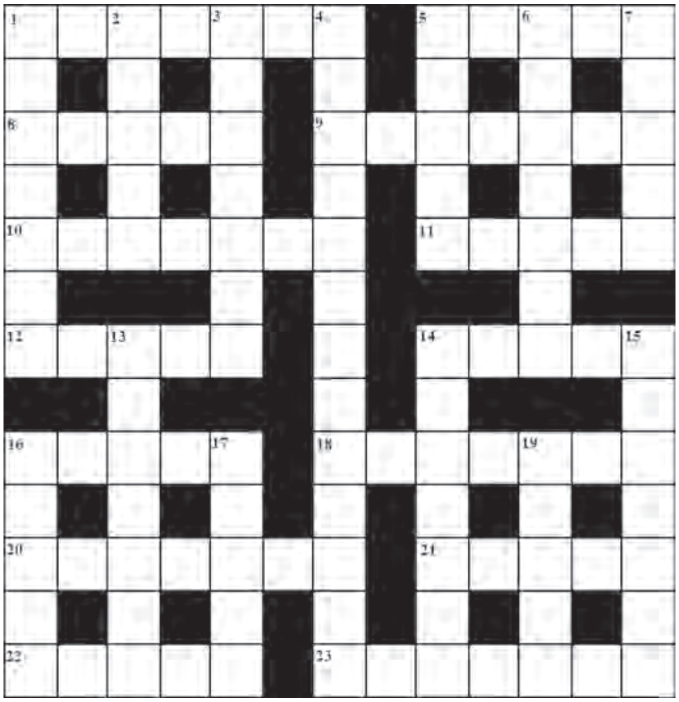
You can see this innovation for yourself at the DRAO. Sadly, the weekend tours for 2025 end in October—but not forever, and I highly recommend a visit if you find yourself on a future summer vacation in the area. Nestled in a valley in a radio-quiet zone, visiting the DRAO has an old-school, offline, atmosphere, juxtaposed by the cutting-edge technology contained in the telescopes hosted there.

Find out more about CHORD:
www.chord-observatory.ca/home ✶

Pamela Freeman recently finished her Ph.D. in astrophysics at the University of Calgary. Specifically, she studies the chemical make-up of star-forming clouds with radio telescopes. Generally, she loves to observe anything and everything about nature.

Astrocryptic

by Curt Nason (nasonc@nbnet.nb.ca)



ACROSS

1. Wintry bird dove under a hare (7)
5. Madam, I'm as full as a moon inside (5)
8. Brightest star in its final phase of development (5)
9. William pondered universal energy loss before nobility (7)
10. The French test oxygen around Saturn (7)
11. I live in an animal shelter with a sprig of wheat (5)
12. As an astronomer she learned to massage (5)
14. Cancel a planned NASA mission due to broken curbs (5)
16. Norton's star faded, sadly, over time (5)
18. Quasar discoverer did not use half a catadioptric (7)
20. Energy lost to an abrading meteoroid (7)
21. Quantum physicist enjoyed his endless cardio workout (5)
22. He charted Neptune and had mistakes, oddly (5)
23. Zhivago's love with tail movement seen in a scorpion (7)

DOWN

1. Hire someone like Will Tirion (7)
2. Larcenist started to change plea for where to wear his Messier pin (5)
3. Assumed star used as our clock standard (4,3)
4. Professional journal from a class I skipped about the Stanley Cup, e.g. (13)
5. Greek characters go around on heavy electrons (5)
6. Comet hunter led me to emergency room round back of space station (7)
7. Telescope company with a nasty disposition (5)
13. Sightless around Europa, a moon around Uranus (7)
14. Car shed rebuilt to brighten the Queen (7)
15. Albireo, alternatively, tag out young pitcher beyond empty base (4,3)
16. Kipling snake follows a north star in Phoenix (5)
17. Dark sky ones are tourist attractions, I hear (5)
19. Preferred format to image for processing when warm after scattered rain (2,3)

Answers to previous puzzle

Across: **1** DAWES (anag); **4** RETICLE (2 def); **8** PATRICK (2 def); **9** CALIF (C+anag); **10** EARTH (anag); **11** AMOEBAE (am+oe+bae); **12** SATURN (an(at)ag); **14** URANUS (U(ran)us); **18** PRIMARY (2 def); **20** DEBUG (anag-t); **22** AMBLE (ana(L)g); **23** YUCATAN (Yu(cat)an); **24** TUESDAY (spoonerism); **25** LISTS (2 def)

Down: **1** DIPPERS (an(pp)ag); **2** WATER (2 def); **3** SLIPHER (anag); **4** RUKBAT (RUK+bat); **5** TYCHO (hid); **6** CALIBAN (an(L)ag); **7** ERFLE (an(L)ag); **13** TRIMBLE (anag); **15** RADICAL (anag); **16** SEGINUS (anag+s); **17** SYZYGY (s+yzygy); **18** PHACT (hom); **19** AREND (anag); **21** BETAS (anag+s)

The Royal Astronomical Society of Canada

Vision

To be Canada's premier organization of amateur and professional astronomers, promoting astronomy to all.

Mission

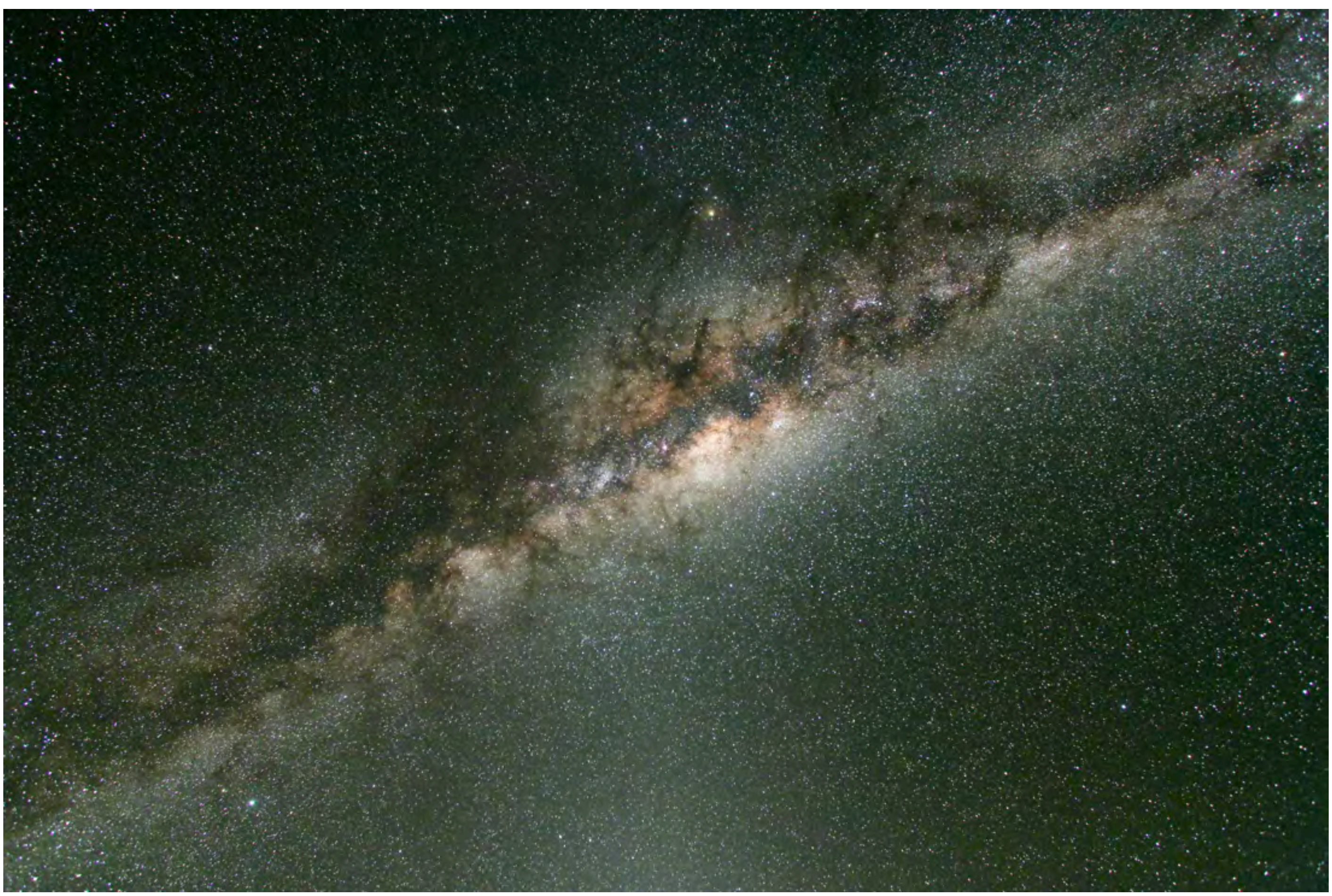
To enhance understanding of and inspire curiosity about the Universe, through public outreach, education, and support for astronomical research.

Values

- Sharing knowledge and experience
- Collaboration and fellowship
- Enrichment of our community through diversity
- Discovery through the scientific method

Great Images

By Dave Cotterell



The Milky Way stretches over Chile in this beautiful image by Dave Cotterell. He used a Canon 60Da camera with a 10-mm wide-angle lens. This is a 30-second exposure, shot at ISO 1600.

Journal

This stunning HαLRGB image of the Cocoon Nebula was taken by Katelyn Beecroft. She took most of the data from her home in London, Ontario, and then captured one more night from the North York Astronomical Association's star party, Starfest, this past August. She used an Askar FRA400 72mm at ƒ/5.6 on a Sky-Watcher HEQ5-Pro mount with a ZWO ASI2600mm Pro camera. 272 × 120s of luminance with the Antlia V-series Pro L filter; 76 × 120s each of RGB with the Antlia V-Series Pro RGB filters; 265 × 300s of Hα with the Antlia 4.5nm Edge Hα filter. Total time: 38h 45min