The Journal of The Royal Astronomical Society of Canada

Journal

Le Journal de la Société royale d'astronomie du Canada

PROMOTING ASTRONOMY IN CANADA

December/décembre 2025
Volume/volume 119
Number/numéro 6 [835]

Inside this issue:

The Misty Mountains

Great Images

By Malcolm Park, Debra Ceravolo

Comet C/2025 A6 (Lemmon) put on quite a show in October. Malcolm Park managed to capture the fleeting visitor from New Mexico (controlled from Ontario) under less than ideal skies, with poor transparency that resulted in some banding. He used an ASI 2600 MC and a Duo Rokinon 135. 10×120s.

Debra Ceravolo of Osoyoos, B.C., writes "Clouds—as an astrophotographer, I usually avoid them but sometimes you have to embrace them. This was the only time I was able to catch the long tail of Comet A6 (Lemmon) before the coming bright Moon washes it out. Captured on October 27 using a 135mm lens on a Canon R6. One-minute tracked exposure. Now, here comes the Moon and there goes the comet.

Journal

December / décembre 2025 | Vol. 119, No. 6 | Whole Number 835

Royal Astronomical Society of Canada

Société Royale d'Astronomie du Canada

contents / table des matières

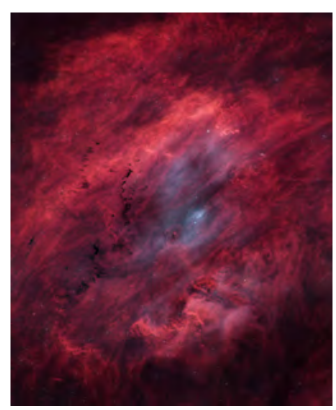
Research Articles / Articles de recherche

Pen & Pixel / Stylo et pixel

Columns / Rubriques

Departments / Départements

Great Images / Superbes images



This incredible image of SH2-119, was taken by Ryan Genier from his home in Kitchener, Ontario, under Bortle 7 skies. Ryan says, "The final image reminds me of a cloud-covered mountain range, hence the name I've chosen [The Misty Mountains]. I think it's appropriate." He used a Celestron 8″ RASA on an iOptron GEM 45, with a ZWO ASI2600MM PRO. $H\alpha$ 101×600s; SII 56×600s; 137×600s.

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.

The *Journal* of The Royal Astronomical Society of Canada is published at an annual subscription rate of $125 (plus Canadian tax), $140 USD for US subscriptions, $150 USD for International subscriptions. Membership, which includes the publications (for personal use), is open to anyone interested in astronomy. Applications for subscriptions to the *Journal* or membership in the RASC and information on how to acquire back issues of the *Journal* can be obtained from:

The Royal Astronomical Society of Canada
203-489 College St
Toronto ON M6G 1A5

nationaloffice@rasc.ca
www.rasc.ca
Tel: 416-924-7973
Fax: 416-924-2911

Canadian Publications Mail Registration No. 09818
Canada Post: Send address changes to 203–489 College St, Toronto ON M6G 1A5

Canada Post Publication Agreement No. 40069313

 ISSN 0035-872X

President's Corner

Following Footsteps in the Snow: An End-of-Year Reflection

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

As we bring the 2025 calendar year to a close and welcome the arrival of winter, I find this is always a good time for reflection—on what was, what could have been, and what may yet be.

The end of a calendar year is, of course, an arbitrary line that had to be drawn somewhere. It may come as no surprise to readers of the *Journal* that I would have preferred the new year to begin on a date of astronomical significance—perhaps the March equinox or the December solstice.

The combination of early sunsets, cold clear nights, and a soft topping of snow ushers in a season of change and contemplation. The return of cold December nights leaves behind the sounds of summer and replaces them with the crunch of snow beneath one's feet on the way to an observing spot. It's a gentle reminder that not all things stay the same—that change is both natural and necessary for progress.

The crisp, clear nights of winter offer views of the sky that feel uniquely special. It takes determination and passion to leave a warm home and step into a snowy field to observe, yet so many of us have done exactly that.

It is this same spirit upon which so many of the Society's accomplishments have been built—and upon which the achievements of tomorrow will depend. We owe much to those who braved cold nights and other hardships to dedicate themselves to exploring the cosmos through an eyepiece. The drive they must have felt—to go out night after night, recording celestial events with care and precision—must have been as inspiring as it was humbling.

Looking to the future can be equally humbling, especially in uncertain times. Political, cultural, and economic winds are shifting in unpredictable ways. Yet, like following footsteps in the snow on a winter's night, a path has already been walked before us—one we can follow. Not a path to a favourite observing spot, but a path that guides us forward as an organization. Each step in that snow represents a value that has proven its worth: cooperation, determination, integrity, and resourcefulness. Step by step—left, right, left—these traits carry us toward our shared goals.

Somewhere between the last glow of evening twilight and the first light of dawn, when I am cold, tired, and the going is tough, one thought always comes to mind—the reason I do this, the reason I love astronomy and the community around it. I follow the steps in the snow, steady and sure, while keeping my head held high toward the stars. As my frosty breath drifts into the sky and I reflect on what's to come, one quote in particular always echoes in my mind:

"We choose to go to the Moon. We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard; because that goal will serve to organize and measure the best of our energies and skills; because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win."
—John F. Kennedy

I choose to be part of the Society because I choose to contribute the best that my abilities allow.

Merry Christmas—and here's to another orbit. ✶

News Notes / En manchette

Compiled by Jay Anderson

Methane gas discovered on dwarf planet Makemake

Makemake, named after a deity in Rapa Nui mythology, is a distant trans-Neptunian dwarf planet, second brightest after Pluto, that circles the Sun in a 305-year orbit. It is currently close to aphelion, at 52.5 au from the Sun. Based on occultation measurements, it has a radius of 715 km, about 1/9th that of the Earth; its day is about 22½ hours. Makemake has one moon, about 80 km in size and orbiting a little over 20,000 km from the dwarf planet.

It has been known since 2007 that Makemake has frozen methane and ethane on its surface, but the presence of an atmosphere was not suspected after stellar-occultation measurements in 2012 failed to find evidence of volatile gases (though the presence of a very thin atmosphere could not be ruled out). Now, however, a Southwest Research Institute-led team has reported the first detection of gas on the distant dwarf planet, using NASA's *James Webb Space Telescope* (JWST). This discovery makes Makemake only the second trans-Neptunian object, after Pluto, where the presence of gas has been confirmed. The gas was identified as methane.

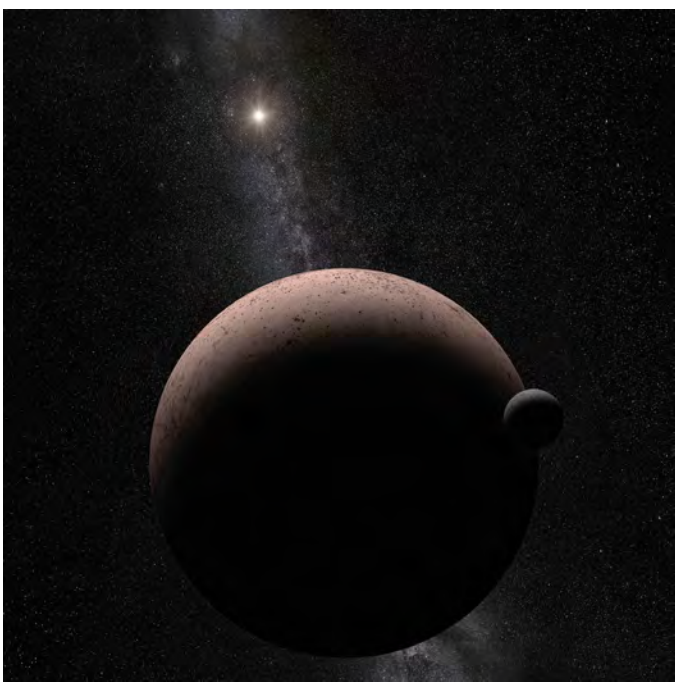


Figure 1 — An artist's concept showing the distant dwarf planet Makemake and its moon, nicknamed MK 2. Credit: NASA, ESA, and A. Parker (Southwest Research Institute)

"Makemake is one of the largest and brightest icy worlds beyond Neptune, and its surface is dominated by frozen methane," said SwRI's Dr. Silvia Protopapa, lead author of the discovery team. "The Webb telescope has now revealed that methane is also present in the gas phase above the surface, a finding that makes Makemake even more fascinating. It shows that Makemake is not an inactive remnant of the outer Solar System, but a dynamic body where methane ice is still evolving."

The observed methane spectral emission is interpreted as solar-excited fluorescence, which is the re-emission of sunlight absorbed by methane molecules. According to Protopapa and her 17 co-authors, this could indicate either a tenuous atmosphere in equilibrium with surface ices—similar to Pluto—or more transient activity, such as cometary-like sublimation or cryovolcanic plumes. Both scenarios are physically plausible and consistent with the current data, given the level of noise and limited spectral resolution of the measurements.

In 2024, observations of Makemake by a suite of satellites revealed a puzzling excess of infrared radiation consistent with a surface temperature near 150 K, much higher than what solid surfaces at Makemake's heliocentric distance could reach by solar irradiation. The study authors (C. Kiss et al. 2024) proposed two explanations: "a continuously visible, currently active region, powered by subsurface upwelling and possibly cryovolcanic activity, covering <1 percent of Makemake's surface, or an as yet undetected ring containing very small carbonaceous dust grains, which have not been seen before in trans-Neptunian or Centaur rings."

"While the temptation to link Makemake's various spectral and thermal anomalies is strong, establishing the mechanism driving the volatile activity remains a necessary step toward interpreting these observations within a unified framework," said Dr. Ian Wong, staff scientist at the Space Telescope Science Institute and co-author of the paper. "Future Webb observations at higher spectral resolution will help determine whether the methane arises from a thin bound atmosphere or from plume-like outgassing."

"This discovery raises the possibility that Makemake has a very tenuous atmosphere sustained by methane sublimation," said Dr. Emmanuel Lellouch of the Paris Observatory, another co-author of the study. "Our best models point to a gas temperature around 40 Kelvin (–233 degrees Celsius) and a surface pressure of only about 10 picobars—that is, 100 billion times below Earth's atmospheric pressure, and a million times more tenuous than Pluto's. If this scenario is confirmed, Makemake would join the small handful of outer Solar System bodies where surface–atmosphere exchanges are still active today."

"Another possibility is that the methane is being released in plume-like outbursts," added Protopapa. "In this scenario, our models suggest that methane could be released at a rate of a few hundred kilograms per second, comparable to the vigorous water plumes on Saturn's moon Enceladus and far greater than the faint vapor seen at Ceres."

The team's research showcases the link between Webb observations and detailed spectral modelling, offering new insights into the behaviour of volatile-rich surfaces across the trans-Neptunian region.

Composed in part with material provided by the Southwest Research Institute.

Where is the silicon?

Why has silicon, one of the most common elements in the Universe, gone largely undetected in the atmospheres of Jupiter, Saturn, and similar gas planets orbiting other stars? A new study using observations from NASA's *James Webb Space Telescope* sheds light on this question by focusing on a peculiar object that astronomers discovered by chance in 2020 and called "The Accident," and more extravagantly known as WISEA J153429.75-104303.3 (W1534).

The Accident is a ball of gas that's not quite a planet and not quite a star. Even among its already hard-to-classify peers, The Accident has a perplexing mix of physical features, some of which have been previously seen only in young brown dwarfs and others seen only in ancient ones. It is classified as a Type Y brown dwarf, insinuating a surface temperature below 500 K and a mass of 19–30 times that of Jupiter.

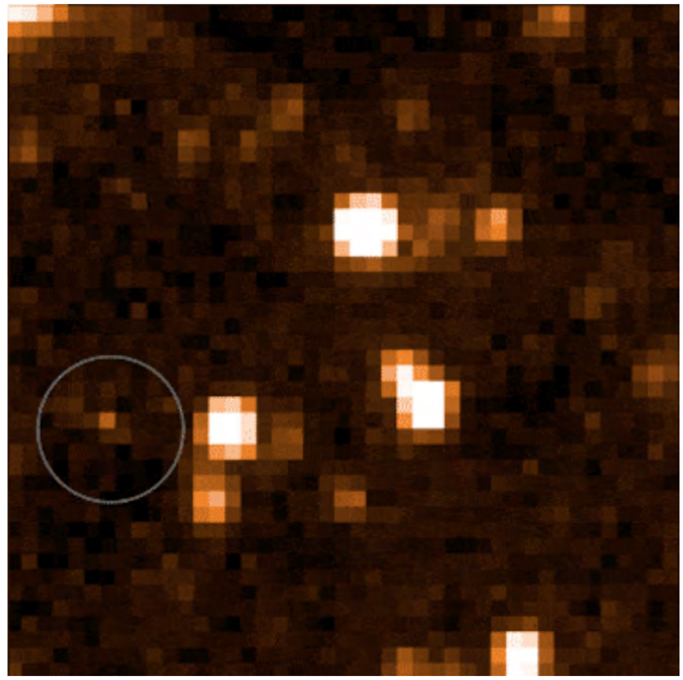


Figure 2 — The brown dwarf nicknamed "The Accident" imaged by NASA's now-retired NEOWISE (Near-Earth Object Wide-Field Infrared Survey Explorer)*, launched in 2009 with the moniker WISE. Credit: NASA/JPL-Caltech/Dan Caselden*

Because of those features, it slipped past typical detection methods before being discovered five years ago by citizen scientist Dan Caselden, participating in Backyard Worlds: Planet 9. The program lets people around the globe search for new discoveries in data from NASA's now-retired NEOWISE (*Near-Earth Object Wide-field Infrared Survey Explorer*).

The Accident is so faint and odd that researchers needed NASA's Webb Telescope to study its atmosphere. Among several surprises, they found evidence of a molecule they couldn't initially identify. It turned out to be a simple silicon molecule called silane (SiH_4).

Researchers have long expected—but been unable—to find silane not only in our Solar System's gas giants, but also in the thousands of atmospheres belonging to brown dwarfs and to the gas giants orbiting other stars. The Accident is the first such object where this molecule has been identified.

Scientists are fairly confident that silicon exists in Jupiter and Saturn's atmospheres but that it is hidden. Bound to oxygen, silicon forms oxides such as quartz that can seed clouds on hot gas giants, somewhat resembling the contents of dust storms on Earth. On cooler gas giants like Jupiter and Saturn, these types of clouds would sink far beneath lighter layers of water vapour and ammonia clouds, until any silicon-containing molecules are deep in the atmosphere, invisible even to the spacecraft that have studied those two planets up close.

Some researchers have also posited that lighter molecules of silicon, like silane, should be found higher up in these atmospheric layers, left behind like traces of flour on a baker's table. That such molecules haven't appeared anywhere except in a single, peculiar brown dwarf suggests something about the chemistry occurring in these environments.

"Sometimes it's the extreme objects that help us understand what's happening in the average ones," said Jacqueline Faherty, a researcher at the American Museum of Natural History in New York City, and lead author on the study.

There are currently 29 known cold, brown dwarfs within 65 ly of the Sun—sources with measured distances and an estimated effective temperature between that of Jupiter (170 K) and approximately 500 K. These sources are almost all solitary, so can act as test beds to study the atmospheres of giant planets beyond our Solar System. These brown dwarfs lack the mass that kickstarts nuclear fusion in the cores of stars, which would cause them to shine in more visible wavelengths.

Located about 50 light-years from Earth, The Accident likely formed 10 billion to 12 billion years ago, making it one of the oldest brown dwarfs ever discovered. The Universe is about 14 billion years old, and at the time that The Accident developed, the cosmos contained mostly hydrogen and helium, with trace amounts of other elements, including silicon. Over eons, elements like carbon, nitrogen, and oxygen forged in the cores of stars, so planets and stars that formed more recently possess more of those elements.

Webb's observations of The Accident confirm that silane can form in brown dwarf and planetary atmospheres. The fact that silane seems to be missing in other brown dwarfs and gas giant planets suggests that when oxygen is available, it bonds with silicon at such a high rate and so easily, virtually no silicon is left over to bond with hydrogen and form silane.

So why is silane in The Accident? The study authors surmise it is because far less oxygen was present in the Universe when the ancient brown dwarf formed, resulting in less oxygen in its atmosphere to gobble up all the silicon. The available silicon would have bonded with hydrogen instead, resulting in silane.

"We weren't looking to solve a mystery about Jupiter and Saturn with these observations," said JPL's Peter Eisenhardt, project scientist for the WISE (*Wide-field Infrared Survey Explorer*) mission, which was later repurposed as *NEOWISE*. "A brown dwarf is a ball of gas like a star, but without an internal fusion reactor, it gets cooler and cooler, with an atmosphere like that of gas giant planets. We wanted to see why this brown dwarf is so odd, but we weren't expecting silane. The Universe continues to surprise us."

Brown dwarfs are often easier to study than gas giant exoplanets because the light from a faraway planet is typically drowned out by the star it orbits, while brown dwarfs generally fly solo. And the lessons learned from these objects extend to all kinds of planets, including ones outside our Solar System that might feature potential signs of habitability.

"To be clear, we're not finding life on brown dwarfs," said Faherty. "But at a high level, by studying all of this variety and complexity in planetary atmospheres, we're setting up the scientists who are one day going to have to do this kind of chemical analysis for rocky, potentially Earth-like planets. It might not specifically involve silicon, but they're going to get data that is complicated and confusing and doesn't fit their models, just like we are. They'll have to parse all those complexities if they want to answer those big questions."

Apollo's Moon rocks redate lunar history

When *Apollo 17* astronauts collected a small rock from the Moon more than 50 years ago, they had no way of knowing it would still be challenging scientists' understanding of lunar history today. The fragment, known as sample 76535, has a mineral structure and texture that suggests it was formed deep in the lunar crust, but lacks signs of a violent shock, expected when deep rocks are blasted to the surface. That puzzle has intrigued scientists for decades, but, even so, many believed the rock was blasted to the surface by the massive impact that formed the Moon's largest crater, the South Pole–Aitken Basin.

Sample 76535 was collected in the Taurus-Littrow Valley by Harrison Schmidt during the *Apollo 17* landing; it has been called the most interesting sample returned from the Moon. It is a coarse-grained rock, formed when magma penetrates the pores and spaces in pre-existing rock. Earlier studies showed that it formed at a depth around 47 km and later cooled at a depth of 10–20 km. Because it is an unshocked sample, a paper in 2007 (Garrick-Bethell, Ian; et al.) was able to conclude that the early Moon had a fluid, conducting core.

New research led by Lawrence Livermore National Laboratory (LLNL) planetary scientist Evan Bjonnes offers a simpler explanation, with broad implications, for the movement of 76535 to the lunar surface. By running advanced computer simulations of giant lunar impacts, the team showed that the impact that formed the Serenitatis Basin, a massive impact basin on the Moon's near side, could have lifted the rock to the surface during the later stages of its evolution.

Figure 3 — Troctolite sample 76535 brought back from the Moon by Apollo 17. This sample has a mass of 156 grams and is up to 5 centimetres across. In its NASA description, 76535 is described as "coarse-grained norite with fresh-appearing plagioclase (white to light gray) that has typical striations of albite twinning. Although pyroxenes (medium gray) are fractured along cleavage planes, they do not appear badly crushed." Image: NASA.

The findings suggest that impact occurred about 4.25 billion years ago, roughly 300 million years earlier than previously thought, pushing the timeline of lunar impacts farther back in time. That shift also reshapes how scientists estimate the bombardment history of Earth and other inner planets.

"This rock may be small, but it carries a huge story about the Moon's early history. It's like a time capsule from 4.25 billion years ago," Bjonnes said.

Scientists have long agreed on two key facts about the Apollo sample: its chemistry and texture show it formed deep in the lunar crust, and it lacks the strong shock features that typically accompany a violent trip to the surface. Earlier studies proposed that only an enormous impact, like the one that created the South Pole–Aitken Basin, could excavate rock from such depths. But there was a catch—carrying the rock from that far-side basin to the *Apollo 17* site would likely require an additional impact, all while avoiding shock strong enough to leave tell-tale scars.

Bjonnes and his team found a more direct path. Using computer simulations of large lunar impacts together with models of the Moon's crust, they showed that during the later "collapse" stage of forming a giant crater, material from tens of kilometres down can be drawn upward gently enough to preserve a rock like sample 76535. In those simulations, a Serenitatis-scale impact can move deep material to within a few kilometres of the surface, precisely the kind of process that could place the sample where *Apollo 17* astronauts found it.

"We sought a simpler, local explanation. And the models kept showing the same thing," Bjonnes said. "Big impacts can lift deep rocks to the surface without over-shocking them."

If sample 76535 dates the Serenitatis impact to 4.25 billion years, other major lunar basins may also be older than currently charted. That moves scientists to rethink how quickly the Moon cooled and how frequently large impacts struck the inner Solar System.

Because Earth's earliest surface record has been largely erased by plate tectonics and geology, scientists often calibrate Earth's impact history using the Moon. Re-dating a cornerstone lunar impact therefore recalibrates our picture of early Earth, including how the other inner planets may have evolved, Bjonnes said. "By pushing Serenitatis back in time, we're shifting the entire timeline of when big impacts happened across the Solar System," Bjonnes said. "That has ripple effects for understanding Earth's early environment too."

The findings underscore the enduring value of the Apollo collection and the power of modern tools to extract new meaning from historic materials. "It's amazing that more than half a century later, Apollo samples are still revealing brand-new insights," Bjonnes said. "They continue to provide valuable new clues about the Moon's past."

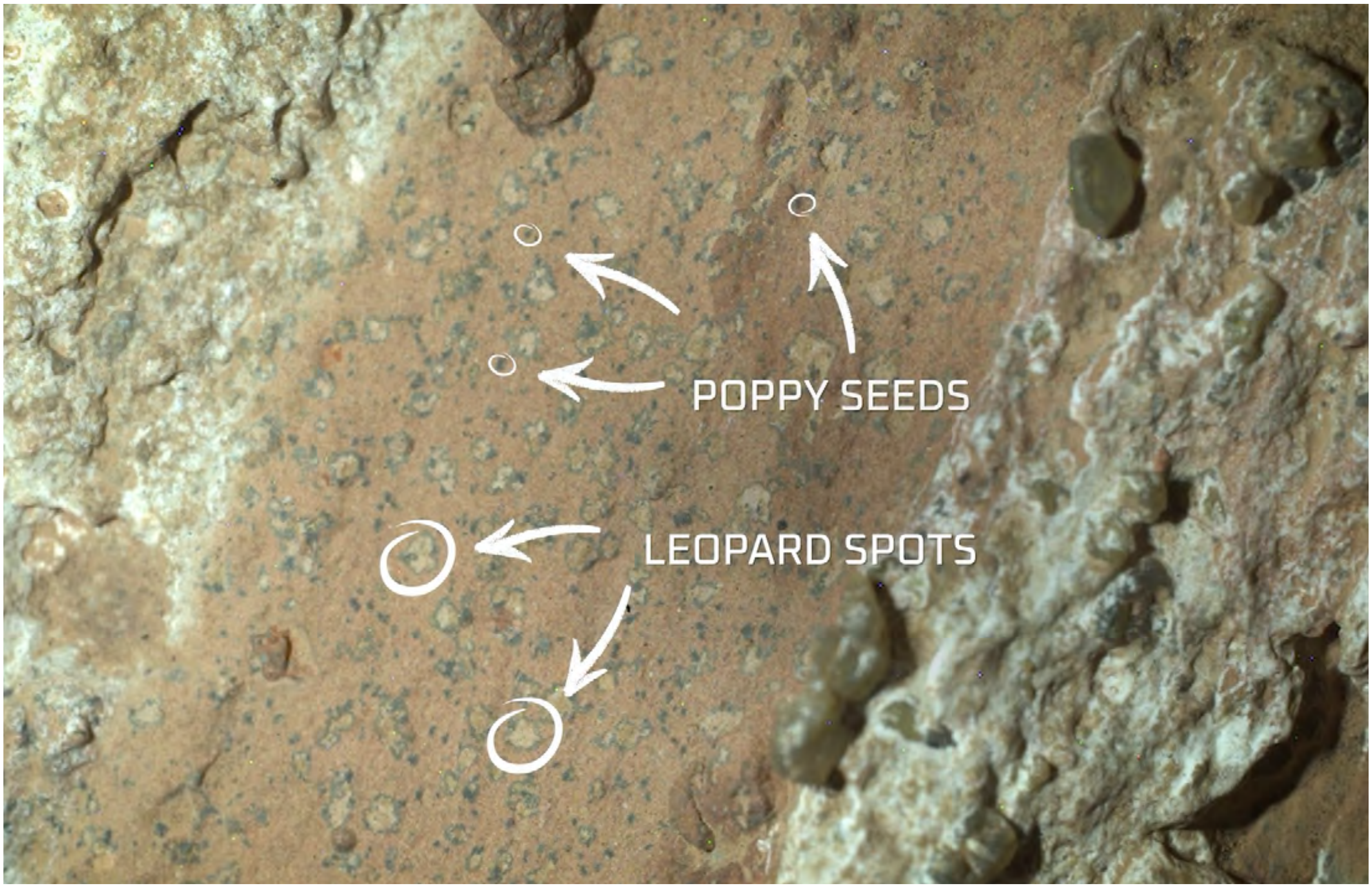


Figure 4 — The 25th Martian sample collected by NASA's Mars Perseverance rover—"Sapphire Canyon"—taken from a vein-filled rock named "Cheyava Falls" and which contains compelling features that help answer whether Mars was home to microscopic life in the distant past. Image: NASA.

The study also offers practical guidance for future missions. Astronauts exploring large lunar basins, Bjonnes said, should keep an eye out for rocks that seem "out-of-place" on the surface. With crater collapse lifting deep rocks upward at many basins, similar samples may be accessible to help fill gaps in the Moon's early story.

Composed with material supplied by the Lawrence Livermore National Laboratory.

Life on Mars, again.

A new study co-authored by Texas A&M University geologist Dr. Michael Tice has revealed potential chemical signatures of ancient Martian microbial life in rocks examined by NASA's Perseverance rover.

The findings, published by a large international team of scientists, focus on a region of Jezero Crater known as the Bright Angel formation. This area, in Mars's Neretva Vallis channel, contains fine-grained mudstones rich in oxidized iron (rust), phosphorus, sulfur and—most notably—organic carbon. Although organic carbon, potentially from non-living sources like meteorites, has been found on Mars before, this combination of materials could have been a rich source of energy for early microorganisms.

"When the rover entered Bright Angel and started measuring the compositions of the local rocks, the team was immediately struck by how different they were from what we had seen before," said Tice, a geobiologist and astrobiologist in the Department of Geology and Geophysics. "They showed evidence of chemical cycling that organisms on Earth can take advantage of to produce energy. And when we looked even closer, we saw things that are easy to explain with early Martian life but very difficult to explain with only geological processes."

Tice went on to explain that "living things do chemistry that generally occurs in nature anyway given enough time and the right circumstances. To the best of our current knowledge, some of the chemistry that shaped these rocks required either high temperatures or life, and we do not see evidence of high temperatures here. However, these findings require experiments and ultimately laboratory study of the sample here on Earth in order to completely rule out explanations without life."

A window into Mars's watery past?

The Bright Angel formation is composed of sedimentary rocks deposited by water, including mudstones (fine-grained sedimentary rocks made of silt and clay) and layered beds that suggest a dynamic environment of flowing rivers and standing water. Using Perseverance's suite of instruments, including the SHERLOC and PIXL spectrometers, scientists detected organic molecules and small arrangements of minerals that appear to have formed through "redox reactions." These are chemical processes involving the transfer of electrons, which, on Earth, are often driven by biological activity.

Among the most striking features are tiny nodules and "reaction fronts"—nicknamed "poppy seeds" and "leopard spots" by the rover team—enriched in ferrous iron phosphate and iron sulfide. These minerals, identified as vivianite and greigite, commonly form in low-temperature, water-rich environments on Earth such as sediments, peat bogs, and around decaying organic matter. Some forms of microbial life on Earth can also produce greigite.

"But there are non-biological ways to make these features that we cannot completely rule out on the basis of the data that we collected," Hurowitz said [Joel Hurowitz is a planetary geochemist at Stony Brook University].

"It's not just the minerals, it's how they are arranged in these structures that suggests that they formed through the redox cycling of iron and sulfur," Tice said. "On Earth, things like these sometimes form in sediments where microbes are eating organic matter and 'breathing' rust and sulfate. Their presence on Mars raises the question: could similar processes have occurred there?"

The SHERLOC instrument detected a Raman spectral feature known as the G-band, a signature of organic carbon, in several Bright Angel rocks at a site called Apollo Temple. "This co-location of organic matter and redox-sensitive minerals is very compelling," said Tice. "It suggests that organic molecules may have played a role in driving the chemical reactions that formed these minerals."

Tice notes it's important to understand that "organic" does not necessarily mean formed by living things.

"It just means having a lot of carbon-carbon bonds," he explained. "There are other processes that can make those besides life. The kind of organic matter detected here could have been produced by abiotic processes or it could have been produced by living things. If produced by living things, it would have to have been degraded by chemical reactions, radiation, or heat to produce the G-band that we observe now."

The study outlines two possible scenarios: one in which these reactions occurred abiotically (driven by geochemical processes) and another in which microbial life may have affected the reactions, as it does on Earth. Strikingly, although some features of the nodules and reaction fronts could be produced by abiotic reactions between organic matter and iron. The known geochemical processes that could have produced the features associated with sulphur usually only work at relatively high temperatures.

"All the ways we have of examining these rocks on the rover suggest that they were never heated in a way that could produce the leopard spots and poppy seeds," said Tice. "If that's the case, we have to seriously consider the possibility that they were made by creatures like bacteria living in Martian-lake mud more than three billion years ago."

While the team emphasizes that the evidence is not definitive proof of past life, the findings meet NASA's criteria for "potential biosignatures"—features that warrant further investigation to determine whether they are biological or abiotic in origin.

Perseverance collected a core sample from the Bright Angel formation, named "Sapphire Canyon," which is now stored in a sealed tube carried by the rover. This sample is among those prioritized for return to Earth in a potential future mission.

"Bringing this sample back to Earth would allow us to analyze it with instruments far more sensitive than anything we can send to Mars," said Tice. "We'll be able to look at the isotopic composition of the organic matter, the fine-scale mineralogy, and even search for microfossils if they exist. We'd also be able to perform more tests to determine the highest temperatures experienced by these rocks, and whether high temperature geochemical processes might still be the best way to explain the potential biosignatures."

Tice, who has long studied ancient microbial ecosystems on Earth, said the parallels between Martian and terrestrial processes are striking—with one important difference. "What's fascinating is how life may have been making use of some of the same processes on Earth and Mars at around the same time," he said.

"We see evidence of microorganisms reacting iron and sulfur with organic matter in the same way in rocks of the same age on Earth, but we'd never be able to see exactly the same features that we see on Mars in the old rocks here. Processing by plate tectonics has heated all our rocks too much to preserve them this way. It's a special and spectacular thing to be able to see them like this on another planet."

"But there are non-biological ways to make these features that we cannot completely rule out on the basis of the data that we collected," Hurowitz said.

Compiled in part with material supplied by Texas A&M University.

Research Article / Article de Recherche

What is the Speed of Earth? — Using H_{II} Galaxies as a Cosmic Speedometer

Simon Brissenden, Sunshine Coast Centre
sbrissenden@hotmail.com

Abstract

Standard cosmology Lambda Cold Dark Matter (ΛCDM) based on the Friedman-Lemaitre-Robertson-Walker (FLRW) metric, interprets cosmological redshift as the expansion of space. Within this framework, Type Ia supernova observations suggest an accelerating Universe driven by dark energy. In contrast, a 2020 JRASC paper showed that a Doppler interpretation of supernova redshifts yields a linear Hubble relation with a slope of ~70 km s^{-1} Mpc^{-1} and no evidence for acceleration or dark energy (Brissenden, 2020). Here, this analysis is extended to a redshift of z ≈ 7.5 using a dataset of 231 H_{II} galaxies. Cepheid variables, supernovae and H_{II} galaxies fall on the same line of proper velocity versus distance, implying that Earth's proper velocity relative to the most distant galaxies exceeds one million km s^{-1}. This result is inconsistent with ΛCDM but consistent with a Doppler framework and Big Bubble cosmology, providing observational evidence that the FLRW metric does not accurately describe the Universe.

Introduction

How fast is Earth moving through space? This is one of the most fundamental questions in astrophysics, but answering it is complicated. Hubble showed that redshift and distance estimates of 24 extra-galactic objects, when analyzed as a Doppler effect, plot on a linear trend of speed versus distance (Hubble, 1929). The slope of this line is now known as the Hubble constant, H_0, and has a value of about ~70 km s^{-1} Mpc^{-1}. The Big Bang Theory, which came from this finding, assumes that at the beginning of the Universe all baryonic matter was concentrated together, and it has spent the past 13.8 billion years moving apart. The observable Universe today is very big, which would imply that over the lifetime of the Universe, matter must have been moving apart very fast.

Peebles, in a review of cosmological anomalies (Peebles, 2022) presents evidence suggesting that Earth is moving through space at about 400–1000 km s^{-1} relative to the cosmic microwave background (CMB). That might seem fast, but in a cosmological context it isn't. The size of the observable Universe is much larger than it would be if matter had been dispersing through space at a mere 1000 km s^{-1} for 13.8 billion years.

Standard cosmology's solution for this dilemma is based on the assumption that space itself is expanding. This is represented mathematically by the FLRW (or FRW) metric, named after Friedmann, Le Maître, Robertson and Walker, who in the 1920–30s modelled an expanding Universe using Einstein's general theory of relativity. The FLRW metric uses comoving coordinates and a scale factor *a(t)* to describe a spherically symmetric expanding Universe. Nearly all cosmological models, including ΛCDM (considered here to be standard cosmology) use the FLRW metric.

The scale factor *a(t)* in the FLRW metric represents the expansion of space. It goes from 0 at the Big Bang to a value of 1 today. With this mathematical representation, galaxies are embedded in expanding space, like raisins in raisin bread dough, in what is called the Hubble flow. Minor deviations from the Hubble flow, such as the movement of the Milky Way and Andromeda galaxies toward each other, are peculiar velocities through space that are not particularly fast in a cosmological context. This is consistent with the modest speed relative to the CMB discussed by Peebles.

For decades, cosmological models constructed using the FLRW metric were consistent with redshift measurements. But in the late 1990s, higher redshift measurements using supernovae showed a deviation between observations and theory that suggested expansion of the Universe is accelerating (Perlmutter et al., 1999; Schmidt, Riess et al., 1999). This was interpreted as evidence for the existence of dark energy.

The concept of dark energy has become an essential component of standard cosmology. It is the Λ of ΛCDM, with CDM being another mysterious component, cold dark matter. ΛCDM also requires the concept of super-luminal inflation shortly after the Big Bang to explain the uniform distribution of matter across the Universe (the *cosmological flatness* and *cosmological horizon* problems). However, despite decades of work, cosmologists are no nearer to understanding the nature of dark energy, dark matter, or inflation, and there have been no experimental results from the laboratory that support the concept of expanding space.

Big Bubble Theory is an alternative cosmological model that postulates that the Universe is a bubble, expanding in four-dimensional space due to radiation pressure, with bubble radius replacing the concept of coordinate time in standard physics (Brissenden, 2019). This model does not use the FLRW metric (Brissenden, 2024) and claims to be able to reproduce supernova redshift measurements without dark energy (Brissenden, 2020) and galactic rotation curves without dark matter or Modified Newtonian Dynamics (MOND) (Brissenden, 2025).

Cepheid variables and supernovae are individual stars and binary stars respectively, which limit how far back in time and space their redshifts can be reliably observed. With current technology, Cepheid variables can be detected in galaxies up to $z \approx 0.01$ (50 Mpc), while supernovae observations are typically robust up to $z \approx 2$.

Baryon acoustic observation (BAO) measurements of the CMB provide another way of measuring the Hubble constant, although there is currently a 5–6 σ mismatch between supernova and BAO estimates of H_0 (Planck Collaboration, 2020; Riess et al., 2022). The BAO methodology is built upon a series of necessarily speculative assumptions about cosmological processes occurring only 380,000 years after the Big Bang. JWST observations indicate that ΛCDM has problems predicting the timing and sequence of more recent events, such as large-scale structure formation, supermassive black holes and the arrival of complex chemistry (Melia, 2023; Wei & Melia, 2025). Big Bubble cosmology has not addressed the observed correlations in the CMB that are used in BAO analysis, but waves or vibrations in the bubble surface are physical mechanisms that may account for these observations.

Recently, a new method of measuring redshift has been developed using H_{II} galaxies (Chávez et al., 2025). H_{II} galaxies are highly luminous compact starburst galaxies. The H_{II} terminology comes from the astronomical classification of hydrogen, where H_I is the un-ionized form of hydrogen, H_{II} is ionized hydrogen and H_2 is molecular hydrogen. Local H_{II} galaxies are observed to have a linear relationship between luminosity L and velocity dispersion σ, and this linear relationship can be used to determine luminosity distance versus redshift at much greater distances than would be possible with individual stars. Using H_{II} galaxies, it is possible to assess cosmological redshift over a range of 0–7.5 with JWST observations.

This paper will apply special relativity Doppler analysis to the dataset of 231 H_{II} galaxies compiled by Chávez et al. It will show that H_{II} galaxies have the same linear trend of celerity versus distance with a slope of 70 km s^{-1} Mpc $^{-1}$ that Type Ia supernovae exhibit in Figure 3 of Brissenden, 2020. The finding that three distinct types of astronomical objects (Cepheid variables, supernovae, and H_{II} galaxies) plot on the same trend of celerity versus distance over a redshift range of 0–7.5 is a remarkable result that is at odds with standard cosmology but consistent with Big Bubble cosmology. It suggests that Earth is moving through space relative to the distant stars with a proper velocity of at least 1 million km s^{-1}, much faster than standard cosmology assumes.

Following convention, in this paper the Greek letter σ is used to represent both velocity dispersion and standard deviation. The correct usage should be clear from the context.

Interpreting Cosmological Redshift as a Doppler Effect

To evaluate cosmological redshift, astronomers measure how emission or absorption lines in the light spectrum of astronomical objects are shifted relative to laboratory benchmarks. If the observed wavelength is bigger, the light is said to be redshifted; if the wavelength is smaller, the light is blueshifted. The equation relating redshift z to wavelength change is:

$$z = \frac{(\lambda_{obsv} - \lambda_{emit})}{\lambda_{emit}} \tag{1}$$

With cosmological models based on the FLRW metric, observations of cosmological redshift are interpreted as being primarily caused by the stretching of space. This approach effectively links redshift to the size of the Universe.

If a spectral line is observed with a wavelength double its lab value, it must have been emitted when the Universe was half as big (in a one-dimensional sense). The link between size of the Universe and age of the Universe is contained in the $a(t)$ function. If this function is more or less linear, then when the Universe was half as big, it was about half as old.

This temporal straitjacket makes it hard to explain some JWST observations. Fully formed large galaxies have been observed by JWST with redshifts of over 14 (Carniani et al, 2024). The FLRW metric puts these galaxies too close to the Big Bang to have had time to evolve, using a pre-JWST cosmological timeline (Melia, 2023).

With a Doppler interpretation, cosmological redshift is due to the relative motion between the light source and detector. If one or both are moving away from the other, the wavelength of light at the detector will appear larger. This process is understood theoretically, has been tested experimentally and conserves energy on a photon-by-photon basis. Redshift due to expansion of space satisfies none of these criteria.

As a Doppler effect, redshift is not necessarily linked to the size of the Universe. If you could invent a mechanism that accelerates the Andromeda Galaxy to a fast enough speed, it too could have a redshift of 14.

Astronomical redshift observations are also affected by gravity. Gravitational redshift is understood theoretically and has been confirmed experimentally but is not significant in this context. On Earth, the gravitational redshift of light from the Sun is equivalent to a Doppler velocity of only 0.6 km s^{-1} (Weinberg, 1972). As we are evaluating light from Cepheid variables, supernovae, and H_{II} galaxies that don't have large gravitational fields, it will be ignored in this analysis.

Ignoring gravitational redshift and ascribing astronomical redshift observations to the relative motion between source and detector, means that special relativity is an appropriate framework for the evaluation of redshift measurements. Special relativity is simpler than general relativity, and as we are not attempting to model the evolution of the Universe, merely analyzing light detected from distant objects, it is adequate for the purpose.

Despite its grounding in standard physics, the Doppler approach adopted in this paper is rejected by nearly all professional astrophysicists and cosmologists. While the Doppler effect was how Hubble processed his observations, it has become axiomatic that this is not how cosmological redshift should be interpreted. When Perlmutter, Schmidt, Riess et al. published their supernova redshift measurements, they did not mention the possibility of a Doppler interpretation of this data.

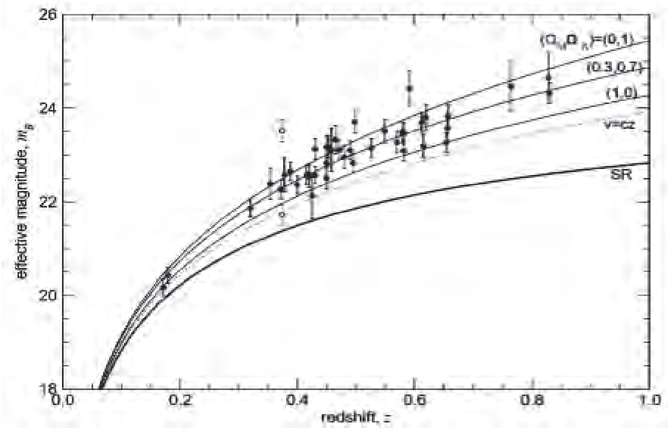


Figure 1 — Davis & Lineweaver's "Expanding Confusion" Figure 5 incorrectly suggests that an SR Doppler interpretation is ruled out at a 23σ confidence level by Type Ia supernova measurements. The (1+z) correction necessary for a special relativity Doppler analysis was omitted from this plot.

Davis & Lineweaver did evaluate a Doppler interpretation of supernova data and concluded "*the interpretation of the cosmological redshift as an SR Doppler effect is ruled out at more than 23σ compared with the ΛCDM concordance model*" (Davis & Lineweaver, 2003). This incorrect conclusion arose from a calculation/plotting error (Brissenden, 2020) but this is not widely appreciated. When the Davis & Lineweaver error was communicated to the Editor-in-Chief of the *Astrophysical Journal*, he gave the assessment that "*the claim that there is a previously unidentified error has been examined and rejected by all the experts in the field*" (Vishniac, 2022). However, after further communication he acknowledged that, despite this expert consensus, the error is indeed present.

The Davis & Lineweaver error was independently spotted by (MacLeod, 2004), (Chodorowski, 2005) and (Farley, 2009), but MacLeod, Farley, and Brissenden are amateurs, and Chodorowski subsequently felt compelled to make the following statement in his paper "*Eppur si muove,*" a title that reflects the quote "and yet it moves" attributed to Galileo:

"Erroneous identification of Special Relativity (SR) with 'real motions', and General Relativity (GR) with the 'expansion of space' has a long history in cosmology. This misconception dates back to Milne (1933) (see Chodorowski 2007 for a discussion). Unfortunately, it has been inherited and is shared by many contemporary authors, including Abramowicz et al. (2007, 2008). They show that Friedman-Le Maître cosmological models are not (except for the empty model) compatible with SR, and use this fact as an argument for the expansion of space. Many other facts and gedanken experiments have been presented as a proof for the expansion of space, but thus far, they have been all abolished (see Chodorowski 2007 for a description and references; Lewis et al. 2008).

Obviously, defenders of the idea of real motions have a hard time, because, as pointed out by Popper, you cannot prove a theory; you can only falsify it. However, there is a long (and good) tradition in science that faith in a given theory is proportional to the number of failed attempts to disprove it. We hope that this will be also the case for the idea of real motions. Personally, however, we have no longer patience to be actively involved in the subject. Let others do it." (Chodorowski, 2008)

For twenty years, the Davis & Lineweaver error has gone largely undetected, despite it being in the foundations of astrophysics. This may reflect confirmation bias toward the concept of expanding space and against real motion through space. At time of writing, the Davis & Lineweaver "*Expanding Confusion*" paper remains a technical reference for Wikipedia's *Expansion of the Universe* page. However, an SR Doppler interpretation cannot be dismissed because of Davis & Lineweaver. With this established, we now turn to new observational tests using H_{II} galaxies.

Doppler Analysis of H_{II} Galaxies

H_{II} galaxies are a class of dwarf starburst galaxies known for their intense star formation and distinctive spectral properties. The luminosity of an H_{II} galaxy comes mainly from rapidly forming stars surrounded by ionized hydrogen. Their spectra resemble H_{II} regions, which are clouds of ionized hydrogen. They exhibit strong Balmer emission lines and have low metallicity, suggesting they are relatively young or have undergone limited chemical evolution.

H_{II} galaxy luminosity depends on the number of new stars being created, which is a function of the galaxy's size and gravitational potential. Bigger galaxies retain more gas, fueling more star formation and increasing luminosity. They also have more kinetic energy, which can be detected as increased velocity dispersion in their spectra. For H_{II} galaxies, this implies a correlation between luminosity L, and velocity dispersion σ, which enables them to be used as standard candles. The velocity dispersion σ, is measured from the temporal broadening of emission lines.

Type Ia supernovae are excellent standard candles since they have the same absolute magnitude. For supernovae, measurements of redshift and apparent magnitude/flux are used to calculate distance and recessional velocity. H_{II} galaxies vary in luminosity, so three measurements (redshift, apparent magnitude/flux, and velocity dispersion) are required to calculate distance and velocity, introducing additional scatter into the H_{II} galaxy datapoints.

Between 1905–1919, when Einstein did his seminal work on relativity, the concepts of galaxies and an expanding Universe were unknown. Special and general relativity were built using inertial frames and rest mass, which implicitly assume that Earth is moving much slower than the speed of light. ΛCDM cosmology, built on a framework of general relativity and the FLRW metric, retains this bias toward considering astronomical bodies to be slowly moving (e.g. Peeble's modest estimate of Earth's velocity relative to the CMB). Time dilation is not significant in this framework, and time measured by clocks on Earth is an acceptable substitute for coordinate time.

With a Doppler interpretation, the peculiar velocity of separation between Earth and more distant galaxies is a significant fraction of the speed of light. At these high speeds, time dilation is significant. Deciding whether it is the distant galaxy or Earth that experiences time dilation is a practical example of the twin paradox. Based on the Copernican Principle that Earth is not the stationary centre of the Universe, and Mach's Principle that inertia and the behaviour of Newton's Bucket are established with respect to the distant stars, this paper assumes that supernovae and H_{II} galaxies play the role of the distant stars, and Earth is moving rapidly through space. This introduces the requirement for appropriate use of the Lorentz γ factor to account for kinematic time dilation at high recession speeds.

To compare Type Ia supernovae and H_{II} galaxies on a common Hubble diagram, observed redshifts are converted into peculiar velocities, then corrected for relativistic effects to obtain proper velocities (celerities). For each object with measured redshift z, the special relativity Doppler formula is used to compute the peculiar recession velocity $v_{pec}(z)$

$$v_{pec}(z) = c\,\frac{(1+z)^2-1}{(1+z)^2+1} \tag{2}$$

where c is the speed of light. The Lorentz factor γ is calculated from v_{pec}

$$\gamma = \frac{1}{\sqrt{1-\left(\frac{v_{pec}}{c}\right)^2}} \tag{3}$$

Proper velocity, or celerity, is obtained by multiplying peculiar velocity by the Lorentz factor:

$$v_{cel} = \gamma\, v_{pec} \tag{4}$$

Distances are derived from published distance moduli (supernovae) or luminosity–velocity dispersion relations (H_{II} galaxies). For supernovae, distance modulus μ, derived from apparent magnitude m, and absolute magnitude M, ($\mu = m - M$) was obtained from the Union2.1 dataset (Suzuki et al., 2011).

Chávez et al. created a dataset of 231 H_{II} galaxies and extragalactic H_{II} regions from several sources (including JWST observations), covering a redshift range of z ≈ 0 to z ≈ 7.5 (Chávez et al., 2025). Their analysis of L–σ data for H_{II} galaxies showed a best-fit linear relationship between the luminosity L of the hydrogen Balmer-β line and velocity dispersion σ, given by the equation:

$$\log(L)H_\beta = 4.989\,\log(\sigma) + 33.285 \tag{5}$$

For H_{II} galaxies, true distance modulus μ_0 is calculated from luminosity, using the best-fit parameters from equation 5 and observed extinction-corrected flux f, (Chávez et al., 2025, eq 3):

$$\mu_0 = 2.5(4.989\,\log(\sigma) + 33.285 - \log(f) - 40.08) \tag{6}$$

Distance modulus μ is converted to luminosity distance D_L in megaparsecs:

$$D_L = 10^{\left(\frac{\mu}{5}+1\right)} / 10^6 \tag{7}$$

To correct for relativistic dimming, retarded distance D_R is calculated from luminosity distance D_L:

$$D_R = \frac{D_L}{1+z} \tag{8}$$

When proper velocity is plotted against retarded distance, Cepheid variables, Type Ia supernovae, and H_{II} galaxies all fall on the same line with slope ~70 km s^{-1} Mpc^{-1} (Figure 2).

There is a stark contrast in the conclusions that can be drawn from Figures 1 and 2. Figure 1, taken from an oft-cited paper that serves as a technical reference for Wikipedia, rules out a Doppler interpretation of cosmological redshift at a high confidence level. Figure 2 suggests that a Doppler interpretation provides a good match to observations for three distinct classes of objects, spanning four orders of magnitude in velocity and distance. All that is required to make this radical change in interpretation is correct use of the (1 + z) factor in equation 8, and introduction of the Lorentz factor γ to convert from peculiar to proper velocity, due to the assumption that Earth is moving rapidly through space.

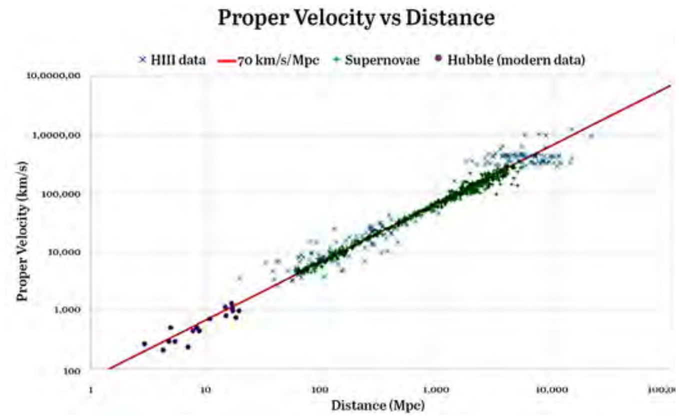


Figure 2 — Proper velocity versus distance has a linear trend of ~70 km s-1 Mpc-1, using redshift measurements of H_{II} galaxies (Chávez et al. 2025), Union2.1 Type Ia supernovae data (Suzuki et al., 2011) and modern values for objects used by Hubble in 1929 (primarily Cepheid variables).

A caveat is appropriate for this analysis. The data points in Figure 2 are derived from astronomical measurements that were made and processed assuming ΛCDM cosmology is correct. The fact that they exhibit straight-line behaviour despite this assumption is encouraging, but it would be preferable if data processing were fully consistent with the Doppler interpretation used here.

R_H=ct Cosmology

Fulvio Melia has proposed an alternative cosmological model to ΛCDM called R_H=ct cosmology (Melia, 2021). This is based on the idea that it is highly improbable that the Hubble radius, R_H, should be equal to *ct* now, just as humans are looking up at the sky, when according to ΛCDM with its phases of inflation, deceleration, and reacceleration, this should only occur once in the lifetime of the Universe. Melia reasons that it is much more likely that if R_H=ct applies now, it will have applied over the lifetime of the Universe, implying a steady expansion rate.

The linear trend of Figure 2 is observational support for Melia's hypothesis that the Universe has had a stable rate of expansion over its lifetime.

Melia is also sympathetic to the idea that space is not expanding (Melia, 2021, p. 189) based on an analysis of coordinate transformations and the general relativity lapse function g_{tt}, which describes how time flows between different reference frames. He argues that ΛCDM prematurely sets g_{tt} =1 (i.e. that proper time and coordinate time are the same), while this can only be true in a Universe without acceleration, which is not the case for ΛCDM. To achieve a stable expansion rate with the FLRW metric, R_H=ct cosmology assumes the Universe has net zero active mass due to a more complex form of dark energy. The age of the Universe with R_H=ct cosmology is estimated at 14.5 billion years (Melia, 2023) which provides more time to accommodate early galaxy formation and other challenging JWST observations than ΛCDM's 13.8 billion years.

However, while Melia is sympathetic to a (predominantly but not uniquely) kinematic interpretation of cosmological redshift, he does not explore the enormous velocities through space this would imply or provide an explanation for the CMB that is consistent with a purely Doppler interpretation of cosmological redshift.

R_H=ct cosmology, based (like ΛCDM) on the FLRW metric, does not predict a linear relationship between distance and proper velocity. Wei & Melia analyzed the Chávez et al. H_{II} dataset and estimated values for H_0 of 81.0 km s^{-1} Mpc^{-1} with R_H=ct cosmology and 82.4 for ΛCDM. When they included an intrinsic dispersion σ_{int} in the $L(H\beta)$ – σ correlation, the best-fitting H_0 values became 119.8 with R_H=ct cosmology and 127.6 for ΛCDM (Wei & Melia, 2025).

While R_H=ct cosmology is intended to replace ΛCDM, it still requires complex dark energy to give a net zero active mass, and dark matter to explain anomalously fast galactic rotation curves, unlike Big Bubble cosmology, which eliminates both.

Big Bubble cosmology, with its four spatial dimensions, coordinate time replaced by radius, and significant kinematic time dilation, describes a larger and older Universe, and can accommodate massive developed galaxies to redshifts of more than 1000. (The CMB is Doppler redshifted light from the far side of the cosmic bubble with this model.) Although Big Bubble cosmology was first described in 2019, before JWST launched, there are currently no JWST observations that are manifestly inconsistent with a Big Bubble cosmological model.

Conclusions

The combined Hubble diagram of Cepheids, Type Ia supernovae, and H_{II} galaxies in Figure 2 reveals a strikingly simple result: three distinct classes of objects, spanning four orders of magnitude in velocity and distance, all lie on a single straight line of proper velocity versus distance with slope ~70 km s^{-1} Mpc^{-1}. It seems a plausible hypothesis that this relation is physical rather than coincidental.

It is possible to match redshift measurements from Cepheid variables, supernovae, and H_{II} galaxies with ΛCDM cosmology, but not as elegantly as a Doppler interpretation. A match with ΛCDM requires the following assumptions beyond standard laboratory physics:

1. A Hubble constant $H_0 \approx 70$ km s^{-1} Mpc^{-1} to match observations.
2. Space itself is assumed to be expanding.
3. Dark energy exists and causes expansion of the Universe to accelerate.

4. The proportion of dark energy $\Omega_\Lambda \approx 0.7$ to match observations.
5. Energy is not conserved, either at a cosmic or photon-by-photon level.

A Doppler interpretation requires the following assumption beyond standard laboratory physics:

1. A Hubble constant $H_0 \approx 70$ km s^{-1} Mpc^{-1} to match observations.

Occam's razor would seem to favour a Doppler interpretation.

ΛCDM assumes that Earth has a peculiar velocity of less than 1000 km s^{-1} relative to the CMB. Peculiar velocity and proper velocity are nearly the same at 1000 km s^{-1}, and if Earth is moving at such a slow speed relative to the CMB, which has a redshift of more than a thousand, how can it be moving at high speed relative to H_{II} galaxies with redshifts of ≤7.5? The straight-line relationship exhibited by Figure 2 makes no sense in a ΛCDM cosmological framework, but it seems to be significant for the Universe.

Before Galileo, consensus held that the Earth is stationary. The Copernican revolution replaced that view with an Earth in motion around the Sun. Today, the scientific consensus is that Earth is embedded in expanding space. And yet it moves.

Acknowledgements

I am grateful to Dr Ricardo Chávez Murillo of the Institute of Radio Astronomy and Astrophysics, National Autonomous University of Mexico, for supplying the dataset of 231 H_{II} galaxies used in this analysis. Microsoft Copilot was used to provide the modern data for the Hubble Cepheid variables and review the text for errors and omissions. ✶

References

Brissenden, S.J. (2019) "Big Bubble Theory", www.researchers.one/article/2019-09-21

Brissenden, S.J. (2020) "Matching Supernova Redshifts with Special Relativity and no Dark Energy," JRASC, 67–70, April, 114, 2 [801]

Brissenden, S.J. (2024) "Cosmological Redshift without Expanding Space," JRASC, 57–63, April, 118, 2 [825]

Brissenden, S.J. (2025). "Matching Galactic Rotation Curves without Dark Matter or MOND," JRASC, 18–23, February, 119, 1 [830]

Carniani, S., Hainline, K., D'Eugenio, F., Eisenstein, D.J., Jakobsen, P., Witstok, J. et al. (2024, May 28). "Spectroscopic confirmation of two luminous galaxies at a redshift of 14." *Nature 633* (8029): 318–322. arXiv:2405.18485. Bibcode:2024Natur.633..318C. doi:10.1038/s41586-024-07860-9. PMC 11390484. PMID 39074505.

Chávez, R., Terlevich, R., Terlevich, E., González-Morán, A.L., Fernández-Arenas, D., Bresolin, F., Plionis, M., Basilakos, S., Amorín, R,. Llerena, M. (2025) "Mapping the Hubble Flow from z~0 to z~7.5 with H_{II} Galaxies" MNRAS, 538, 1264

Chodorowski, M.J. (2005, September 13). "Cosmology Under Milne's Shadow". https://arxiv.org/pdf/astro-ph/0503690.pdf

Chodorowski, M.J. (2008, December 20) "Eppur si muove". https://arxiv.org/pdf/0812.3972

Davis, T.M. & Lineweaver, C. (2003) "Expanding Confusion: common misconceptions of cosmological horizons and the superluminal expansion of the Universe." arXiv.org:astro-ph/0310808v2.

Farley, F.J. (2009, March 1) "Supernovae Redshifts fitted by Special Relativity, no Dark Energy." https://arxiv.org/pdf/0901.3854v2.pdf

Hubble, E. (1929) "A relation between distance and radial velocity among extra-galactic nebulae", PNAS 15 (3) 168-173.

MacLeod A. (2004). Redshift and Energy Conservation. arXiv.org/pdf/physics/0407077.

Melia, F. (2021) "The Cosmic Spacetime", CRC Press, ISBN 13: 978-0-367-53241-3, DOI: 10.1201/9781003081029

Melia, F. (2023). The Cosmic Timeline Implied by the JWST High-redshift Galaxies. MNRAS Letters, 521, L85.

Peebles, P.J.E. (2022). "Anomalies in Physical Cosmology". arXiv:2208.05018v1 [astro-ph.CO]

Perlmutter, S., Aldering, G., Goldhaber, G., Knop, R., Nugent, P., Castro, P., . . . Nunes, N. (1999). "Measurements of Ω and Λ from 42 High-Redshift Supernovae". ApJ, 517, 565.

Planck Collaboration, Aghanim, N., Akrami, Y., Ashdown, M. et al. (2020) "Planck 2018 results. VI. Cosmological parameters". A&A, 641, A6. https:/doi.org/10.1051/0004-6361/201833910

Riess, A.G., Filippenko, A.V., Challis, P., Clocchiatti, A., Diercks, A., & Garnavach, P.M. (1999). "Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant." *Astronomical Journal, 116*, 1009-1038.

Riess, A.G., Yuan, W., Macri, L.M. et al. (2022) "A Comprehensive Measurement of the Local Value of the Hubble Constant with 1 kms^{-1}Mpc^{-1} Uncertainty from the Hubble Space telescope and the SHOES Team". *ApJ Letters, 934*, L7, https://doi.org/10.3847/2041-8213/ac5c5b

Suzuki, N. et al. (2011, May 17) "The Hubble Space Telescope Cluster Supernova Survey: V. Improving the Dark Energy Constraints Above z>1 and Building an Early-Type-Hosted Supernova Sample," arXiv:1105.3470v1[astro-ph.CO].

Vishniac, E.T. (2022, May 23). Personal communication

Wei, J.J. & Melia, F. (2025, June 5) "Model selection using the Hii galaxy Hubble diagram." arXiv:2506.04819 [astro-ph.CO]

Weinberg, S. (1972). "Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity." John Wiley & Sons Inc.

Mary Lea Heger and the Century-old DIBs Mystery That Still Puzzles Astronomers

by Tina A. Harriott,[1,2] Cercis Morera-Boado,[3] Halis Seuret,[4] Lou Massa,[5] Chérif F. Matta[1,6-8]

1 *Department of Chemistry and Physics, Mount Saint Vincent University, Halifax, Nova Scotia, B3M2J6 Canada.*

2 *Department of Mathematics and Statistics, Mount Saint Vincent University, Halifax, Nova Scotia, B3M2J6 Canada.*

3 *IXM-Cátedra Conahcyt-Centro de Investigaciones Químicas, IICBA, Universidad Autónoma del Estado de Morelos, Cuernavaca, 62209, Morelos, Mexico.*

4 *Centro de Investigaciones Químicas, IICBA, Universidad Autónoma del Estado de Morelos, Cuernavaca, 62209, Morelos, México.*

5 *Hunter College & the PhD Program of the Graduate Center, City University of New York, New York, USA.*

6 *Department of Chemistry, Saint Mary's University, Halifax, Nova Scotia, B3H3C3 Canada.*

7 *Département de Chimie, Université Laval, Québec, G1V0A6 Canada.*

8 *Department of Chemistry, Dalhousie University, Halifax, Nova Scotia, B3H4J3 Canada.*

Abstract

In 1919, Mary Lea Heger (Shane) (1897-1983), then a 25-year-old graduate student at the University of California, Berkeley, made a seminal discovery that continues to shape modern astrophysics: the identification of mysterious broad absorption features in stellar spectra, now known as Diffuse Interstellar Bands (DIBs). These bands, arising from the interstellar medium (ISM) rather than the stars themselves, have remained one of astronomy's most enduring enigmas. More than a century later, the molecular carriers responsible for almost 600 catalogued DIBs remain unidentified, with the notable exception of the ionized buckminsterfullerene (C_{60}^{+}), first suggested as the source of two DIBs, nearly a century after Heger's initial observation. This article revisits Heger's overlooked legacy and contextualizes the importance of DIBs within contemporary astrophysics, astrochemistry, and the search for life's molecular precursors. The identification of DIB carriers represents a complex inverse problem constrained by astronomical, spectroscopic, and computational limitations and remains a frontier of interdisciplinary research. Heger's quiet but profound contribution exemplifies how foundational discoveries often emerge from patient, careful observation and why historical recognition must be extended to the women scientists who opened new vistas yet were long excluded from the scientific spotlight.

Keywords: Diffuse Interstellar Bands (DIBs). Mary Lea Heger. Interstellar Medium (ISM). Molecular Astrochemistry. Women in Astronomy

1. Introduction

In 1919, at the age of just 25, Mary Lea Heger, (whose married name was Mary Lea Heger Shane) (1897–1983), made a discovery that would echo through the next century of astrophysics. Working at Lick Observatory (Figure 1) as a graduate student at the University of California, Berkeley, Heger was studying interstellar absorption lines in the spectra of binary stars when she noticed a set of faint and broad absorption features that did not correspond to any known atomic or molecular transitions. These features, later termed Diffuse Interstellar Bands or DIBs, constitute a persistent astronomical mystery to the present day.

Over 100 years later, almost 600 DIBs have now been catalogued, appearing in optical and near-infrared spectra of many stars whose light is observed after passing through gas and dust clouds of the interstellar medium (ISM) [1–5]. Yet despite extensive observational, laboratory, and theoretical work, the identity of most of the molecular carriers responsible for these bands remains unknown. Only one carrier has had strong corroborative evidence in support of its identification: the ionized (cationic) buckminsterfullerene (C_{60}^{+}) [6–9], a

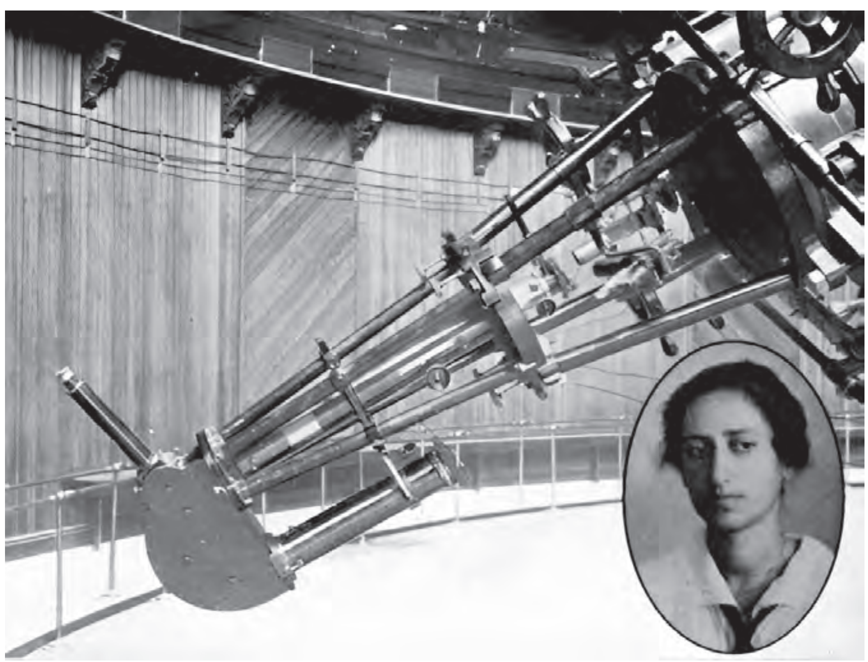


Figure 1 — The Mills spectrograph on the 36-inch refractor at Lick Observatory used by Mary Lea Heger in her discovery of the first DIBs (image adapted from Campbell). Heger's portrait appears in the 1919 Blue & Gold Yearbook (courtesy of the Bancroft Library, University of California, Berkeley). [Source/credit: 1919 Blue & Gold Yearbook, Bancroft Library, University of California at Berkeley.]

soccer-ball shaped carbon molecule discovered in the laboratory in 1985 by Kroto, Smalley, et al. [10,11], and widely accepted as a DIB carrier only in 2015 (and subsequent work).

That such an important open question was first uncovered by a young woman working in the then male-dominated field of early 20th-century astronomy, makes Heger's story all the more remarkable.

Life and achievements of Mary Lea Heger Shane

Mary Lea Heger Shane (née Heger) (Figure 2), born in 1897 in California, was a scientifically gifted student who earned her undergraduate degree in astronomy from the University of California, Berkeley. She gravitated toward astronomy over other sciences because of the welcoming and intellectually stimulating environment of the small department where she was mentored by the likes of W. W. Campbell and Heber D. Curtis. In 1919, she began postgraduate work at Lick Observatory, then one of the premier astronomical institutions in the world. Her assignment was to investigate the spectra of early-type spectroscopic binary stars, particularly focusing on the sodium D-lines. During her research, she studied the spectra of stars such as β Scorpii and δ Orionis. She discovered that, while the stellar spectral lines shifted periodically due to Doppler effects—an expected outcome of the orbital motion of binary stars—the sodium D-lines (Na I doublet at 5890

Figure 2 — Mary Lea Heger Shane (1897–1983) in April 1969 on the terrace of her house. [Source/Copyright [18]]

and 5896 Å) remained stationary in wavelength [12,13]. This suggested, in agreement with Hartmann's 1904 calcium K-line findings for δ Orionis [14], that these absorption features were of interstellar origin. Her confirmation using both β Scorpii and δ Orionis provided compelling evidence that the ISM was responsible for these stationary lines, solidifying the concept of a structured interstellar medium composed of diffuse gas and dust [15–17].

Beyond confirming the interstellar medium as a structured light-absorbing component of the galaxy, Heger made a further groundbreaking observation. In addition to the sharp sodium lines, she identified a set of broader, less defined absorption bands in the same spectra. These lines, notably the ones at 5780 and 5797 Å [5,13], were also stationary across observations and bore none of the characteristics of known atomic transitions. Their broader profile and stability suggest they arise from large, likely molecular, species in the ISM [19–22]. These features are now known as the first reported Diffuse Interstellar Bands (DIBs), one of astronomy's most persistent spectroscopic problems. Heger's observations were published in 1922 in the *Lick Observatory Bulletin* under the titles "The occurrence of stationary D lines of sodium in the spectroscopic binaries, β Scorpii and δ Orionis" and "Further study of the sodium lines in class B stars." In her interview of 1969, she downplayed her achievements, referring to her thesis topic as a "neat, clean-cut, easy problem that was simply irresistible. You know what I mean? It was as though the thesis came and said, 'Take me.'" In reality, her work tackled an inverse ill-posed problem [23,24] of tremendous complexity, one that would remain unsolved for nearly a century. The first widely agreed upon identification of a DIB carrier (C_{60}^+) occurred only in 2015 [6,7,25–27], requiring the convergence of several astronomical observations, laboratory spectroscopy results, and quantum chemical calculations.

In a 1969 oral history interview (a more than five-hour long recording, transcribed into a 240-page document) [18], Heger recalled her work with joy and enthusiasm. She described the exhilaration of conducting night-time fieldwork, operating telescopes in frigid temperatures, manually tracking stellar objects, and guiding exposures for hours at a time. Despite the technical challenges of the era, including manually sensitizing photographic plates and relying on primitive dome controls, she delighted in the observational process, often reciting poetry at the eyepiece to stay alert and pass the time. She emphasized how thrilling it was to see stellar spectra develop and to know she was probing an unknown cosmic medium. The observatory was not just another place of work for her but rather it was a vibrant community. In that regard, she recalled with fondness the camaraderie among assistants, the hospitality extended by senior astronomers, and the stimulating conversations that spanned science, art, and daily life. These interactions, she noted, were vital to her sense of belonging and scientific growth.

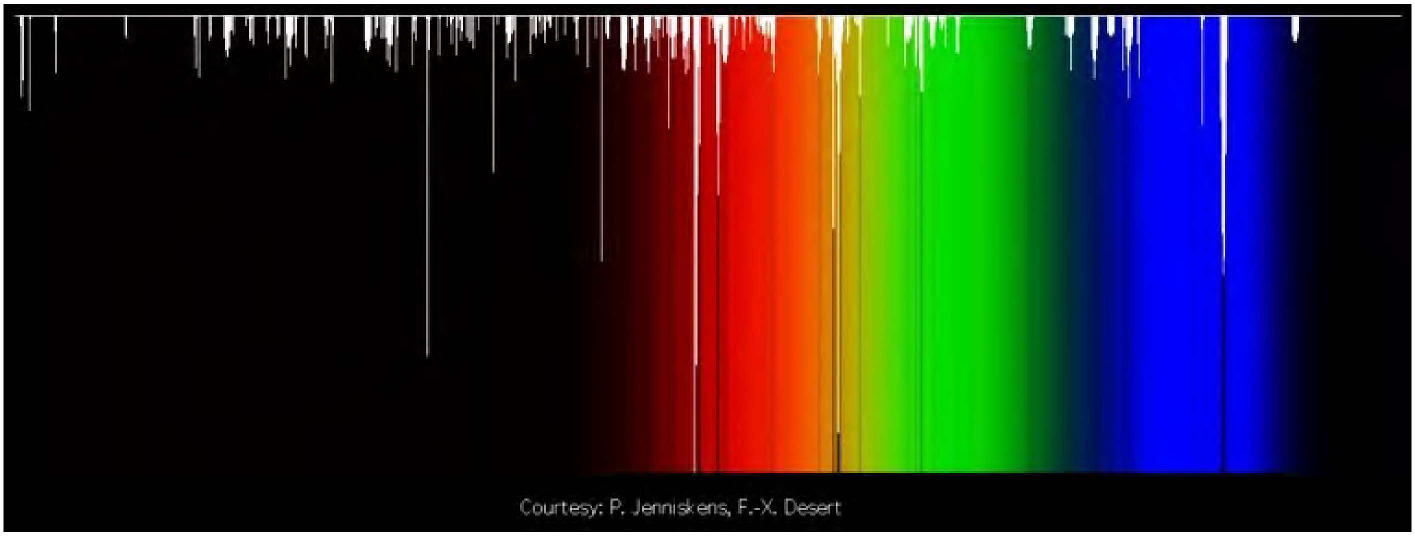


Figure 3 — A representation of the relative equivalent widths (strengths) of observed diffuse interstellar bands. Credit: Wikipedia

Though Heger did not continue in academic research after marrying fellow astronomer C. Donald Shane in 1920, she remained a vital and highly engaged figure in the astronomical world. She taught mathematics and navigation at UC Berkeley during World Wars I and II, actively contributing to scientific education in times of national need. As her husband assumed leadership roles, including Director of the Lick Observatory from 1945 to 1958, Heger took on extensive administrative and diplomatic responsibilities. She personally managed the logistical preparations for the 1961 meeting of the International Astronomical Union (IAU) at Berkeley, which brought together over 1100 astronomers from across the globe. Her organizational skills and attention to detail earned her accolades from the international astronomy community. At Lick, she ran a *de facto* guest house for visiting scientists, fostering dialogue and forging international connections that transcended scientific publication.

Heger became the observatory's unofficial historian and archivist. She undertook the systematic organization of Lick's extensive documentary history, including handwritten correspondence from the 19th century, scientific notes, and personal letters. She sought out descendants of past astronomers to preserve valuable records and ensure their donation to the archives. In doing so, she preserved the institutional memory of one of the world's historic observatories. Heger lived a rich and impactful life in science, one in which she consistently chose engagement, mentorship, and stewardship over personal ambition. Her story serves as a valuable counterpoint to narratives that portray women in science solely through the lens of marginalization.

What are the DIBs?

The diffuse interstellar bands are broad absorption features seen in the visible and near-infrared spectra of stars whose light passes through diffuse clouds of interstellar gases and dust. Unlike sharp atomic lines, the DIBs are wide (often several angstroms across) and extremely stable in wavelength, suggesting they are caused by large, complex molecules or ions. The same lines are visible at the same respective wavelengths and with the same proportion of their relative extinctions along many sightlines. When such a set of lines are observed at exactly the same wavelengths, and all have the same extinction ratios (the technical term is "equivalent width" (EW) ratios) then the group constitutes a "family" and are generally considered to be potentially associated with one particular molecular carrier.

The stability of DIBs across different environments suggests that their carriers are stable, possibly carbon-based molecules that can survive the harsh conditions of interstellar space such as high ultraviolet radiation flux densities. Over the decades, astronomers and chemists have proposed numerous candidates, including polycyclic aromatic hydrocarbons (PAHs), long carbon chains, fullerenes, and heterocyclic compounds as potential carriers. Yet despite intense effort, including laboratory spectroscopy, quantum chemical modelling, and space-based observations, no definitive candidate has emerged yet, with one exception. That notable exception is C_{60}^{+}. In 2015, a study led by Maier *et al.* successfully matched laboratory spectra of gas-phase C_{60}^{+} with two prominent DIBs near 9632 and 9577 Å, suggesting this molecule might be the first identified carrier [6]. Subsequent work has increased confidence in this identification. That it took nearly a century to potentially identify even one DIB carrier underscores both the complexity of the problem and the brilliance of Heger's early intuition. Figure 3 shows the iconic depiction of DIBs.

Why do DIBs matter?

To the casual observer, the DIBs may seem like a niche curiosity, a quirk in stellar spectra. But the implications of understanding the DIBs are profound.

First, they provide a direct probe of the interstellar medium, the vast expanse of diffuse gas and dust that permeates our galaxy and from which stars and planets form. The nature and distribution of the molecules responsible for DIBs can tell us about the chemistry, density, and radiation environment of the ISM across different galactic regions.

Second, DIBs bridge the worlds of chemistry and astronomy, suggesting a rich organic inventory in space that includes stable, complex molecules. If some of these carriers turn out to be prebiotic or related to molecules found in meteorites or comets, this raises fascinating questions about the cosmic origins of life. The idea that biologically relevant molecules, or their precursors, could be widespread in interstellar clouds strengthens the hypothesis that life's building blocks may have an extraterrestrial origin.

Finally, understanding DIBs is essential for accurate stellar modeling. Because the bands are ubiquitous in stellar spectra, they affect our interpretation of starlight and thus our estimates of stellar distances, compositions, and motions which are all key ingredients in mapping galactic structure.

Why is the DIBs problem such a difficult one to solve?

The difficulty of identifying the molecular carriers of the hundreds of diffuse interstellar bands exemplifies an *ill-defined inverse problem* in astrophysics [23,24]. Unlike a forward problem, where known molecules yield predictable spectra, the DIB challenge begins with observed spectral features and attempts to infer their unknown molecular origins. It is as if we walk from the effect to the cause, just like forensic scientists reconstruct a crime scene. This "inversion" of the flow-chart is fraught with ambiguity: Hundreds of broad absorption bands are known but the candidate molecular space spans thousands of complex species, many of which lack complete or reliable laboratory spectra. The problem is underdetermined and non-unique since multiple molecules can yield similar spectral profiles especially under varying interstellar conditions such as low temperature, low density, and high radiation. In fact, estimates place the number of possible compounds that we can form from the known elements of the periodic table is on the order of of 10^{60}, hence certainly there will be scores of compounds with nearly identical spectra. Further, it is almost certain that the spectral lines observed and used for identification of a source are only a fraction of the complete spectrum of any given molecule. Further complicating the matter, environmental factors can shift or broaden the features. Additionally, most available spectra are recorded under terrestrial conditions that poorly mimic conditions found in interstellar space. Observational limitations such as noise, blending, Doppler shifts associated with Brownian motion and with ISM winds, among other things, add other layers of uncertainty. Consequently, even with high-quality astronomical data, deducing the correct carriers remains elusive unless extremely tightly constrained by laboratory spectroscopy, quantum chemical calculations, and astrophysical modelling. The identification of C_{60}^+ in 2015 as the first likely confirmed DIB carrier took nearly a century, which illustrates both the complexity of the problem, and the painstaking interdisciplinary effort required to achieve even just one probable identification.

Heger's deserved recognition

Despite the importance of her contribution, Mary Lea Heger's name is scarcely mentioned in general astronomy textbooks, and she rarely appears on lists of pioneering women astronomers (see her conspicuous absence in a recent popular article on women astronomers [28]). This is particularly surprising given the DIBs' central role in modern astrophysics.

Like many women of her era, Heger was not afforded the same institutional support or visibility as her male peers. After marrying C. Donald Shane, who would go on to become director of Kitt Peak National Observatory, Heger supported his career while stepping away from active research. The inclusion of her story in the centre of the narrative of astronomical discovery is overdue.

Conclusion

Mary Lea Heger's discovery of the diffuse interstellar bands marked the beginning of a long-standing mystery in astrophysics. Her early insight drawn from spectroscopic observation opened a new domain of inquiry into the molecular complexity of the interstellar medium that continues to challenge astronomers, chemists, and physicists more than a century later. As efforts to identify the molecular carriers of the DIBs continue through advanced spectroscopy, quantum chemical modelling, and space-based observatories, Heger's legacy endures as a trailblazer and as a reminder of overlooked figures who have quietly shaped the trajectory of science (see Scerri's book spotlighting the "little people," that is, relatively unknown chemists and physicists, whose work propelled major discoveries [29]). Recognizing Heger's contributions enriches both the history and future of astronomy.

Acknowledgments

Natural Sciences and Engineering Research Council of Canada (NSERC), the Canada Foundation for Innovation (CFI), and Mount Saint Vincent University, are acknowledged for their financial support. ✶

References

(1) Herbig, G.H. Diffuse interstellar bands. 4 Region 4400-6850 Å. *ApJ 196*, 129–160 (1975).

(2) Herbig, G.H. The diffuse interstellar bands. *Ann. Rev. Astron. Astrophys.* 33, 19-73 (1995).

(3) Fan, H, Hobbs, L.M., Dahlstrom, J.A., Welty, D.E., York, D.G., Rachford, B., Snow, T.P., Sonnentrucker, P., Baskes, N., Zhao, G., The Apache Point Observatory Catalog of Optical Diffuse Interstellar Bands. *ApJ 878*, Article # 151 (2019).

(4) Smith, F., Majaess, D., Harriott, T.A., Massa, L., Matta, C.F., Establishing new diffuse interstellar band correlations to identify common carriers. *MNRAS 507*, 5236–5245 (2021).

(5) Seuret, H., Sullivan, A., Morera-Boado, C., Harriott, T.A., Majaess, D., Massa, L., Matta, C.F., Vetting Molecular Candidates Linked to the First Diffuse Interstellar Bands Discovered (5780 and 5797 Å). *Phys. Chem. Chem. Phys. (PCCP)* 27, 12666–12674 (2025).

(6) Campbell, E.K., Holz, M., Gerlich, D., Maier, J.P., Laboratory confirmation of C_{60}^+ as the carrier of two diffuse interstellar bands. *Nature 523*, 322–323 (2015).

(7) Campbell, E.K., Holz, M., Maier, J.P., Gerlich, D., Walker, G.A.H., Bohlender, D., Gas phase absorption spectroscopy of C_{60}^+ and C_{70}^+ in a cryogenic ion trap: Comparison with astronomical measurements. *Astrophys J.* 822, 17 (7pp) (2016).

(8) Omont, A., Interstellar fullerene compounds and diffuse interstellar bands. *Astron. Astrophys. 590*, Article # A52 (2016).

(9) Majaess, D., Harriott, T.A., Seuret, H., Morera-Boado, C., Massa, L., Matta, C.F., Strengthening the Link Between Fullerenes and a Subset of Diffuse Interstellar Bands. *MNRAS 538*, 2392–2395 (2025).

(10) Kroto, H.W., Heath, J.R., O'Brien, S.C., Curl, R.F., Smalley, R.E., C_{60}: Buckminsterfullerene. *Nature 318*, 162–163 (1985).

(11) Kroto, H.W., Chains and grains in interstellar space. *In: Polycyclic Aromatic Hydrocarbons and Astrophysics, A. Léger et al. (eds.), D. Reidel Publishing Company, Dordrecht* 197-206 (1987).

(12) Heger, M.L., The occurrence of stationary D lines of sodium in the spectroscopic binaries, ß Scorpii and d Orionis. *Lick Obs. Bull. 10*, 59–63 (1919).

(13) Heger, M.L., Further study of the sodium lines in class B stars. The spectra of certain class B stars in the regions 5630A-6680A and 3280A-3380A. Note on the spectrum of [gamma) Cassiopeiae between 5860A and 6600A. *Lick Obs. Bull.* 10, 146–147 (1922).

(14) Hartmann, J., Investigations on the spectrum and orbit of delta Orionis. *ApJ 19*, 268–286 (1904).

(15) Tielens, A.G.G.M., The molecular universe. *Rev. Mod. Phys. 85*, 1021–1081 (2013).

(16) Snow, T.P. and McCall, B.J., Diffuse Atomic and Molecular Clouds. *Ann. Rev. Astron. Astrophys. 44*, 367–414 (2006).

(17) Snow, T.P. and Destree, J.D., The Diffuse Interstellar Bands in History and in the UV. *EAS (European Astronomical Society) Publications Series Vol. 46: PAHs and the Universe: A Symposium to Celebrate the 25th Anniversary of the PAH Hypothesis (C. Joblin and A.G.G.M. Tielens (eds))* 341–347 (2011).

(18) Shane, M.L. and Calciano, E.S., *Mary Lea Heger Shane: The Lick Observatory (interview audio and transcript with Mary Lea Heger Shane (née Heger), dated 5 August 1969). (https://escholarship.org/uc/item/4q3206g8, accessed 2025 August 2).* The University of California, Santa Cruz, the University Library, Santa Cruz, (1969).

(19) Fortenberry, R.C., A Vision for the Future of Astrochemistry in the Interstellar Medium by 2050. *ACS Phys. Chem. Au* 4, 31–39 (2023).

(20) Dyson, J.E. and Williams, D.A., *The Physics of the Interstellar Medium (Third Edition)*. CRC Press, Taylor & Francis Group, Boca Raton, (2021).

(21) Kwok, S., *Physics and Chemistry of the Interstellar Medium*. University Science Books, Sausalito, California, (2007).

(22) Tennyson, J., *Astronomical Spectroscopy: An Introduction to the Atomic and Molecular Physics of Astronomical Spectra (2nd Ed.)*. World Scientific Publishing, Co. Pte. Ltd., Singapore, (2011).

(23) Groetsch, C.W., *Inverse Problems: Activities for Undergraduates*. The Mathematical Association of America (MAA), Washington, DC, USA, (1999).

(24) Tikhonov, A.N. and Goncharsky, A.V., *Ill-Posed Problems in the Natural Sciences (English Translation)*. Mir Publishers, Moscow, (1987).

(25) Galazutdinov, G.A. and Krelowski, J., Looking for the weak members of the C_{60}^+ family in the interstellar medium. *Acta Astronom. 67*, 159–169 (2017).

(26) Schlarmann, L., Foing, B., Cami, J., and Fan, H., $^{C}60^{+}$ Diffuse Interstellar Band Correlations and Environmental Variations. *Astron. Astrophys. 656*, Article # L17 (2021).

(27) Majaess, D., Harriott, T.A., Morera-Boado, C., Seuret, H., Massa, L., and Matta, C.F., The Critical 9365 Å Diffuse Interstellar Band and C60+ Association. RNAAS 9, Article # 248 (2025).

(28) Hill, S., 10 Women who changed astronomy: Often bucking tradition, these women sought knowledge of the universe and reimagined the way we view the cosmos. *Astronomy 53* (Issue 5 (of 8 May)), (2025).

(29) Scerri, E.A., *Tale of Seven Scientists and a New Philosophy of Science*. Oxford University Press, Oxford, UK, (2016).

Nothing Minor

by Dr. Roy Bishop & Judy Black (Halifax)
(black.judy@gmail.com)

It's nothing minor to have an asteroid named after you.

The International Astronomical Union (IAU) is the official body for naming them and, as you can imagine, there are naming rules; Dave Chapman provided a great explanation at the March 2022 RASC Halifax Centre Members Meeting (www.youtube.com/watch?v=FRnnQrlqMfs).

Many asteroids are named by their discoverer but in the cases where this is not the case, the RASC steps in, specifically Peter Jedicke (London Centre member, RASC Past President) who has taken the lead in this initiative since 2018. In 2023, Peter invited Centres across Canada to submit nominations to him and formatted the application as per the requirements of the IAU's *Small Bodies Nomenclature Working Group (WGSBN*). A group of Canadian nominees submitted in January 2023 was accepted at once instead of a few per cycle.

There are now 686 asteroids with Canadian connections, thanks to the efforts of the RASC, with 15 from the RASC Halifax Centre or from Nova Scotia prior to the existence of our Centre. It is because of this it was felt members should be aware of our astronomy history through the recognition these men and women received and for which they will be remembered in perpetuity.

Judy Black approached Roy Bishop almost 3 years ago about co-authoring a series of documents about these asteroids, to which he agreed. Consequently, they presented a series of six articles in which they collaborated – Judy found the asteroid names, their official citations and histories, and Roy provided the science for each. There were six instalments to the series:

1: Introduction: Names and Orbits

2: Introduction to the Asteroid Belt

3: The Inner Main Belt

4: The Main Belt, Zone I

5: The Main Belt, Zone II

6: The Main Belt, Zone III

While Judy instigated the series, she states categorically that Dr. Roy Bishop is the lead author. She has learned much from this knowledgeable gentleman, and with the series printed in the Centre's newsletter *Nova Notes,* she hopes to share these learnings with her fellow RASC members. Judy and Roy also extend much gratitude to Peter Jedicke (London Centre) who was of great assistance in locating the citations (even during a London Knights hockey game – thanks, Peter!).

Introduction to Names & Orbits

Most asteroids (*aka* minor planets) orbit the Sun in the wide space between the orbits of Mars and Jupiter. They are believed to be remnants of the primordial solar nebula from which the Solar System formed some 4.6 billion years ago.

With apparent visual magnitudes below the usual threshold of unaided human vision, the asteroids were unknown until dedicated telescopic searches were undertaken. On 1801 January 1, Giuseppe Piazzi, at Palermo Observatory in Sicily, discovered Ceres, the largest asteroid. William Herschel proposed the name "asteroid" (Latin for "star like") because in Earth-based telescopes asteroids are too small to show noticeable disks. When closest to Earth, Ceres has an angular diameter of less than one arcsecond. Today the orbits of more than half a million asteroids are known.

Once an asteroid's orbit is determined well enough to locate it in future years, asteroids are numbered sequentially in that order. Once assigned a number, an asteroid can be named. Hence (1) Ceres, (2) Pallas, (3) Juno, (4) Vesta, etc.

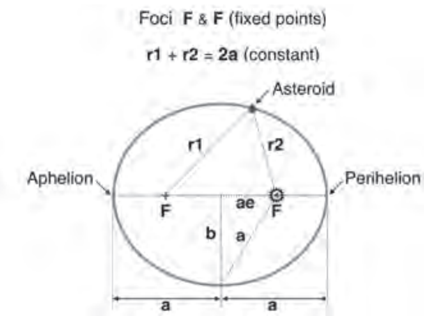
Traditionally, the discoverer of an asteroid suggests a name. Since the founding of the International Astronomical Union in 1919, the IAU has become the world authority for certifying the names of all objects beyond our planet. Yes, you can send money to a commercial firm to name a star, a crater on the Moon, or celestial whatever, but all you will have to show for the money you parted with is a paper certificate that has no formal or official validity.

Ignoring time, space is three-dimensional, yet an asteroid's orbit about the Sun is a planar (two-dimensional) curve. It is planar because the Sun's gravity is isotropic, directed toward the Sun's centre, a so-called central force. In this situation there is nothing to deflect an orbiting body out of its plane. The inclination "i" of an orbit is the angular tilt of the plane of the orbit to the plane of Earth's orbit, the ecliptic.

As Kepler discovered to his delight, orbits around the Sun are ellipses, an elegantly simple curve that closes upon itself, with the Sun at one focus. Using nature's language, mathematics, Newton showed that orbits are ellipses because the Sun's gravity weakens inversely with the square of the distance.

Because of small gravitational effects, or perturbations, from other bodies, no orbit is precisely an ellipse, but to a good approximation over not too long a time span, those perturbations can usually be ignored.

To better appreciate an asteroid (and the subsequent five instalments to be presented), you the reader should know something about orbits. Meet the ellipse:



The two statements at the top of this diagram ***define*** the ellipse. If you have never done the following simple exercise, *DO IT* once in your life so your brain will understand the ellipse: Place a sheet of paper on a cork board (or pine board), secure it with two small nails placed a few centimetres apart somewhere in the middle of the paper. Tie the ends of a piece of string to the nails (one end to one nail, the other end to the other nail, leaving some slack in the string). With the point of a pencil extend the string so it resembles r1 and r2 in the diagram. Then keeping the string taut, carefully move the pencil point across the paper wherever the string allows it to move. The nails ensure that F and F are fixed points, and the string ensures that r1 + r2 is constant . . . Voilà, an ellipse! Play around by altering the spacing of the nails (producing ellipses having the same major axis) or altering the length of the string (producing ellipses having different major axes).

F and F are the foci of an orbit, and the Sun resides at one focus (more about the other focus in the last paragraph). The size of an orbit is specified by "a", its semi-major axis, half of the maximum diameter of the ellipse. "a" determines the orbital period, and the total energy (kinetic energy plus gravitational potential energy) per unit mass of the asteroid in its orbit. "b" is the semi-minor axis, half of the orbit's minimum diameter.

The eccentricity "e" specifies the shape of an ellipse (the "out of centre-ness" of its foci, how much the ellipse deviates from a circle), where "e" is defined as the dimensionless fraction: (distance between the foci) / (major axis). Thus "e" = 0 is a circular orbit for which r1 = r2 = a. Apply Pythagoras' Theorem to the right-angled triangle in the diagram to obtain a formula for e in terms of a and b. (The ellipse in the diagram has an eccentricity of 0.52).

As its eccentricity approaches 1, an ellipse becomes more and more flattened. In the limit e = 1, either b = 0 and the asteroid falls into the Sun, or the asteroid has gained sufficient energy through a favourable encounter with another body to cause its semi-major axis to become infinitely large. In the latter instance the asteroid's path has become parabolic or hyperbolic (depending upon its total energy per unit mass), and the asteroid escapes the Sun's grasp, leaving the Solar System never to return.

An asteroid in an elliptical orbit travelling from aphelion (furthest from the Sun) to perihelion (closest to the Sun), accelerates as it falls deeper into the Sun's gravitational well,

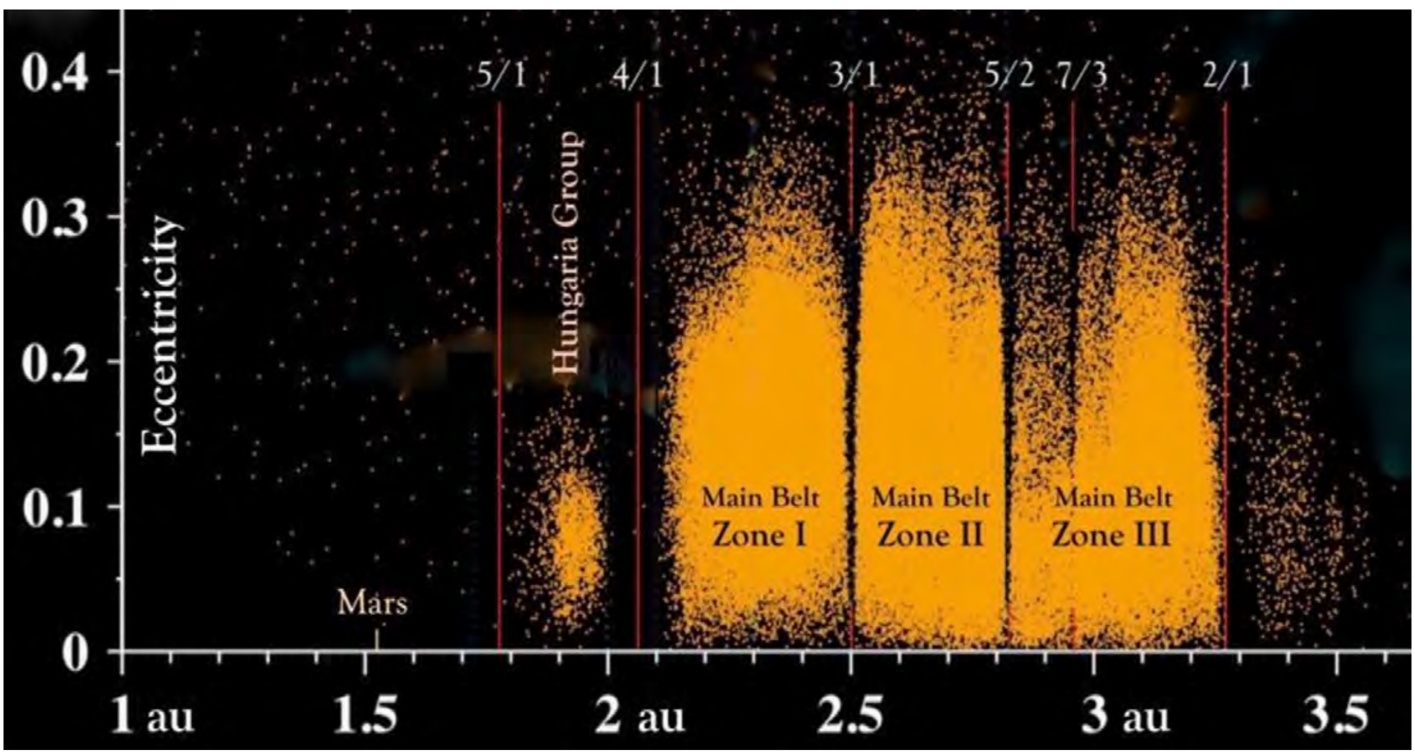


Figure 1 – A plot of the eccentricities versus semi-major axes of a few hundred thousand asteroids between Mars and Jupiter (adapted from a 2007 JPL/Caltech diagram by Alan Chamberlin). Mars is at 1.52 au (eccentricity not plotted), Jupiter at 5.20 au (off scale to the right). Four Kirkwood Gaps are obvious: at 2.06 au (4/1 resonance with Jupiter), 2.50 (3/1), 2.82 (5/2), and 2.96 (7/3). Two unlabelled gaps are less obvious: in Zone II 2.70 (8/3) and in Zone III at 3.03 (9/4). The main clusters are bounded on the left at 1.78 au (5/1) and on the right at 3.28 au (2/1). By Kepler's third law, the distance of a Kirkwood Gap from the Sun equals Jupiter's semi-major axis divided by the resonance ratio to the* $2/3^{rds}$ *power.*

**https://ssd.jpl.nasa.gov/images/dist_ae_ast.ps* moving fastest as it passes perihelion, and then slowest as it passes aphelion again. As Kepler discovered and Newton proved, a line between the asteroid and the Sun (r2 in the diagram) sweeps out equal areas in equal times.

The other (empty) focus has a rarely mentioned, interesting property; an observer located there would see the asteroid moving with constant angular speed against the background stars, neither speeding up nor slowing down as it moves around its orbit! (Imagine a clock with an elliptical dial and the clock hands pivoting at the empty focus.) As viewed from the empty focus the asteroid's transverse linear speed varies directly with its distance. Thus, in the diagram, an asteroid spends half of its time in the shorter segment of its orbit to the left of the empty focus.

Introduction to the Asteroid Belt

The region between the orbits of Mars and Jupiter (semi-major axes of 1.52 and 5.20 au, respectively) is huge, nearly four times wider than Earth's distance from the Sun. With a mass 3000 times that of Mars, it is no wonder that Jupiter, the first planet to form in the solar nebula, has prevented the debris in that region from coalescing into a sizeable planet. Jupiter's presence likely also is why Mars was able to accumulate only one-tenth the mass of Earth, ending up today as a small planet without plate tectonics, a protective magnetic field, or a substantial atmosphere.

The largest asteroid, (1) Ceres, also classed as a dwarf planet, is 940 km in diameter (27% the diameter and 1.3% the mass of Earth's Moon) and contains approximately 1/3rd of the mass of all the asteroids. There are perhaps a million asteroids with diameters greater than 1 kilometre, and many more that are smaller.

The American astronomer Daniel Kirkwood (1814-1895) was the first to notice that the distribution of asteroids as a function of their mean distances (semi-major axes) from the Sun is not random. "Kirkwood gaps" occur, corresponding to resonant gravitational perturbations by Jupiter, similar to the influence of Mimas producing Cassini's division in Saturn's rings (a 2/1 resonance). Where the orbital periods of an asteroid and Jupiter are in the ratio of small integers such as 4/1, 3/1, or 5/2, there are gaps containing few if any asteroids.

Although obscured by the sheer number of asteroids in this two-dimensional diagram, in a three-dimensional, high-resolution diagram with orbital inclination on the third axis, several concentrations of asteroids appear highlighting orbits having almost the same semi-major axis, eccentricity, and inclination to the ecliptic (i.e., very similar orbits). Those concentrations are "Hirayama families", first noted by the Japanese astronomer Kiyotsugu Hirayama (1874 – 1943). It is customary to name each family after the largest asteroid in the group.

Families of asteroids, of which about two dozen are known, apparently arise when a larger asteroid suffers a catastrophic collision in the not too distant past. Using the orbital elements for a particularly tight Hirayama family and taking orbital perturbations by the four gas giant planets (the largest orbit-changing effects during several million years) into account, a team of astronomers ran an orbital simulation *backward* in time. They found that the orbits of 13 asteroids were essentially identical 5.8 million years ago, linking the family to the breakup of a single asteroid at that time in the past.

In recent decades, advances in Solar System dynamics enabled by the electronic computer have revealed that although Jupiter has the major influence on the asteroid belt, gravitational interactions with all the other planets perturb the asteroids. In the long term, these complex interactions can produce chaotic orbits, sending some asteroids inward on Earth-crossing orbits (the main source of random meteors striking Earth), or even deflecting some asteroids out of the still-evolving Solar System.

The Inner Main Belt

In the first two instalments, we gave brief introductions to the millions of asteroids residing between Mars and Jupiter. With that background, our readers will now better understand and appreciate the circumstances to be presented concerning the fifteen Nova Scotia Asteroids (NSAs).

Descriptions of the NSAs now follow, arranged in order of their increasing distances from the Sun, and grouped together in four remaining articles according to the four, well-populated sections of the asteroid belt where they reside: the Inner Main Belt, and the Main Belt Zone I, Zone II, and Zone III.

Two NSAs reside in the Inner Main Belt, a region occupied by the *Hungaria Group*, named after the largest asteroid (diameter about 10 km) in the group: 434 Hungaria. The collisional *Hungaria family* dominates the *Hungaria Group*. **(27810) Daveturner** and **(6901) Roybishop** are members of that family, as revealed by similar orbital data:

	a	e	i	T	diameter
(434) Hungaria	1.945 au	0.0736	22.51°	2.712 y	9 km
(27810) Daveturner	1.935 au	0.0540	18.40°	2.691 y	—
(6901) Roybishop	1.943 au	0.1114	23.14°	2.708 y	5 km

"a" is the size of the semi-major axis. "e" is eccentricity (how much the ellipse deviates from a circle). "i" is the inclination of the orbit. "T" is orbital period.

Of the fifteen NSAs, not only are Daveturner and Roybishop the nearest to Earth and the Sun, but also they are the most inclined to the ecliptic, with Roybishop having an even larger tilt (23°) than Daveturner (18°).

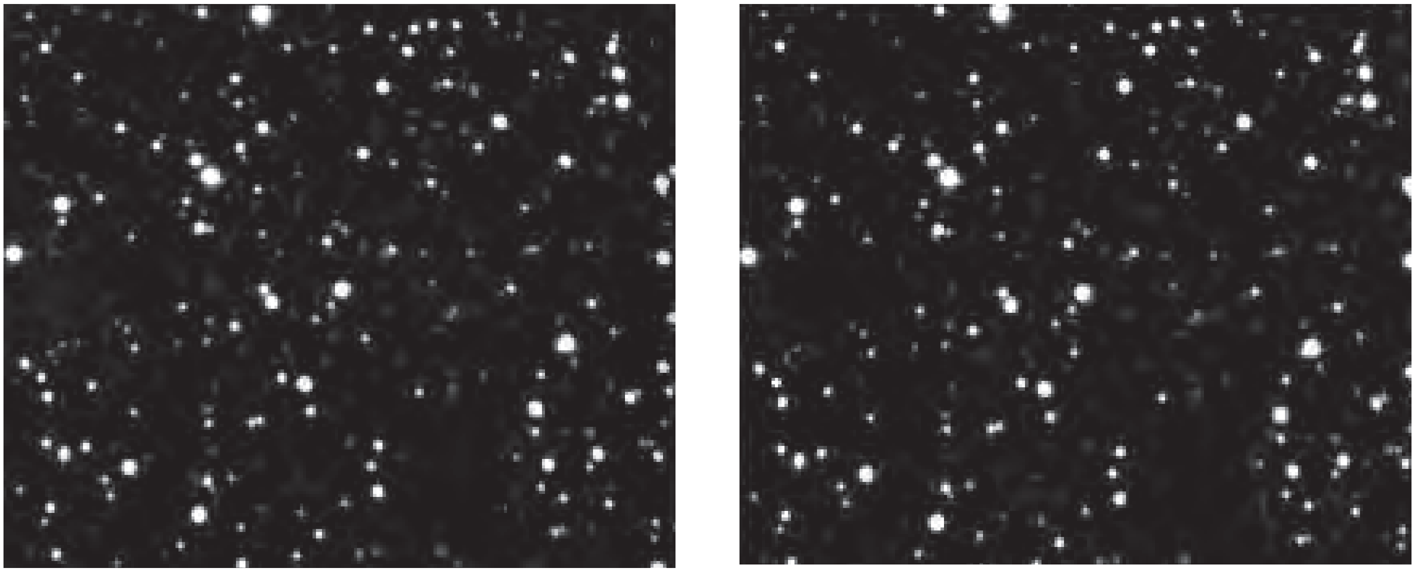


Figure 2 – A sequence of photos of (6901) Roybishop.

There is a reason for their large inclinations. The Inner Main Belt asteroids are the group nearest the orbit of Mars, and Mars significantly perturbs their orbits, particularly those of small inclination as they remain near the plane of the Martian orbit (inclination 1.85°). Not only is the Hungaria group hemmed in by the 5/1 (1.78 au) and 4/1 (2.06 au) resonances with Jupiter (see the above diagram), but nearby Mars also restricts this group with 4/5 (1.77 au) and 2/3 (2.00 au) resonances. Most low inclination Inner Main Belt asteroids have long since been scattered out of the Hungaria group by Mars, leaving only the high inclination members that do not pass as close to Mars, including **(27810) Daveturner** and **(6901) Roybishop**.

One night in April 2002 with the 0.61-m Cassegrain telescope on the 4200-m summit of Hawaii's Mauna Kea, David Lane took a sequence of photos of **(6901) Roybishop**. Here are two of those photos (look carefully below the bright star in the centre) See figure 2:

If you stereo the pair of photos (use a stereo viewer or train your left eye to look at the left photo while your right eye looks at the right photo), the photos merge and the dot that is **(6901) Roybishop** will leap into the foreground in front of the background stars. In 1989 at Palomar Observatory, Carolyn Shoemaker used that technique to spot the asteroid that the Minor Planet Centre of the International Astronomical Union subsequently labelled 1989PA. In 1997, she and Gene Shoemaker proposed to the IAU that it be named Roybishop.

(27810) Daveturner has the smallest semi-major axis (1.93 au) and thus the shortest orbital period (2.69 y) of all the NSAs. However, **(6901) Roybishop** (semi-major axis 1.94 au, orbital period (2.71 y) has a sufficiently greater eccentricity than **(27810) Daveturner** (0.111 versus 0.054), that Roybishop has the smaller perihelion distance (1.73 au versus 1.83 au) and thus comes closer to Earth and the Sun than all the other NSAs.

(6901) Roybishop possibly has another distinction not shared by any other NSA—Roy Bishop has actually seen his namesake asteroid. When near an autumn opposition well north of the ecliptic, 16th magnitude Roybishop is just visible in the 0.44-m Newtonian telescope at Roy's Maktomkus Observatory as it drifts slowly past the background stars.

In the order of increasing semi-major axes, here are the original citations that accompanied the naming of:

(27810) Daveturner (discovered 1993, named 2004)

David G. Turner, editor of the *Journal of the Royal Astronomical Society of Canada* between 1996 and 2000, is an enthusiastic professor of astronomy and physics at Saint Mary's University in Nova Scotia. By means of photoelectric photometry and CCD imaging, he has pursued a study of Cepheid variable stars.

[*Minor Planet Circ.* 50464]

(6901) Roybishop (discovered 1989, named 1997)

Named in honour of Roy L. Bishop, retired professor of physics at Acadia University. Nova Scotia. Since 1982 Bishop has edited the *Observer's Handbook* of The Royal Astronomical Society of Canada, a vital reference for professional and amateur astronomers. Bishop is also known for his unique photographs, especially one of a double rainbow over Isaac Newton's birthplace. Citation provided by Carolyn and Eugene Shoemaker and Wendee and David Levy.

[*Minor Planet Circ.* 30477]

The Main Belt, Zone I

Four of the fifteen NSAs are located in the Main Belt, Zone I, bounded by the Kirkwood gaps at the 4/1 (2.06 au) and 3/1 (2.50 au) resonances with Jupiter:

	a	e	i	T	diameter
(3314) Beals	2.218 au	0.045	7.41°	3.30 y	7 km
(20018) Paulgray	2.306 au	0.158	5.33°	3.5l0 y	4 km
(10047) Davidchapman	2.344 au	0.052	14.22°	3.59 y	5 km
(855) Newcombia	2.362 au	0.180	10.88°	3.63 y	12 km

"a" is the size of the semi-major axis. "e" is eccentricity (how much the ellipse deviates from a circle). "i" is the inclination of the orbit. "T" is orbital period.

All four asteroids are well within Zone I, not near the bounding Kirkwood gaps. Also, amongst the fifteen Nova Scotia Asteroids (NSAs), none of these four has an unusually large or small eccentricity or inclination.

However, one of the four is the largest of the fifteen NSAs, 855 Newcombia has the brightest absolute magnitude* (11.79) and the largest diameter, approximately 12 km. That distinction is not surprising as it was the first of the fifteen NSAs to be discovered (in 1916).

*The absolute magnitude of an asteroid is the apparent magnitude it would have for an observer located at the Sun (!) if the asteroid were 1 au from the Sun.

In December 2023, Dave Chapman used the 0.61-m robotic telescope at Saint Mary's Burke-Gaffney Observatory to take image pairs of (20018) Paulgray and (10047) Davidchapman. A few hours separate the images in each pair. In the order of increasing semi-major axes:

In the order of increasing semi-major axes, here are the original citations that accompanied the naming of:

(3314) Beals (discovered 1981, named 1987)

Named in memory of Canadian astronomer Carlyle Smith Beals (1899-1979), fourth Dominion Astronomer and the only person who has been both President of the American Astronomical Society and the National President of the Royal Astronomical Society of Canada. Beals made important contributions to the observation and interpretation of emission lines in the spectra of hot stars, to the understanding of the nature of interstellar gas clouds, and to the development of instrumentation for astronomy. He also initiated a program to identify and study meteorite craters in Canada. Name proposed by the discoverer following a suggestion by P.M. Millman.

[*Minor Planet Circ.* 12210]

The above citation for (3314) Beals is silent concerning his connection to Nova Scotia. In brief: Beals was born in Canso, N.S., his primary and secondary education took place in Upper Canard, N.S., he graduated from Acadia University in physics, taught physics at Acadia for a year, married a lady from Annapolis Royal, and he is buried in Wolfville. (Like Newcomb was honoured, a lunar crater is named Beals.)

(20018) Paulgray (discovered 1991, named 2023)

Paul Michael Gray (b. 1972) is a Canadian amateur astronomer who has served as President of both the RASC Halifax Centre and the RASC New Brunswick Centre. He edited the RASC *Observer's Calendar* from 2013 to 2022. Gray was co-discoverer of SN 1995F, the first supernova discovered from Canada.

[Ref: *WGSBN Bull.* 3, #15, 7]

(10047) Davidchapman (discovered 1986, named 2021)

David Chapman (b. 1953) is a retired physicist who studied ocean acoustics at Canada's Defence Research Establishment Atlantic. He won the Royal Astronomical Society of Canada's Simon Newcomb Award in 1986 and an RASC Service award in 2015. He was editor of the *Observer's Handbook* (2012–2016) and led the establishment of Kejimkujik Dark Sky Preserve. [Ref: *WGSBN Bull.* 1, #10, 5]

(855) Newcombia (discovered 1916, named —)

[The original citation was not available. The paragraph below is adapted from one by the RASC.]

Named in honour of Simon Newcomb (1835–1909) an astronomer born in Wallace, Nova Scotia. He was a professor of mathematics and astronomy and director of the U.S. Nautical Almanac Office. Newcomb worked on cometary and planetary orbits and on the theory of the orbit of the Earth. He measured the velocity of light and determined the astronomical unit anew. He is also honoured by having a crater on both the Moon and Mars named Newcomb. He was elected an Honorary Member of the Astronomical and Physical Society of Toronto in 1891, one year after the founding of the Society now known as the RASC.

The Main Belt, Zone II

Six of the fifteen Nova Scotia Asteroids (NSAs) are distributed across Zone II of the Main Belt, bounded by the Kirkwood gaps at the 3/1 (2.50 au) and 5/2 (2.82 au) resonances with Jupiter:

	a	e	i	T	diameter
(246913) Slocum	2.540 au	0.220	12.15°	4.05 y	~ 2 km
(5547) Acadiau	2.615 au	0.123	12.72°	4.23 y	9 km
(22421) Jamesedgar	2.662 au	0.158	3.55°	4.34 y	~ 4 km
(6898) Saint-Marys	2.665 au	0.123	14.19°	4.35 y	8 km
(117032) Davidlane	2.716 au	0.140	11.58°	4.48 y	~ 3 km
(516560) Annapolisroyal	2.771 au	0.148	17.07°	4.61 y	~ 2 km

"a" is the size of the semi-major axis. "e" is eccentricity (how much the ellipse deviates from a circle). "i" is the inclination of the orbit. "T" is orbital period.

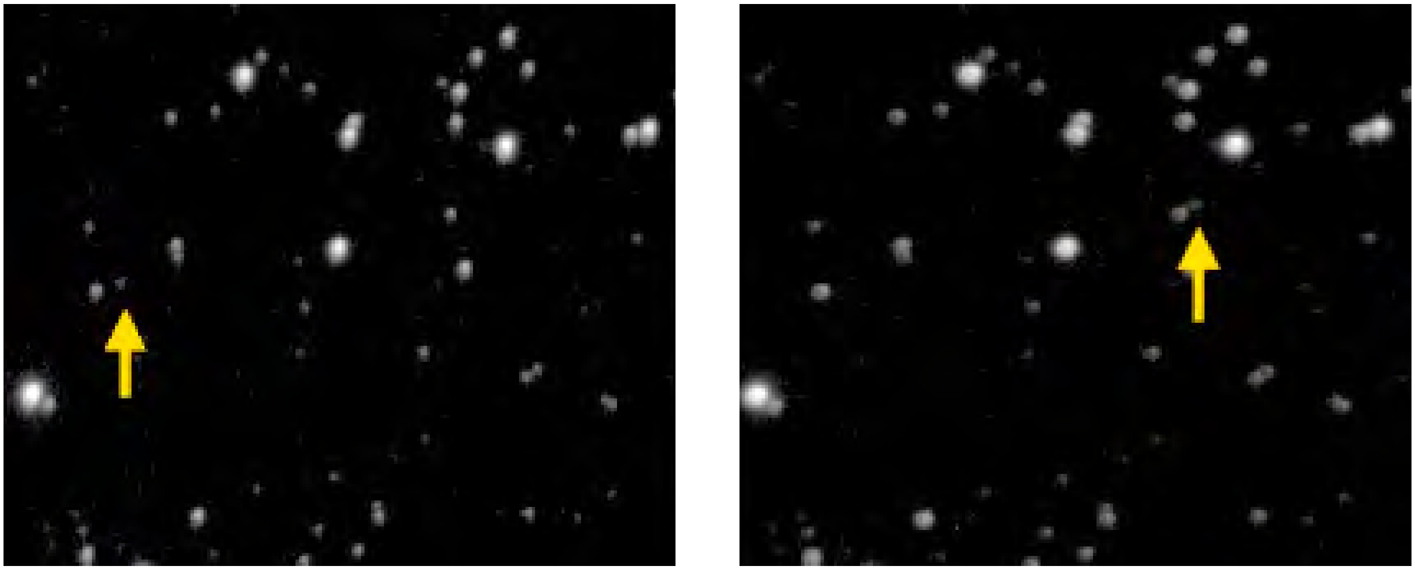


Figure 3 – Movement of asteroid (20018) Paulgray

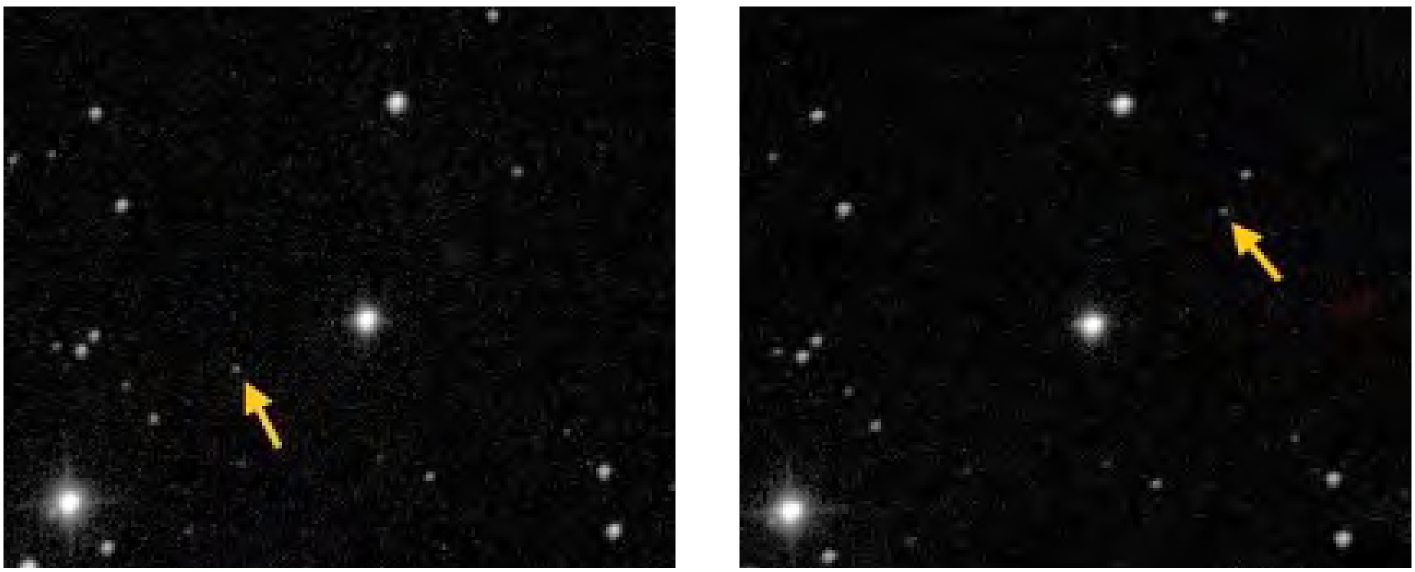


Figure 4 – Movement of asteroid (10047) Davechapman

In the text Solar System Dynamics by Murray and Dermott (Cambridge 1999), a prominent family of asteroids (apparently the result of a collisional breakup) is the Eunomia family, having semi-major axes between 2.6 and 2.7 au, eccentricities near 0.15, and inclinations near 13°. Four of the six NSAs in Zone II — Acadiau, Saint-Marys, Davidlane, Annapolisroyal — are clustered in that region of three-dimensional "aei" space. Thus, they must be members of the Eunomia family (named after (15) Eunomia, its largest member, having a diameter of 232 km and "aei" parameters 2.64 au, 0.187 and 11.75°).

The other two NSAs in Zone II might also be members of the Eunomia family. Slocum has the appropriate inclination, but his eccentricity is high; indeed he is the most eccentric of all fifteen NSAs (no wonder he sailed around the world alone)! Jamesedgar is eccentric enough to be a member of the Eunomia family, but his inclination is very low, the second lowest inclination of all fifteen NSAs, almost flat on his back on the ecliptic! Perhaps Slocum and Jamesedgar received especially violent kicks during the collision that produced the Eunomia family.

Another feature of the NSAs in Zone II is notable: the close similarity of the two university asteroids, Acadiau and Saint-Marys. Their semi-major axis differs by less than 2%, their inclinations by less than 1.5°, and their eccentricities by less than 0.1%!

Yet another remarkable coincidence is that not only are Saint-Marys and Davidlane in the middle of the Eunomia family, but they are also next to each other in the sequence of semi-major axes. David Lane made tremendous contributions to Saint Mary's University during his career there. In January 2024, the university conferred an honorary doctorate on him. With profound sadness we record Dave's death on 2024 March 24..

In the order of increasing semi-major axes, here are the original citations that accompanied the naming of:

(246913) Slocum (discovered 1998, named 2012)

Joshua Slocum (1844 – 1909) was the first person to circumnavigate the world alone. He sailed Spray, his rebuilt sloop, from Boston in April 1895, and returned three years later after a 74,000-km journey. His book Sailing Alone Around the World is a first-hand account of his remarkable voyage.

[Minor Planet Circ. 80329]

As for (3314) Beals, the above citation for (246913) Slocum is silent concerning Slocum's connection to Nova Scotia. In brief: Slocum was born on the North Mountain in Annapolis County, Nova Scotia and grew up in Westport, N.S.

(5547) Acadiau (discovered 1980, named 1995)

Named in honour of Acadia University, Wolfville, Nova Scotia. Founded in 1838, Acadia U. has become one of Canada's finest liberal arts institutions. It is located near the Minas Basin, which boasts some of the most dramatic tides on Earth, and it is also located under some of Canada's darkest night skies. Acadia's academic excellence and small student population provide a fertile environment for a good undergraduate education. Name proposed and citation prepared by D. H. Levy.

[Minor Planet Circ. 24918]

(22421) Jamesedgar (discovered 1995, named 2016)

James Somerville Edgar (b. 1946) spent 40 years as a Locomotive Engineer and rail Supervisor. He became President of The Royal Astronomical Society of Canada in 2014. Name suggested by R. and P. Jedicke.

[Minor Planet Circ.102253]

(6898) Saint-Marys (discovered 1988, named 2002)

Saint Mary's University, Halifax, N.S., is Atlantic Canada's primary center for instruction, public relations and research in astronomy and astrophysics. The university, founded in 1802, is the site of the Burke-Gaffney Observatory, used for the detection of supernova 1995F, the first such discovery of an all-Canadian nature.

[Minor Planet Circ. 46101]

(117032) Davidlane (discovered 2004, named 2008)

David Lane (b. 1963) is the author of The Earth Centered Universe, a brilliantly easy-to-use planetarium and telescope-control program. With Paul Gray, Lane has discovered three supernovae — SN1995F, 2005B and 2005ea. He is scheduled to assume the presidency of The Royal Astronomical Society of Canada in June 2008.

[Minor Planet Circ. 62931]

(516560) Annapolisroyal (discovered 2006, named 2018)

The Town of Annapolis Royal, Nova Scotia, is recognized as the cradle of the Canadian nation for its prominent role in the country's early origins and remains influential as a leader in heritage stewardship and preservation.

[Minor Planet Circ. 111804]

The Main Belt, Zone III

The last three of the fifteen Nova Scotia Asteroids (NSAs) are in the outer-most Zone III of the Main Belt, bounded by the Kirkwood gaps at the 5/2 (2.82 au) and 2/1 (3.28 au) resonances with Jupiter:

	a	e	i	T	diameter
(304233) Majaess	2.864 au	0.0703	12.63°	4.85 y	~ 2 km
(497593) Kejimkujik	2.868 au	0.0310	4.93°	4.86 y	~ 2 km
(144907) Whitehorne	2.963 au	0.1105	0.50°	5.10 y	3 km

"a" is the size of the semi-major axis. "e" is eccentricity (how much the ellipse deviates from a circle). "i" is the inclination of the orbit. "T" is orbital period.

In terms of both eccentricity and inclination, **(304233) Majaess** is unremarkable, falling within a standard deviation of the eccentricity and inclination averages of the fifteen NSAs.

With e = 0.0310 **(497593) Kejimkujik** has the smallest eccentricity of all fifteen NSAs. In words, the spacing of the foci of its orbit (2ae) is barely 3% of the major axis (2a). Its orbit is almost indistinguishable from a circle. Copernicus, who used circles to model the orbits of the planets, would have liked Kejimkujik!

With an orbital period of more than 5 years, **(144907) Whitehorne** is the furthest of the NSAs from the Sun. Furthermore, she has the smallest inclination, merely half a degree, staying closer to Earth's orbital plane, the ecliptic, than any other NSA. Another remarkable feature of Whitehorne is her semi-major axis (2.963 au), almost at the position of the 7/3 orbital resonance with Jupiter (2.957 au), a resonance that almost splits Zone III of the Main Belt in two.

In the order of increasing semi-major axes, here are the original citations that accompanied the naming of:

(304233) Majaess (discovered 2006, named 2012)

Daniel Majaess (b. 1984) is a young Canadian observational astronomer who researches the Cepheid distance scale, variable stars, and the Milky Way's spiral structure and its many star clusters. He frequently makes innovative use of photometric surveys and data from small telescopes.

[*Minor Planet Circ.* 79108]

(497593) Kejimkujik (discovered 2006, named 2022)

Kejimkujik National Park and National Historic Site is an area of natural beauty and historical significance in Nova Scotia, Canada. The indigenous Mi'kmaq people consider Kejimkujik to be a sacred ancestral place. The Royal Astronomical Society of Canada declared Kejimkujik to be a Dark Sky Preserve in 2010.

[*WGSBN Bull. 2*, #8, 11]

(144907) Whitehorne (discovered 2004, named 2007)

Mary Lou Whitehorne, currently second vice-president of The Royal Astronomical Society of Canada, has devoted much of her life to educating young people in the basics of astronomy. Her original and interesting approach has led to a surge of interest in astronomy among young people throughout Canada.

[*Minor Planet Circ.* 59925]

Supplementary Note

Eight of the fifteen NSAs are named for individuals who have made major contributions to the national RASC. In the list that follows, there is some duplication with the original asteroid citations, but a few major contributions to the national Society either were not mentioned in the original citations, or occurred after the citation was published. Contributions to our Centre were also not included. In the order of their asteroids outward from the Sun:

David Turner — RASC (Editor of the *Journal*); Halifax Centre Councillor/Director

Roy Bishop — RASC (President, 1st Vice-President, 2nd Vice-President, Editor of the *Observer's Handbook*, FRASC); Halifax Centre (President, Honorary President, Secretary, National Council Representative, Nova East Coordinator)

Carlyle Beals — RASC (President, 1st Vice-President, 2nd Vice-President, Honorary President)

Paul Gray — RASC (Editor of the *Observer's Calendar*); Halifax Centre (President, 1st Vice-President, Observing Chair, Councillor, Nova East Coordinator)

David Chapman — RASC (Editorial Board, *Explore the Universe* Consultant, Editor of the *Observer's Handbook*, FRASC); Halifax Centre (1st Vice-President, Dark-Sky Preserve (DSP) Committee Co-Chair, Observing Chair)

James Edgar — RASC (President, Secretary, Recorder, Editor of the *Observer's Handbook*, Production Manager of the *Journal,* Information Technology Committee, RASC web content editor, National Council Representative, FRASC); Halifax Centre Associate Member

David Lane — RASC (President, 1st Vice-President, 2nd Vice-President, Editor of the *Observer's Calendar*, Information Technology Committee, Server Administrator, FRASC); Halifax Centre (President, Treasurer, Secretary, Observing Chair, *Nova Notes* Editor, National Council Representative, Auditor, Nova East Coordinator)

Mary Lou Whitehorne — RASC (President, 1st Vice-President, 2nd Vice-President, Author of *Skyways*, *Astronomy Handbook for Teachers,* FRASC); Halifax Centre (President, Secretary, Honorary President, Councillor, Observing Chair, National Council Representative, Nova East Coordinator) ✶

Great Images

Michael Gatto

Michael Gatto of the Halifax Centre submitted this recent sketch of the crater Gassendi. Sketched at the eyepiece of his 8″ f/7.5 newtonian on 2025 October 02 from Dartmouth, Nova Scotia. Seeing conditions were great, and the sketch took about 90 minutes, using magnifications between 150 and 200X. Pencil on paper, and then scanned and coloured in Procreate.

Pen & Pixel

Figure 1 – Bright, detailed and colourful, M27 is a delight to image," says Mark Germani who imaged a favourite target of many astronomers. "This image is a combination of 13 hours of Hα and OIII signal from the Optolong L-eXtreme filter and 2 hours of broadband (visible light) signal from the L-Pro filter. Imaged over 5 nights in July & August 2025."

Figure 2 – Here is a widefield view of the Iris Nebula, a reflection nebula in the dust-rich constellation of Cepheus. This image was taken by Toronto Centre member Shraddah Pai over two nights, at the Starfest star party in Ontario and at Algonquin Park. A number of notable deep-sky objects are seen in the frame. Flanking the Iris is The Scorpion (LDN 1125) on the right and The Ghost Nebula (Sh2-136) on the left. The red arc on the bottom left is a bit of an emission Nebula (Sh2-133), cradling the star 6 Cephei. Shaddha used an ASI 2600MM Pro with a Rokinon 135-mm lens at ƒ/2.8 on a GEM28 Mount, Antlia V-Pro filters, Asiair Plus, EAF. Luminance 10×180s; Red 17×180s; Green 21×180s; Blue 20×180s. Processed in PixInsight and Lightroom Classic.

Continues on page 237

What's Up in the Sky?

December/January 2025/2026

Compiled by James Edgar

December Skies

The Moon presents a waxing gibbous phase as the month begins, with the full phase appearing on the 4th. Also on the 4th, the Moon drifts just north of the stars of the Pleiades (M45). The full Moon, at perigee of 356,963 km, generates high tides at coastal areas. On the 7th, Jupiter is 4 degrees south of the waning Moon, one day later, the Moon is 1.4 degrees north of the Beehive Cluster (M44). The 10th sees Regulus 0.7 degrees south of our satellite; this is an occultation for most of Canada. Last quarter comes a day later, on the 11th.On the 14th, Spica is 1.4 degrees north of the Moon. The 17th sees Luna at apogee of 406,322 km. The 18th has the Moon 0.4 degrees south of Antares; another occultation, but in the Southern Hemisphere. The Moon is new on the 19th. For those seeking an observing challenge, Pluto is 0.6 degrees south of the Moon–an occultation in eastern Canada–on the 22nd. By the 27th, the two large planets Saturn and Neptune are 4 degrees and 9 degrees, respectively, south of the first-quarter Moon. Once again, the waxing gibbous Moon is 0.9 degrees north of the Pleiades.

Mercury appears in the eastern dawn sky for the best morning apparition of 2025 for Northern Hemisphere viewers.

Venus is too close to the Sun to be seen.

Mars is too close to the Sun to be seen.

Jupiter rises in the east shortly after sunset, presenting a favourable opportunity for Northern Hemisphere viewing. The 7th sees the waning gibbous Moon 4 degrees north of the gas giant planet. A double shadow crosses the disk on the morning of the 24th.

Saturn is among the stars of Aquarius, slowly beginning prograde motion. The ring system opens up a little during the month, so we can see more of the south side. The first-quarter Moon glides by on the 27th.

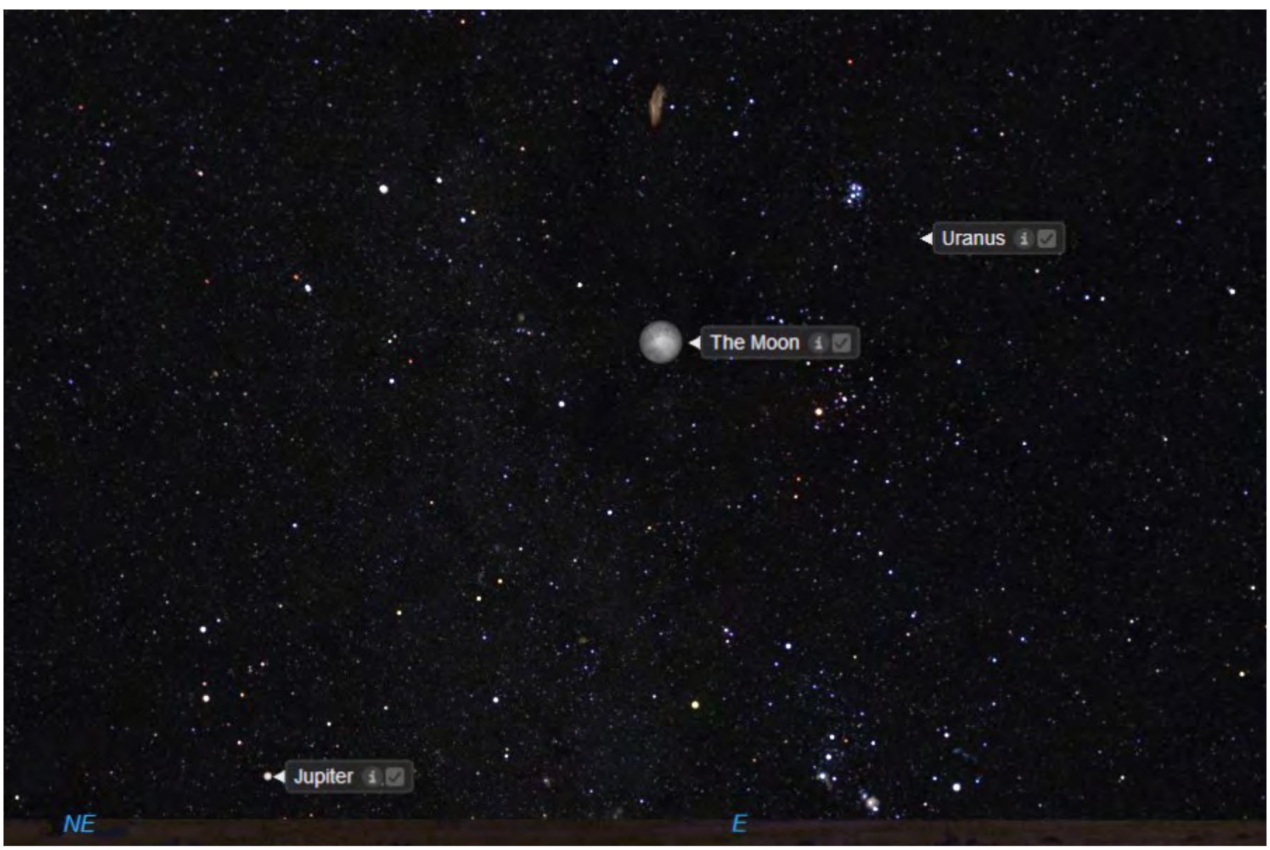
Uranus is well placed for viewing all through the night.

Neptune and Saturn are a pair in the western evening sky, but far enough apart that they're in separate constellations–Pisces for Neptune and Aquarius for Saturn.

The **Geminid Meteors** peak on the morning of December 14

Winter solstice is on the morning of the 21st.

The **Ursid meteors** peak on the morning of the 22nd.



December: *Early in the month, Jupiter shines near the horizon in the evening, a little southwest of Pollux. Uranus rides high near The Pleiades, with the full Moon to the southeast.*

Continues on page 236

The Sky December/January 2025/2026

Compiled by James Edgar with cartography by Glenn LeDrew

Celestial Calendar (bold=impressive or rare)

December 2025

Dec. 3 Moon 0.8° north of Pleiades (M45)

Dec. 4 Moon at perigee (356,963 km) Large tides

Dec. 4 full Moon at 6:14 p.m. EST

Dec. 7 Jupiter 4° south of waning gibbous Moon

Dec. 8 Moon 1.4° north of the Beehive Cluster (M44)

Dec. 10 Regulus 0.7° south of Moon, occultation

Dec. 11 Moon at last quarter

Dec. 14 Geminid meteors peak

Dec. 17 Spica 1.4° north of waning crescent Moon

Dec. 17 Moon at apogee (406,322 km)

Dec. 18 Antares 0.4° north of thin crescent Moon

Dec. 19 new Moon (lunation 1274)

Dec. 21 Solstice

Dec. 22 Ursid meteors peak

Dec. 24 Double Shadows on Jupiter

Dec. 27 Saturn 4° south of first-quarter Moon

Dec. 27 Neptune 3° south of first-quarter Moon

Dec. 27 Moon at first quarter

Dec. 31 Moon 0.9° north of Pleiades (M45)

January 2026

Jan. 1 Moon at perigee (360,348 km)

Jan. 3 full Moon at 5:03 a.m. EST

Jan. 3 Earth at perihelion (147,099,894 km)

Jan. 3 Jupiter 4° south of full Moon

Jan. 3 Quadrantid meteors peak

Jan. 5 Moon 1.3° north of Beehive (M44)

Jan. 6 Regulus 0.5° south of Moon

Jan. 9 Moon at last quarter

Jan. 10 Spica 1.7° north of last-quarter Moon

Jan. 13 Moon at apogee (405,438 km)

Jan. 14 Antares 0.6° north of Moon

Jan. 18 new Moon (lunation 1275)

Jan. 23 Saturn 4° south of Moon

Jan. 26 Moon at first quarter

Jan. 27 Moon in Pleiades (M45)

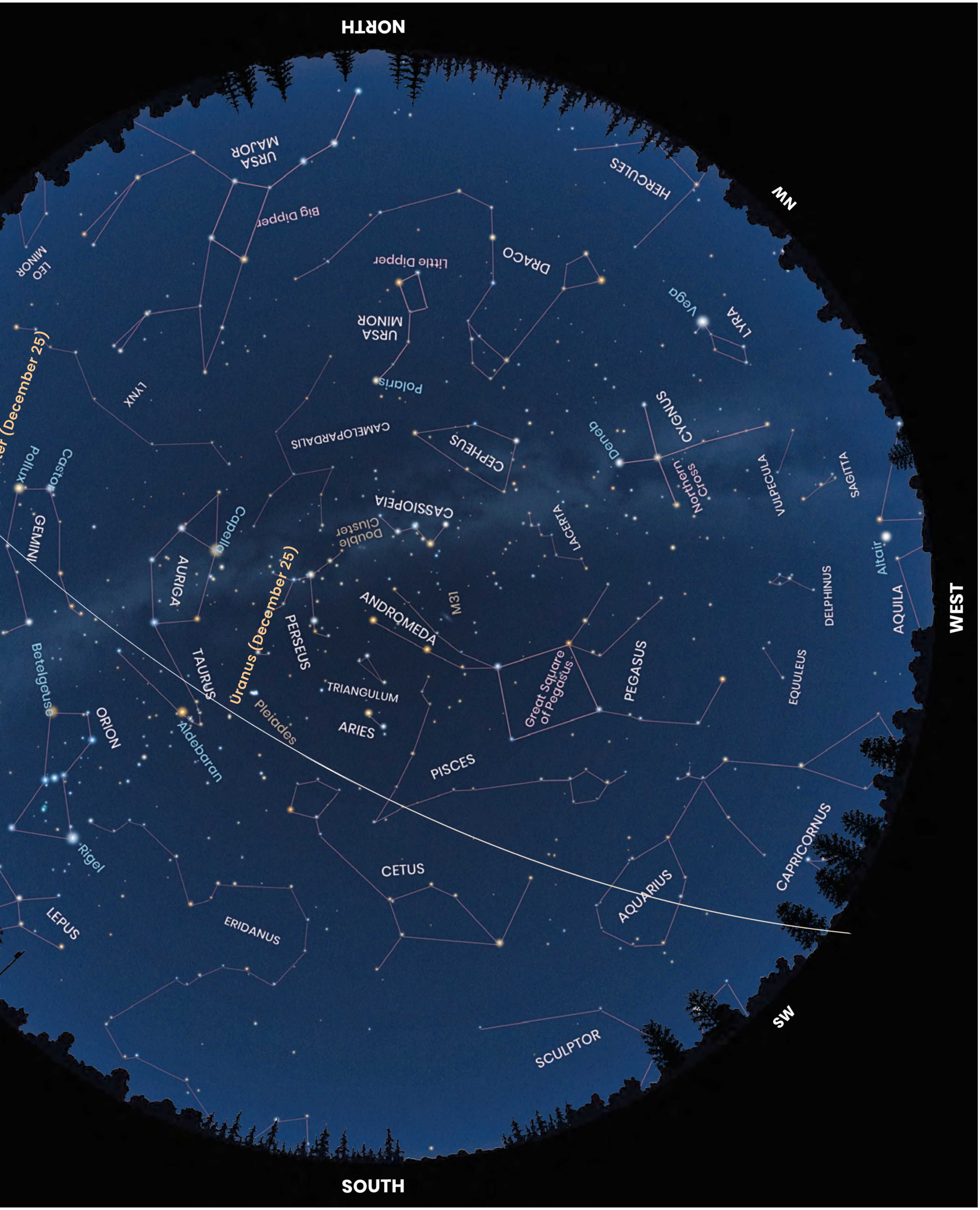
Jan. 28 Mercury 0.7° south of Venus

Jan. 29 Moon at perigee (365,871 km)

Jan. 31 Jupiter 4° south of Moon

Planets at a Glance

	DATE	MAGNITUDE	DIAMETER (″)	CONSTELLATION	VISABILITY
Mercury	Dec. 1	0.0	8.0	Libra	Dawn
	Jan. 1	—	4.9	Sagittarius	—
Venus	Dec. 1	—	9.9	Libra	—
	Jan. 1	—	9.8	Sagittarius	—
Mars	Dec. 1	—	3.9	Ophiuchus	—
	Jan. 1	—	3.9	Sagittarius	—
Jupiter	Dec. 1	–2.5	44.2	Gemini	Evening
	Jan. 1	–2.7	46.5	Gemini	Evening
Saturn	Dec. 1	1.0	18.1	Aquarius	Evening
	Jan. 1	1.1	17.1	Aquarius	Evening
Uranus	Dec. 1	5.6	3.8	Taurus	Evening
	Jan. 1	5.6	3.8	Taurus	Evening
Neptune	Dec. 1	7.9	2.3	Pisces	Evening
	Jan. 1	7.9	2.3	Pisces	Evening


NORTH
NW
WEST
SW
SOUTH
URSA MAJOR
Big Dipper
HERCULES
LEO MINOR
DRACO
Little Dipper
URSA MINOR
LYRA
Vega
Polaris
LYNX
Jupiter (December 25)
CYGNUS
Deneb
CAMELOPARDALIS
CEPHEUS
Northern Cross
VULPECULA
SAGITTA
Pollux
Castor
GEMINI
Capella
CASSIOPEIA
Double Cluster
LACERTA
Altair
AURIGA
Uranus (December 25)
DELPHINUS
AQUILA
ANDROMEDA
M31
PERSEUS
TAURUS
PEGASUS
Great Square of Pegasus
Betelgeuse
EQUULEUS
TRIANGULUM
ORION
Pleiades
ARIES
Aldebaran
PISCES
CAPRICORNUS
Rigel
CETUS
AQUARIUS
LEPUS
ERIDANUS
SCULPTOR

Continued from page 233

January Skies

The Moon during 2026 occults planets, significant asteroids, and 1st-magnitude stars within 5° of the ecliptic. With 38 such events visible around the globe, including monthly occultations of Antares and Regulus all year, a 4-month series for Jupiter, and several more for Venus, there will be many showing up on these pages.

January starts off with the Moon at perigee (closest to Earth) at 306,348 km distance. Full phase occurs two days later, on the 3rd, with Jupiter 4 degrees south. The Beehive Cluster (M44) is 1.3 degrees south of the Moon on the 4th, and Regulus is 0.5 degrees south on the 6th–an occultation in the Eastern Hemisphere. On the 11th, Spica is 1.7 degrees north of the last-quarter Moon. Apogee occurs on the 13th at 405,438 km. Antares, the bright red star in Scorpius, is 0.6 degrees north of the Moon–another occultation, this time in the Southern Hemisphere. The Moon is new on the 18th. January 23 sees the crescent Moon 4 degrees north of Saturn. The Moon is among the stars of the Pleiades on the 27th. Perigee occurs on the 29th at 365,871 km. The 30th finds the nearly full Moon 4 degrees north of Jupiter.

Mercury is too close to the Sun to be visible.

Venus is too close to the Sun to be visible.

Mars is too close to the Sun to be visible.

Jupiter reaches opposition on the 10th. This is a good time to view the Galilean moons, discovered by Galileo in 1609. He tracked their movement over a period of days and realized that not only do those satellites orbit the gas giant, so must the planets orbit the Sun. A heretical notion at the time, but he was right. The Moon is nearby on the 3rd and the 30th.

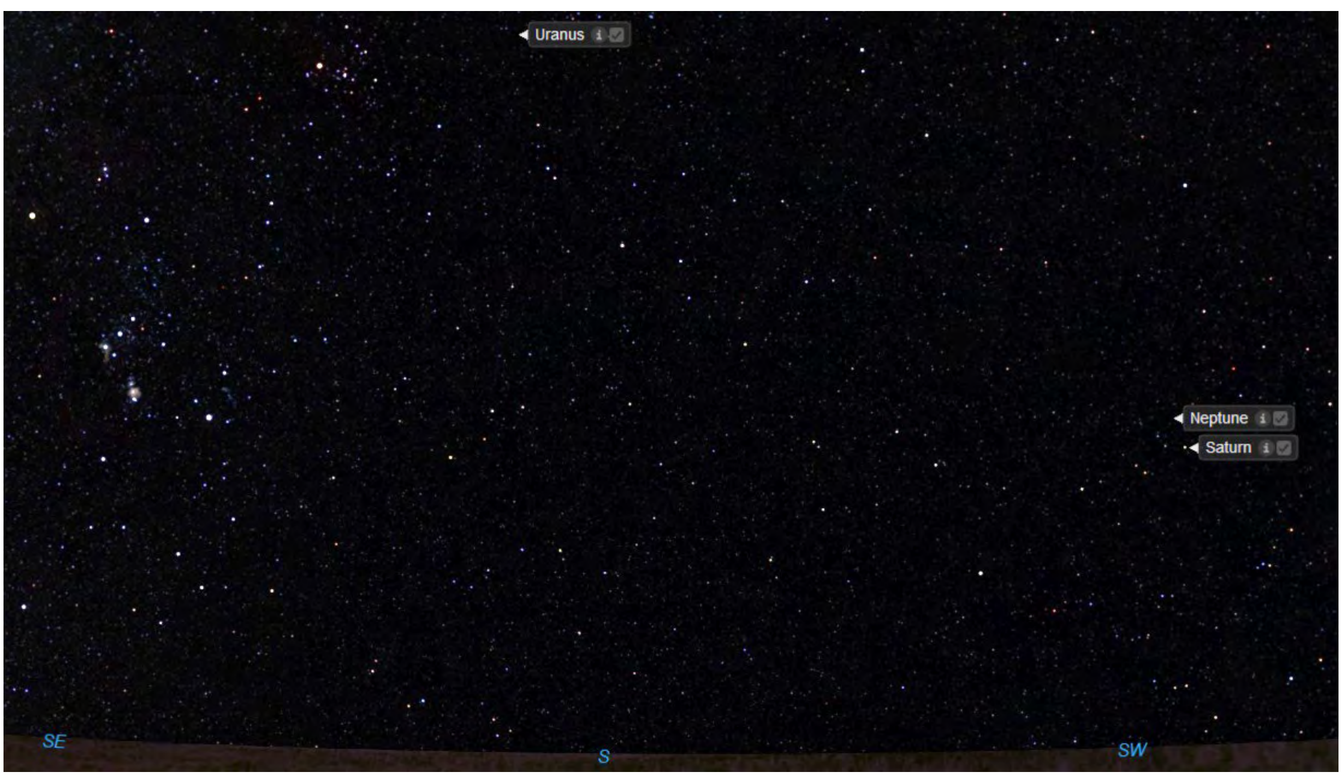
Saturn is well placed for evening viewing in the southwest. Watch for the ring tilt to gradually increase over the next months and years. Watch also for the occasional shadow of one of Saturn's moons to transit the globe. The Ringed Planet closes in on Neptune over the course of the month, getting to less than 2 degrees away, or so it appears from our vantage. The Moon is 4 degrees away on the 23rd

Uranus is in Taurus for all of 2026, hovering near the Pleiades. The blue-green gas planet has been retrograding for several months, now slowing to its stationary point in early February. It's good to recall that retrograde motion is only apparent, caused by Earth's more rapid orbit closer to the Sun.

Neptune is near Saturn in Pisces, where it remains all year. Optical aid is necessary to see the tiny distant disk of the furthest-most planet–30.76 astronomical units away. That's 30.76 times farther than Earth's average distance from the Sun, or 4.5 billion kilometres away.

Earth is at perihelion of 147,099,894 km (closest distance to the Sun) on January 3.

The **Quadrantid meteors** peak in the afternoon of January 3. ✶



***January:** The early southwest evening finds Saturn paired with the very dim Neptune among the stars of Pisces, The Fish. Uranus hovers near The Hyades in Taurus, The Bull. Credit for both: Image courtesy of Starry Night Pro Plus.*

Continued from page 232

Figure 3 – NGC 2336 is a barred spiral galaxy located roughly 100 million light-years away in Camelopardalis. Kimberly Sibbald captured this beautiful image over four nights in April and May of this year. Luminance 90×240s; Red 60×240s; Green 40×240s; Blue 49×240s. Total integration was 15 hours and 56 minutes. She used a PlaneWave CDK14 at 2,563 mm, a Mesu Mark II friction drive mount, with a QHY268M camera.

Figure 4 – Shakeel Anwar captured a rare Titan transit of Saturn on July 18. "Orange Titan is in orbit to the top left, and its shadow is being cast on the clouds of Saturn. The moon Tethys is emerging from behind the planet just below the rings on the left." Shakeel used a Celestron 11-inch SCT, Tele Vue 2.5× Powermate, and a Uranus-C camera. Several images were derotated in Winjupos and the final image was processed in Photoshop.

Keep Calm and Orbit On

Reflect Orbital is the Worst

By Samantha Lawler, Regina Centre
(samantha.lawler@uregina.ca)

I know that the title of this column includes "keep calm," but I'm going to have to ask all of you to freak out a little here. I've seen a lot of truly terrible ideas for satellites but Reflect Orbital has me completely horrified. They have filed with the FCC to launch the first of several thousand orbital mirrors to deliver "sunlight as a service." Not only will this be devastating to astronomy, but they won't even be effective at delivering sunlight to solar farms, which is their stated goal. Let me walk you through all of the problems.

As a professor who frequently teaches astronomy courses to non-science majors, I'm used to students being truly terrified of math, often arriving at answers many orders-of-magnitude away from the correct answer. I have become very good at gently coaching students while they work through problems, patiently reminding them how to plug numbers into formulas, how to check for unit cancellations, how to look at their answer and think about if it makes any intuitive sense or not.

I am far, far less forgiving when order-of-magnitude mistakes are made in simple math calculations by people who have apparently received millions of dollars from investors to launch a light-pollution machine into orbit claiming (and failing) to solve a minor problem in the worst, most complicated way possible.

A quick historical reminder: the Russians tried exactly this same experiment in the 1990s[1], because nighttime-sunlight-you-can't-refuse sounded great to scientists who were constantly afraid of losing their jobs and getting shipped off to remote concentration camps in unlivable places. It was a massively ignorant, unhelpful idea then, and nothing has changed (except that now a different country's government is threatening to fire scientists and ship people off to concentration camps).

Reflect Orbital wants people to pay for sunlight reflected down onto them from space. Solar farms, random dudes who are too cool to use a flashlight, creepy weirdos who want to spy on everyone in their neighbourhood during the night, farmers who are too detached to realize that plants need reliable day/night cycles. Anybody who has the cash! Oh, but there's a catch, they can only shine a light on you for four minutes (possibly less) before their satellite goes whizzing off beyond the horizon.

Also, a much, much bigger catch: the spotlight will be bright enough to be as annoying as a kid shining a flashlight in your face in the middle of the night, but not actually anywhere near bright enough to power a solar panel. Really! I honestly have NO IDEA how they convinced investors that solar farms will pay them and that will be their main revenue source. Because the math shows their solar farm aspirations are just a giant lie.

The Sun gives us a beautiful 1366 watts of energy shining down on every square metre of the daytime side of Earth at the top of the atmosphere. You could theoretically grab some more of that sunlight from orbit and reflect it down to Earth. How much you grab depends on the size of your mirror: Reflect Orbital is initially planning for 18 x 18 m (about the area of a tennis court), giving 324m^2, making them able to grab about 442 kW of solar energy. (We're ignoring the fact that the mirror is not 100% reflective, it will be tilted and not presenting its full area to the Sun, and the Earth's atmosphere will reflect or absorb about 70% of that before it gets to the ground.)

That 442 kW will be distributed over a circle at least 5 km in diameter (this might end up being a lot more spread out than that, depending on the mirror quality and angle, but let's roll with it for now). That gives you a whopping… 22 milliwatts per square metre. MILLIWATTS. Solar panels need at least a few watts per square metre to generate any electricity at all, or you can't run the inverter, and they're nowhere near 100% efficient. Even with their grand plan for 4000 satellites, if they all reflected onto the same spot (which is physically impossible), you *could* get up to 88 watts, which is almost as much sunlight as you get on a completely overcast day. But in reality, the most they'd be able to get is a dozen or so, which gives you, generously, one quarter of a watt per square metre.

This is garbage!! Why is anyone giving this company money?!

Well, their positives are all a lie, what about the negatives? Aside from having a creepy spotlight shining into your bedroom window for four minutes anytime someone else in your town pays Reflect Orbital, their initial presentations indicate they cannot stow their mirrors. So, when switching from one paying customer to another (every four minutes), they will sweep their spot of light across the ground. If you're outside, under the beam, your dark-adapted eyes will see a bright flash that completely destroys your night vision. This seems like a very bad idea for anyone driving a car, or flying a plane, or even just trying to walk around outside. One paper[2] by a physicist and an optometrist studying the original Russian Znamya space-mirror showed that it can permanently damage your eyes if you accidentally look at a space-mirror through binoculars or a telescope. This whole design sounds like a lawsuit factory!

The environmental effects could also be devastating, though there's no research currently available on ecological effects of short, intense pulses of artificial light. You've probably read about baby sea turtles hatching and then dying because they crawl toward beach resort spotlights instead of toward the ocean. How will animals like that react to a moving spotlight from the sky? Will it disrupt bird migrations? Reset circadian clocks in wildlife anywhere the spotlight shines? Disrupt human sleep cycles (which can happen with flashes as short as a millisecond[3]) and increase cancer risks[4]?

I haven't even talked about astronomy yet, which is why I started on this rant in the first place. If this satellite, about four times the brightness of the full Moon, reflects directly onto a

Figure 1 — Reflect Orbital wants to shine a spotlight like this on your city or town for four minutes, if someone in your town pays for it. Just be careful not to look at the mirror with your telescope, or it might be the last thing you look at. Image by Reflect Orbital.

research telescope, it may actually destroy the camera. It could even start a fire. Pointing a research telescope at something as faint as Saturn[5] is a very bad idea, and you cannot point a research telescope at the Moon without taking extreme precautions first. From their preliminary calculations[6] (which are not in the least bit reassuring), the whole sky will be at least full Moon brightness anytime a Reflect Orbital satellite is in the sky, limiting astronomers to only a handful of bright observing targets.

We also haven't talked about how dangerous this will be in orbit! Starlink, at 550 km altitude, reports one collision avoidance maneuver every two minutes[7], and that maneuver rate is growing. How can something the size of a tennis court avoid the millions of pieces of debris and micrometeorites travelling several times faster than bullets? Well, it can't. Within one year, estimates show that this giant orbital dust-trap will collect hundreds of micrometeorite hits[8]. Reflect Orbital says they use "rip-stop material," but assuming the material can even survive getting blasted by the equivalent of a handful of shotgun pellets per day, all these holes will make the mirror's reflection to Earth even fainter and even more out of focus.

They also haven't demonstrated or made any statements about their pointing accuracy. Keeping your giant mirror pointed at a single target on the ground while travelling several times faster than a bullet is no easy feat, but they seem to think it's a piece of cake, not even worth discussing. Given how bad they are at simple math, I have my doubts!

This whole mission is so poorly planned I have a hard time putting it into words.

The only thing that could make it worse is if they were using microwaves to transmit solar energy to the ground, as has been proposed by some other completely money-goggled start-up companies. In order to use microwaves to transmit energy from solar panels in orbit to energy-distribution sites on the ground, you need a microwave beam kilometres wide that would be strong enough to instantly cook any life (human or animal) that was unfortunate enough to be nearby. I hope I don't need to elaborate further on why that's an incredibly stupid idea?

Venture capitalists who have too much money should be investing in battery storage for solar farms, which is the safest and most efficient way to dole out the oodles of energy available from sunlight during the daytime. Solar power from space is a dangerous pipe dream with devastating consequences and no measurable benefit. Please stop. ✶

Endnotes

1 Lewis, D. (2016). How a Russian Space Mirror Briefly Lit Up the Night. Smithsonian Magazine. www.smithsonianmag.com/smart-news/how-russian-space-mirror-briefly-lit-night-180957894/

2 Laframboise, J.G. & Chou, B.R. (2000). Space Mirror Experiments: A Potential Threat to Human Eyes. JRASC 94, 237.

3 Zeitzer, J. et al. (2011). Response of the Human Circadian System to Millisecond Flashes of Light. PLOS One 6, 7. doi:10.1371/journal.pone.0022078

4 Al-Naggar, R. & Anil, S. (2016). Artificial Light at Night and Cancer: Global Study. Asian Pac J Cancer Prev. 17, 10. doi:10.22034/APJCP.2016.17.10.4661

5 Lawler (2025). Saturn's 128 New Moons (Oops!) JRASC August 2025.

6 Sidick, E. et al. (2025). Night Sky Brightness Caused by Orbital Reflectors. Small Satellite Conference, P2-61. digitalcommons.usu.edu/smallsat/2025/all2025/98/

7 SpaceX (2025). SpaceX Gen 1 and Gen 2 Status Report December 1, 2024-May 31, 2025 www.scribd.com/document/883045105/SpaceX-Gen1-Gen2-Semi-Annual-Report-7-1-25?v=0.738

8 Moorhead, A.V. & Matney, M. (2021). The Ratio of Hazardous Meteoroids to Orbital Debris in Near-Earth Space. Advances in Space Research 67, 1. doi:10.1016/j.asr.2020.09.015

Sam Lawler is an associate professor of astronomy at the University of Regina. She studies the orbits of small bodies in the outer Solar System, and increasingly studies and advocates for regulation of the thousands of new artificial satellites streaking through her research images, crawling across her huge prairie skies, and crashing onto nearby farmland. She's active on Mastodon@sundogplanets@mastodon.social and BlueSky@sundogplanets.mastodon.social.ap.brid.gy

John Percy's Universe

Cool Stars Are Really Cool!

John R. Percy, FRASC
(john.percy@utoronto.ca)

Some people—maybe even some astronomers—might think that stars are boring. They just sit there and twinkle. And it's Earth's atmosphere that does the twinkling, not the star. But every star is different. They are complex and fascinating, especially the "performing" variable stars that my students and I study. We use a unique century-long database of brightness measurements, made by skilled amateur astronomers through the American Association of Variable Star Observers (AAVSO).

Stars shine! In the hot, dense cores of stars like the Sun, hydrogen fuses into helium, producing 400 million million million million Watts of power (that's 4×10^{26} Watts) for 10 billion years. But, as the energy source runs out (as all energy sources do, unfortunately), the core shrinks and the star expands and cools, until it's millions of times bigger in volume than before—a red giant. It then shines by fusing hydrogen into helium in a shell around its core. Then, after a short period of fusing helium into carbon and oxygen (and a rest from being a red giant), it again swells and cools, and shines by fusing helium in a shell outside its carbon-oxygen core. The structure and evolution of red giants is complicated; see *Wikipedia* for the gory details.

What do red giants look like? Not bland and featureless, but dominated by huge, bright, random convection cells that well up, stick around for a few years, then gradually disappear. The Sun has convection cells on its surface, too, but they are tiny, compared with the size of the Sun, and minuscule compared to the size of a red giant. In the outer half of a red giant, convection (rather than radiation) is the primary means by which the star's energy is transported to the surface. The red giant then radiates energy into space, mostly as infrared light. If you had infrared eyes, they would look even brighter!

As the red giant rotates, which it does with periods of many years or more, the brightness will change irregularly as these bright convection cells rotate in and out of the line of sight. Indeed, many red giants have small, slow, poorly understood brightness variations on this time scale, and are probably due to the star's rotation.

Half of all stars are binary or multiple, including the nearest star, alpha Centauri. What would happen if a big red giant had a companion? If the companion was well-separated from the red giant (many AU), then not much would happen, other than we would see a pretty double star. But if it was a close binary, all hell could break loose: mass transfer; a disk of captured matter around the companion and, if the companion was a dense white dwarf or neutron star, then X-rays, outbursts, and more.

And what would happen if the red giant star had *planets* (and hundreds of them are known to do so)? In our Solar System: when the Sun swells into a red giant, Mercury and Venus will be swallowed up, Earth will be in the Sun's hot atmosphere, and Mars will be in the tenuous outer atmosphere. The outer planets will be relatively unaffected. But this planetary scenario may help explain the phenomenon of "long secondary periods," which occur in about a third of red giants, and may be due to eclipses of the red giant by low-mass, dust-enshrouded companions, which may have begun as planets and accreted matter and grown into brown dwarfs or low-mass stars (Soszyński et al. 2021)

Red giants pulsate—vibrate—and consequently vary in brightness. That's why my students and I study them; from the changes in brightness, we can discover the physical properties of the star, its nature and evolution.

The simplest property of the pulsation is the *period*—the time for one vibration. The second-simplest property is the *amplitude*, the amount, in magnitudes, by which it varies. In red giants, the amplitude can be as large as 10 magnitudes. And in some stars, the amplitude itself can vary by up to a factor of 10. We are not sure why.

The pulsation period is related to the size and luminosity of the star, so it shows a *period-luminosity relation* like the famous Cepheid pulsating variable stars (though not quite as "clean"). If this relation can be calibrated using pulsating red giants of known luminosity, they can be used to estimate the distance of the star, as the Cepheids can.

The simplest type or *mode* of pulsation is fundamental radial pulsation. All parts of the star expand and contract together. It's like plucking an open violin or guitar string, or blowing the lowest note on a bugle. It produces the lowest pitch, with the longest period of vibration. First-overtone radial pulsation is the second-simplest pulsation "mode." It's like shortening the violin or guitar string by half, or blowing the second-lowest note on the bugle. It produces about twice the pitch, with about half the period.

A red giant can pulsate in one mode, or more (in which case, if you like, it is "playing a chord"). In bimodal stars, the amplitude of each mode can vary, so that, at some times, one mode dominates and, at other times, the other does. So, the star appears to be switching modes and periods. We can watch this happening to a star through the AAVSO's decades of observations, aided by the "black art" of time-series analysis. Bimodal red giants are very common; Kiss et al. (1999) identified dozens of them using AAVSO data. The ratio of the first-overtone period to the fundamental period is close to 0.5; the exact value can tell us the mass of the star, so they are astrophysically very useful.

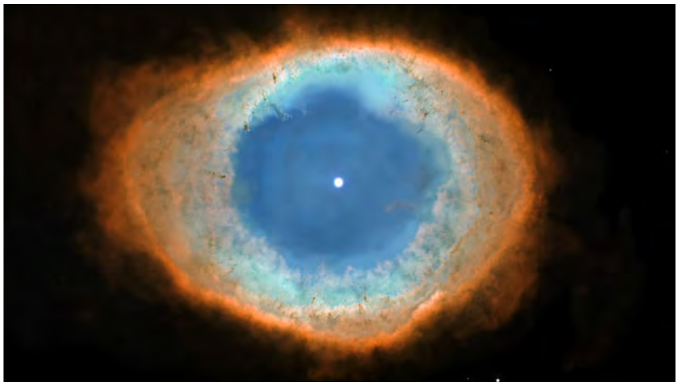


Figure 1 — The Ring Nebula, in Lyra, is a planetary nebula. The slowly-expanding nebula of gas and dust was driven off the star by its pulsation-driven winds, in its recent red giant stage, revealing the dense, hot core of the star that you can see at the centre. Source: Hubble Space Telescope.

The pulsation period does not actually remain exactly constant, but "wanders" randomly, up and down, by a few percent. This seems to be an effect of the huge convection cells that appear randomly in the star's outer layers and make the star slightly variable and non-spherical in shape.

Convection cells may also be involved in the even-more-mysterious *amplitude variations*. Mira, in Cetus, is the prototype pulsating red giant. It's a "Mira star." If you have ever observed Mira, you may have noticed that the maximum brightness ranges from 2 to 5. Kiss *et al.* (2000) have tackled this problem using AAVSO data, and proposed several possible causes: pulsation mode switches, either one-time or repeated; "beating" or interference between modes with close periods; and interaction between the rotation of the star and non-radial pulsation modes. Non-radial modes are ones in which some parts of the outer layers may be moving outward while others are moving inward. Variable stars are very complicated!

In a very small fraction of red giants, the period slowly increases or decreases by tens of percent over the course of decades. This is caused by "hiccups" called helium shell flashes, which occur a few times in the red giant's evolution, as it slowly swells and brightens, using the last of its thermo-nuclear fuel. It is easily seen in the AAVSO data (Templeton et al. 2005). Similar "hiccups" can dredge up carbon from deep within the star, producing *carbon stars* (there's a section on these in the RASC *Observer's Handbook*). Even the normal slow evolution of the red giant can be seen if the results from a large number of stars are averaged (Percy and Au 1999). If you are a variable-star observer, you can help us to watch these stars evolve!

Pulsation has other effects, besides brightness variation. The in-and-out pulsation velocity is tens of km *per second*, in a low-gravity star. Shock waves develop, driving the outer layers of the atmosphere into space. After a million years or so, when about half the star has been ejected, the hot dense core is exposed, energizing the gas around the star and producing a beautiful *planetary nebula* with a tiny, hot core at the centre. The best-known example is the Ring Nebula, in Lyra (Figure 1).

Mira, the prototype, has grown a tail. Pulsating with a period of about a year, Mira has been pumping a stellar wind into space. But the star is also zipping through the interstellar gas and dust at 130 km/sec, leaving a tail of gas and dust, 13 light-years long!

What about red supergiants? They are a different beast entirely, the semi-final stage in the life of a massive star, before its core collapses and the star explodes. The best-known example is Betelgeuse. There are occasional predictions, usually when its brightness is unusually high or low, that Betelgeuse is about to explode. I've already made my views known about that in this column (Percy 2020). A century of AAVSO observations shows that it fades quite often, as the amplitude of its pulsation and its mysterious "long secondary period" vary. But there are still diverse opinions about Betelgeuse, based on diverse observations—as there should be. So, the star is definitely worth watching.

You can contribute to astronomy—and have a lot of fun and satisfaction—by observing these cool stars. Just go to the AAVSO website—www.aavso.org—and get started. The Long Period Variable (LPV) Observing Section has their own web page to help you out, whether you are a beginner or an old hand.

Acknowledgments. As always, I thank the research students who have worked with me, and the AAVSO observers and staff, without whose contributions our studies of variable stars would not be possible. ✶

References

Kiss, L.L. et al. (1999). Multiperiodicity in semi-regular variables. I. General properties, *Astron. Astrophys., 346*, 542.

Kiss, L.L. et al. (2000). Multiperiodicity in semi-regular variables. II. Systematic amplitude variations, *Astron. Astrophys. Suppl., 145,* 283.

Percy, J.R. and Au, W. (1999), Long-term changes in Mira stars. II. A search for evolutionary period changes in Mira stars, *Publ. Astron. Soc. Pacific, 111*, 98.

Percy, J.R. (2020), What's up with Betelgeuse? *JRASC, 114,* 134.

Soszyński, I. et al. (2021), Binarity as the origin of the long secondary periods in red giant stars, *ApJLett, 911*, 22.

Templeton, M. *et al.* (2005), Secular evolution of Mira stars, *Astron. J., 130,* 776T.

John Percy FRASC is a very active Professor Emeritus in Astronomy & Astrophysics, and Science Education, at the University of Toronto. He is a former President (1978–80) and Honorary President (2013–17) of the RASC.

Mostly Variable Stars

A companion for Betelgeuse

by Hilding Neilson
(hneilson@mun.ca)

Betelgeuse is not just a star, Betelgeuse is a celebrity. And like most celebrities whenever anything happens like a celebrity with another person there has to be a story. This is Betelgeuse's story of having a newly discovered companion, a celestial love story as it were?

The story starts with the long-term variability of Betelgeuse where there appears to be a long-secondary period (LSP) of about 2100 days or about 5.8 years. This period was found about a century ago (Spencer Jones 1928) from radial velocity observations. The existence of an LSP should not be too surprising, LSPs have been measured for a plethora of red giant and red supergiant stars from visual data (Percy & Shenoy 2023). The question about the LSP is why does it occur at all.

There are a number of hypotheses to explain the LSP in these semi-regular red giant and red supergiant stars including, mixing of pulsation modes, some sort of convection interaction in the star, or maybe an interaction with a low-mass binary companion. Strothers (2010) suggested for the red supergiants Betelgeuse and Antares that the LSP is related to convection at the surface of the stars. In these stars we know that convection is seen as slowly rising blobs that carry heat from below to the surface similar to what happens in the Sun. The difference is that the convective blobs are really large relative to the size of the star so that really red supergiant stars like Betelgeuse are not truly spherical both wobbly like jelly in space. Strothers (2010) suggested that these blobs or eddies take so long to rise and turn over and sink back down that they could explain the LSP and the long-term variations in both light and radial-velocity observations. Strothers (2010) tested this theory with measurements for two red supergiant stars, but the implication of the theory is that LSPs should exist in all cool red giant and supergiant stars. As Percy & Szpigiel (2025) note, the LSPs are not seen in all red giant stars, hence it is unlikely that convective turnover is the explanation.

Another possibility was suggested that includes some kind of pulsation interaction. For instance, Wood et al. (2004) suggest that the LSP is related to some kind of gravity wave, that is non-radial pulsations in the stars, while Kiss et al. (2000) suggested the LSP could be related to an interaction between two radial modes. But, most interestingly, Kiss et al. (2006) analyzed the main periods and LSPs for a sample of semi-regular variable stars and found that the stars all had similar pulsation constants for the main periods and separately for the LSPs. The pulsation constant is derived from the equations that describe stellar pulsation where the pulsation period squared times the mean density of the star is a constant. This relation is analogous to physics of the standing waves and strings on a guitar. This is definitely not a satisfactory explanation because there are a lot of missing links between connecting the shorter main pulsation period to the LSPs. In some stars we do find multiple pulsation periods that appear to match up to create the LSP, that is, the difference between the main frequencies ($f = 1/P$) create the frequency for the LSP. Gravity waves, related to buoyancy in the star, may well be a plausible explanation but then we need to understand why it is only seen in a fraction of these semi-regular stars.

The third option is both a pretty new and a pretty old idea. Soszyński et al. (2021) analyzed light curves of thousands of semi-regular variables in the Milky Way and the Magellanic Clouds [BTW, can we get a better name for the clouds? (de los Reyes 2023)] and showed that many of the stars had LSPs consistent with a dusty low-mass binary companion. Since then this idea has become more and more popular as an explanation for the LSPs. But, in many ways, this is also a very old idea.

Astronomers used to think that classical Cepheids were eclipsing binary systems until their parallaxes were measured. After that it was realized the light curves could only be explained by an eclipsing companion if one star was inside the other.

But, in this case, we don't have to worry about that problem and can focus on the binary explanation. Now, for Betelgeuse there are indications from radial-velocity measurements and from the light curve that it has a long secondary period that could be a binary companion. However, since Betelgeuse is so much more luminous than the red giants we usually think about then this companion might be something other than a dusty planet or brown dwarf-sized object. Goldberg et al. (2024) used radial-velocity measurements to infer that the companion exists at a distance of about two Betelgeuse radii with a mass of around a half to two solar masses. Basically, there could be a Sun-like object hiding in the dusty shadow of Betelgeuse. That is a story for the presses. Based on the measurements, Goldberg et al. (2024) suggested a model of the companion emitting photons in the dusty shell around Betelgeuse, clearing a region around the companion so that when the companion is in front of the star and moving tangentially, then Betelgeuse is also orbiting around the centre-of-mass in the tangential direction, hence its radial velocity will be zero. Because the companion is in front and has cleared out some of the dust, then this is when the system appears brightest. The system is dimmest when the companion is behind Betelgeuse and the radial velocity is at the extreme values when the system is near mean brightness.

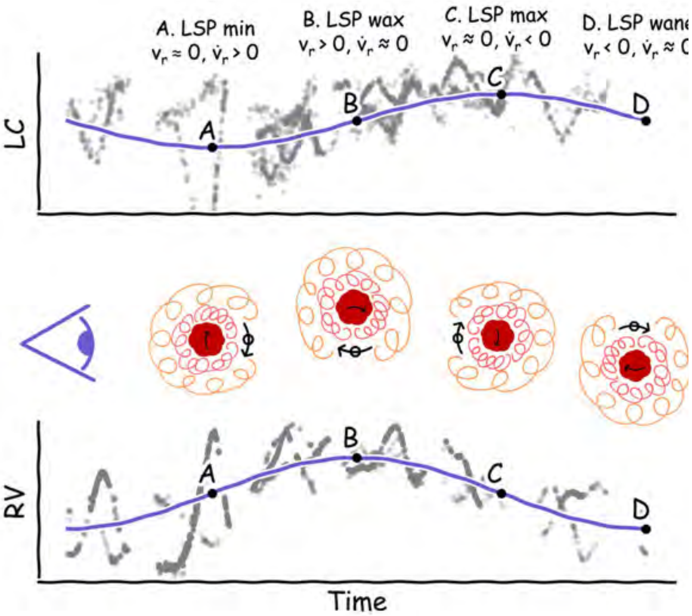


Figure 1 — Schematic of the dust modulation by a companion over the course of one orbit from Goldberg et al. (2024). The diagram in the centre shows four orientations of the companion (black circle) as well as Betelgeuse (solid red blob) and some circumstellar gas and dust (curly lines). The arrows represent the motion of the two objects. This is compared to the light curve (top) and radial-velocity variation (bottom). The phase-folded data are overplotted in gray, with the four highlighted phases labelled as A, B, C, and D. These approximately correspond to (A) the minimum brightness (increasing RV, with the stellar photosphere accelerating away from the observer), (B) increasing brightness (approximate RV maximum), (C) maximum brightness (decreasing RV, star accelerating toward the observer), and (D) decreasing brightness (minimum RV). (Image used with permission of the author.)

At the same time, another research group found pretty much the same result from an analysis of the light curve and radial velocity data (MacLeod et al. 2025), except they suggested the companion is a bit less massive and about the same surface temperature at Betelgeuse.

This is a cool story (sorry puns), but how to test this idea? Betelgeuse is about 65,000 times more luminous than the Sun so to directly observe the potential companion is like finding a firefly in the high beams of your car's light. At least that is the case over all wavelengths. Being a cool supergiant Betelgeuse emits little to no ultraviolet and x-ray radiation while a sun-like object should be pretty bright at those wavelengths, particularly since the companion is probably a very young protostar to match the age of Betelgeuse. This was the suggestion of Dr. Anna O'Grady at Carnegie Mellon University (and fellow Newfoundlander). O'Grady et al. (2025) presented observations of Betelgeuse with the *Chandra X-ray Telescope*, but alas, the companion was not visible to the X-ray paparazzi.

The result is that if there is a companion it is very dim and very young. It may even be that the phenomenon is not a true companion but a transient phenomenon that lasts a few centuries. But, altogether this creates a new tabloid story of Betelgeuse to go with the Great Dimming in 2020 and other issues, like how is Betelgeuse a runaway star (Harper et al. 2008), or at least a stumble-away star? Or, most importantly, when is Betelgeuse finally going to explode? ✶

References

de los Reyes, M. (2023). *Physics, 16*, 152. physics.aps.org/articles/v16/152
Goldberg, J. A., Joyce, M., & Molnár, L. (2024). *ApJ 977*, 1.
Harper, G., Brown, A., & Guinan, E., Kiss, L.L., Szatmáry, K., Szabó, G., & Mattei, J. (2000). *A&A, 145*, 283.
MacLeod, M., Blunt, S., De Rosa, R. J., et al. (2025). ApJ, 978, 1.
Percy, J.R. & Shenoy, M.H. (2023). *JAAVSO, 51*, 2.
Percy, J.R. & Szpigiel, M. (2025). Retrieved from arxiv.org/abs/2502.08842
Soszyński, I., Olechowska, A., et al. *ApJL, 911*, 2.
Spencer Jones, H. (1928). *MNRAS, 88*, 660.
Strothers, R.B. (2010). *ApJ, 725*, 1.
Wood, P.R., Olivier, E.A., & Kawaler, S.D. (2004). *ApJ, 604*, 800.

Hilding Neilson, Ph.D., is an astrophysicist and professor in the Department of Physics & Physical Oceanography at Memorial University of Newfoundland & Labrador in St. John's Newfoundland, where his research focuses on stellar and exoplanet physics and the stories we can learn from stars and planets. He is also Mi'kmaw from Ktaqmkuk and works to integrate Indigenous knowledge in astrophysics research and how we relate to outer space exploitation and the future of large astronomical observatories. Dr. Neilson has been featured on numerous outlets, including the CBC, The Globe and Mail, The Guardian, *and more. He has also published over 50 research articles.*

Skyward

What Can Happen When You Are in a Bad Mood

by David Levy, Kingston & Montréal Centres

Most of the story that follows is true, although I admit possibly to a few exaggerations.

It was an August evening, in 1863, at the U.S. Naval Observatory in Washington, D.C., and Asaph Hall, who was observing with the 9.6-inch refractor, was not in a good mood. The night was not going particularly well. To add to his stress, there was a knocking at the observatory's front door. Planning to vent his unease at whoever was knocking, Hall descended the stairs and thrust the front door open.

At the door were two gentlemen. According to George William Hill's Biographical Memoir of Asaph Hall, 1829–1907, one was likely Edwin Stanton, the Secretary of War. The other was Abraham Lincoln, the 16th President of the United States. Lincoln explained that they were out walking and wanted to know if they could have a brief look through the telescope, the wonderful refractor. Hall's bad mood vanished instantly, and the three proceeded to enjoy a look at the Moon, and the star Arcturus.

Two nights later there was another knock at the door. This time Hall, in a far better mood, was ready. Lincoln was alone this time. (In those days, Lincoln thought he could get away with walking alone without protection; he was sadly wrong about that.) He wanted to ask some questions. He was puzzled that the telescope view was upside down. Hall explained that astronomical telescopes do not have correcting lenses.

A not-too-dissimilar event happened 131 years later. On the evening of 1994 July 19, the Vice President of the United States, Al Gore, strolled across the vice-presidential property to the Naval Observatory, where Geoff Chester, then public affairs officer at the United States Naval Observatory, was observing with the giant 26-inch refractor. He showed the Vice President the latest impact spots decorating the southern half of Jupiter. I know this because the very next day at a White House ceremony celebrating the 25th anniversary of the *Apollo 11* landing and walk on the Moon, Mr. Gore told me.

It was wonderful when Gene and Carolyn Shoemaker and I got to meet and chat with Al Gore. He was interesting, personable, and smart. He also told us how he enjoyed the impact sites on Jupiter the previous evening. He did not want to discuss politics; he just wanted to share S-L 9 stories.

In the darkest days of the U.S. Civil War, Asaph Hall enjoyed two delightful evenings with the President of the United States. I know of a few other Presidents who were interested in the night sky. One was John Quincy Adams, who in 1825 signed a bill into law establishing what he wanted to call a national observatory, and which evolved into the Naval Observatory. Adams had a keen interest in astronomy. Another was John F. Kennedy, who once claimed that he had no interest in astronomy. But in an address to the American University in June 1963 he said, "For in the final analysis, our most basic common link is that we all inhabit this small planet. We all breathe the same air. We all cherish our children's futures. And we are all mortal." ✶

Figure 1 — A single beautiful US Capitol picture taken May 1975 when I could take a good picture.

David H. Levy is arguably one of the most enthusiastic and famous amateur astronomers of our time. Although he has never taken a class in astronomy, he has written more than three dozen books, has written for three astronomy magazines, and has appeared on television programs featured on the Discovery *and* Science *channels. Among David's accomplishments are 23 comet discoveries, the most famous being Shoemaker–Levy 9 that collided with Jupiter in 1994, a few hundred shared asteroid discoveries, an Emmy for the documentary* Three Minutes to Impact, *five honorary doctorates in science, and a Ph.D. that combines astronomy and English Literature. Currently, he is the editor of the web magazine* Sky's Up!, *has a monthly column, "Skyward," in the local Vail Voice paper and in other publications. David continues to hunt for comets and asteroids, and he lectures worldwide. David was President of the National Sharing the Sky Foundation, which tries to inspire people young and old to enjoy the night sky.*

Dish on the Cosmos

Are Comets the Secret to Understanding our Solar System?

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

The Atacama Large Millimetre/submilletre Array (ALMA), a favourite of this column, is well known for its ability to see distant galaxies, extragalactic star-forming clouds, and protoplanetary disks. It helped astronomers directly image a black hole. It's often used to peer out into the Universe, seeing distant things we could only imagine. It turns out, this incredible resolution is also suited for studying our own Solar System, including small, icy, gas-expelling comets.

Comets are thought to be the most pristine remnants of our early Solar System. Their frozen composition has not been modified or processed since they formed. Current theories of Solar System formation suggest that comets were formed alongside planets in the midplane of the protoplanetary disk surrounding the Sun before being flung out to the edges of the Sun's gravitational influence. Now, we distinguish comets in different flavors based on how they orbit the Solar System: the short-period comets, including the Jupiter-family and Halley-type comets, and the long-period comets.

Jupiter-family comets, named as they are influenced by Jupiter's gravity, have orbits near the ecliptic with periods of less than 20 years. These are thought to arise tens to hundreds of AU (astronomical units, the approximate average distance between the Earth and the Sun) from the Sun in the donut-shaped Kuiper Belt or the scattered disk—two associated regions of icy bodies past Neptune that are slightly poofed from the ecliptic.

Halley-type comets are named for the prototype comet 1P/Halley and the person who discovered its reappearances, Edmund Halley. These comets have periods of 20 to 200 years and are thought to originate from the distant, spherical Oort Cloud, a collection of icy objects thousands of au from the Sun.

Long-period comets have orbits of more than 200 years, up to thousands or more years. They are also thought to originate in the Oort Cloud, in the farthest realms of the Solar System. These comets get flung inward at any odd orientation.

When comets approach the inner Solar System and are heated by the Sun, they develop their signature look with tails. A gas tail of vapourized material flows directly away from the Sun. Dust, expelled with the gas, forms a second tail curved away under the influence of the comet's motion—the dust particles are larger than the gas particles and are less influenced by the Sun.

This gas structure developed around a comet is called a coma. The core comet material of rock, ice, and dust is called the nucleus. The solid material is made of silicates and organic material, while the gaseous material contains many simple molecules dominated by carbon, oxygen, nitrogen, and sulphur, such as H_2O, CO_2, CO, CH_4, O_2, CH_3OH, H_2CO, NH_3, SO_2, H_2CS, OCS, H_2S, CH_3CN, or HC_3N.

This is a beneficial look back in time at the composition of the area of a protoplanetary disk where planets may be forming. The cold midplane of a protoplanetary disk is opaque in important molecular tracers and is hard to study in star- and planet-forming regions. Comets are formed with the chemical composition of these areas, and conveniently retain information for us to study billions of years after a stellar system forms.

It has been 100 years since a major scientific discovery was made about the composition of our Solar System. In 1925, Cecilia Payne-Gaposchkin published her then-overlooked, now-revered thesis on the elemental composition of the Sun. At Harvard College Observatory she used recent developments in physics—understandings of discrete spectral lines and of ionization processes—to determine what information was hidden in stellar spectra. She found that hydrogen and helium were by far the dominant elements in our Sun, a stark contrast to the contemporary thought that the Sun and the Earth had the same composition. (Earth, in comparison, is made of iron, oxygen, silicon, magnesium, and other heavier elements.) She also found that a star's spectra is a reflection of its temperature. Her findings changed our view of what the Universe was made of.

In the century since, we've made great strides in understanding matter, in the basic composition of the Universe, in stellar evolution, and in star and planet formation. Alongside these, we've come to understand the make-up of our own Solar System, from planets to distant comets, in greater detail. There have been decades of work in spectroscopic observations at longer wavelengths contributing to this work, and these days, ALMA is a forefront instrument allowing us to not only observe, but image in great detail, the molecular composition of these astronomical objects.

A decade ago, astronomers observed the distribution and evolution of HCN, HNC, and H_2CO in the coma of the comets C/2012 F6 (Lemmon) and C/2012 S1 (ISON). An important distinction was revealed—HCN was vapourized from the comet nucleus, while HNC and H_2CO were formed in the gaseous environment of the coma. Potentially, they were formed from the breakdown of larger molecules. In follow-up

Figure 1 — An artist's impression of the comet C/2014 UN271 (Bernardinelli-Bernstein). Credit: NRAO/Melissa Weiss.

observations of C/2012 S1, snapshots of the comet over time showed the gas production was variable on timescales of minutes or days. (In astronomy, we don't often get to monitor how things change in real time.) As comets orbit the Sun, new layers or chunks of heterogeneous material may be expelled.

The molecular composition of comets can be directly revealing of Earth's evolutionary history. This year, ALMA observations of the Halley-type comet 12P/Pons-Brooks studied two water isotopes—H_2O and the deuterium-substituted HDO. Deuterium is an isotope of hydrogen, meaning it is a form that has the same number of protons and a different number of neutrons. Isotopic ratios like D/H (or 12C/13C, or 14N/15N) are key in deciphering the history of different astronomical bodies. For example, determining where less-common isotopes are substituted in molecules helps study if cometary ices were formed before or after the Sun formed, or where Earth's water came from. The D/H ratio in comets seems to be diverse with the limited sample of comets that scientists have been able to observe, but bright and active comets like 12P/Pons-Brooks provide important data points. The D/H ratio derived with these recent observations matches that of Earth's oceans—evidence supporting the idea that comets or other icy bodies provided Earth with its water through collisions.

ALMA, as well this year, observed the behemoth 140-km large comet C/2014 UN271 (Bernardinelli-Bernstein) at a distance of 16.6 au. C/2014 UN271 is visiting the inner Solar System during its orbit that also reaches out to 55,000 au from the Sun, in the depths of the Oort Cloud. The current observations show CO gas being expelled from the comet (Figure 1). As C/2014 UN271 approaches near the Sun, reaching its closest point in 2031, it will continue to be monitored. Astronomers expect to see the vapourization of other molecules, of deeper layers of material, but only time will tell. C/2014 UN271 may represent a class of primordial "megacomets" that have remained unfragmented since their formation billions of years ago.

Serendipitously, astronomers have been able to study primordial objects from other stellar systems. In 2020, ALMA observed our second interstellar visitor 2I/Borisov. As 2I/Borisov passed its closest approach to the Sun, astronomers monitored its gas production. The ratio of CO and H_2O changed drastically, representing a heterogeneity in the makeup of the nucleus—a direct look at the conditions affecting planet formation in its home planetary system.

While studying comets here provides key details about how our own Solar System formed, there are limitations to what we can study. Looking outward to other stellar systems challenges, or supports, ideas that we have developed. The Resolved ALMA and SMA Observations of Nearby Stars survey imaged 74 comet belts around other stars to do just this. The striking images (Figure 2) aren't uniform—the belts come in all sorts of shapes and sizes. These belts are the debris left over

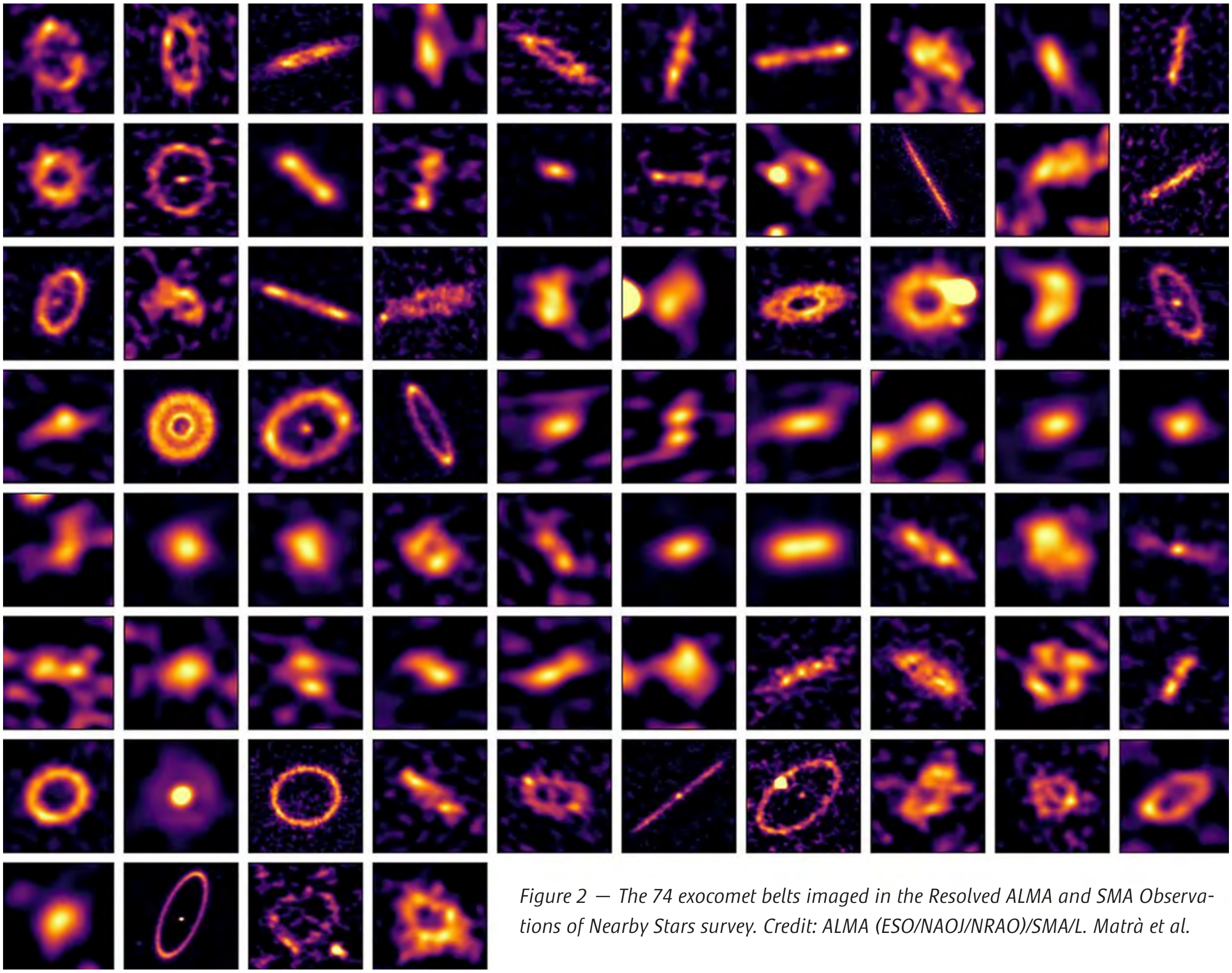


Figure 2 — The 74 exocomet belts imaged in the Resolved ALMA and SMA Observations of Nearby Stars survey. Credit: ALMA (ESO/NAOJ/NRAO)/SMA/L. Matrà et al.

from planet formation, holding important clues about how and where planets form. These images are just the start of this research.

Newly observed objects such as interstellar comets and exocomet belts demonstrate the observing capabilities of modern telescopes. From here, increasingly powerful telescopes across wavelengths will provide enormous data sets to uncover the true nature of comets. The Vera C. Rubin Observatory, equipped with the world's largest digital camera, will scan the whole sky above itself every few nights. It is primed to find small, icy bodies wandering around the Solar System. The next-generation Very Large Array (ngVLA) will push forward this research at longer wavelengths. It will harness the perks of current radio observations—good spectral resolution and spatial resolution—and only improve it. In the centimetre wavelength regime of the ngVLA, important constituents of comets, like NH_3 and OH, will be mapped at high resolution for the first time. These molecules may reveal the true nature of comets, potentially filling in chapters in the story of how our Solar System began.

Read more on

C/2014 UN271 (Bernardinelli-Bernstein): iopscience.iop.org/article/10.3847/2041-8213/add526

12P/Pons-Brooks: www.nature.com/articles/s41550-025-02614-7

21/Borisov: www.nature.com/articles/s41550-021-01336-w

Exocomet belts: www.aanda.org/articles/aa/full_html/2025/01/aa51397-24/aa51397-24.html

Check out the Zooniverse to hunt for comets in early Rubin Observatory images: www.zooniverse.org/projects/orionnau/rubin-comet-catchers ✶

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.

Astronomical Art & Artifact

Discovery of Rare Field Glasses Signed by Charles Potter, one of the Eight Founders of the Toronto Astronomical Club of 1868

by R.A. Rosenfeld, FRASC
(r.rosenfeld@rasc.ca)

Abstract

A rare instrument bearing the signature of the Toronto based scientific instrument maker Charles Potter (1831–1899) was discovered earlier this year. Potter was one of the eight founders of the Toronto Astronomical Club in 1868, the organization from which the RASC can trace its ultimate origin (and he was the only scientific professional among them). This brings to sixteen the number of known instruments under Potter's name produced after he left the partnership with William Hearn, and the working arrangement with his brother A. F. Potter. The field glasses are the sole surviving Potter instrument thus far identified that could have been used for the sort of recreational astronomy practiced by many early Society members. Doubts about the instrument's real origin provide further information about the nature of Potter's trade.

Expectations of Survival

Many of us harbour assumptions about the number of instruments of a certain type, or period, or from a certain manufacturer, that "ought to have" survived. Surely the more important a discovery with a particular make of instrument, or the greater the maker's reputation, the greater the likelihood that such an instrument will be extant. Our assumptions and expectations of artifact survival are usually heavily influenced by cherished narratives of the progress of science culminating in us. Those narratives are hard to lay aside.

Figure 1 — Photograph of Charles Potter. Reproduced after Watson 1917, plate II.

Several dramatic instances can serve as illustration. Galileo's telescopic discoveries conferred Europe-wide fame on both the discoverer, and his instruments, ensuring that his telescopes were in high demand (Del Santo et al. 2008, 45). His fame has proved a thing for the ages, but his instruments have proved less eternal. At present count just two telescopes attributed to Galileo have survived (and only one with complete original optics), along with an objective glass from a third (Van Helden 1999, 30–33). There are in fact many more extant astrolabes from ca. 1400 CE attributed to Jean Fusoris's (ca. 1365–ca. 1436) atelier than telescopes from Galileo's *officina* two centuries latter (Poulle 1963; King 2019, 364–365).[1] Many of us would have expected the opposite, given the values nurtured by popular ideas of scientific progress.

Benedict Spinoza (1632–1677), in the years after his fortuitous expulsion from the Amsterdam Sephardic community, became celebrated as a philosopher, and as a maker of optics for microscopes and telescopes. Christiaan Huygens (1629–1695), famous himself as a maker and user of telescopes, remarked that the optics of Spinoza's microscopes "have an admirable polish," and that through his technical accomplishments "he renders them very excellent" (Nadler 2000, 1426; Vermij 2013, 75; Nadler 2018, 217; Klever 2020). No less a person than Gottfried Wilhelm Leibniz (1646–1716) wrote "To the Illustrious and most Distinguished Mr. B.D.S.," that "Among the other praises the common report has bestowed on You, I understand that you also have outstanding skill in Optics" (Spinoza 2016, 392–393, letter 45). Despite Spinoza's enduring fame and philosophical importance, the fate of his instruments is even more obscure than Galileo's—not a single one is known to have survived to the present.[2]

Real data about the relative rate of instrument survival can be derived from comparing production lists or old inventories with tallies of surviving instruments. Unfortunately, the records that would enable such comparisons frequently don't survive, even for many 20th-century firms. Canadian material is particularly underexplored, especially when it comes to the retrieval of old inventories. Without those records, we can only speculate as to the cause(s) of rare, moderate, or rich representation in the artifactual record. These relative terms (rare, moderate, and rich) would also have to be given quantitative or at least qualitative definition. A poor rate of survival may be due to factors such as: a) limited advertising, sales, or distribution; b) a short period of production or availability; c) poor build quality; d) or a combination of all three. Or conversely it could result from attrition from resulting from the heavy use of instruments that were popular, fit to the task, and widely distributed. In the absence of production numbers or even estimates, it is difficult to know which is the case.

INSTRUMENT TYPE	*LIST NUMBER*	*SIGNATURE*	*DATE OF MANUFACTURE (OR DATE RANGE)*	*PRESENT LOCATION*	*SOURCE*	*COMMENTS*
CIRCUMFERENTOR						
	1	"C. Potter" [?]		The Association of Ontario Land Surveyors, Toronto ON	Brooks & Daniels 1993, 1044	
	2	"C. Potter" [?]	*ca.* 1870	University of Toronto Mississauga, ON	Brooks & Daniels 1993, 1044	
	3	"Potter, Toronto, C.W." [?]	*ca.* 1860–1867	Alberta Land Surveyors Association, Edmonton AB	Olsson (n.d.)	This instrument could be by either Charles Potter, or his younger brother, A.F. Potter. "C.W."=Canada West.
FIELD GLASS/OPERA GLASS						
	4	"C. Potter[,] Toronto"	*ca.* 1890s?	private collection, Toronto ON	this paper	
LEVEL						
	5	"Charles Potter" [?]		Wellington County Museum & Archives (acc. no. 991.23.30.05), Fergus ON	Wellington County Museum & Archives, Collections Catalogue	
MAGIC LANTERN						
	6	"Chas. Potter, Toronto"	*ca.* 1860–1910	University of Manitoba, Department of Physics and Astronomy, Winnipeg MB	Fisher 2023, 347–348	"The Potter Lantern"
MICROSCOPE						
	7	"Charles Potter" [?]		City of Waterloo Museum, ON	City of Waterloo Museum, Meet Charles Potter	monocular, student model?
SHIP'S COMPASS						
	8	"C.A. Potter" [?]		Thunder Bay Military Museum, ON	Brooks 1992, Part 1: Non-NMST Instruments, 12	
	9	"C.A. Potter" [?]		Hudson's Bay Company (HBC) Museum Collection, Manitoba Museum, Winnipeg MB	Brooks & Daniels 1993, 1045	
SURVEYOR'S COMPASS						
	10	"C.A. Potter" [?]	*ca.* 1860?	Manitoba Museum (H8-54-1), Winnipeg MB	Brooks 1992, Part 1: Non-NMST Instruments, 9; Brooks & Daniels 1993, 1045	
THEODOLITE						
	11	"Charles Potter" [?]		Glenbow Museum (HP-3935.1), Calgary AB	Brooks 1992, Part 1: Non-NMST Instruments, 9; Brooks & Daniels 1993, 1045	
	12	"Charles Potter" [?]	*ca.* 1880	The Association of Ontario Land Surveyors (99 1 .T- 1), Toronto ON	Brooks & Daniels 1993, 1044	
TRANSIT						
	13	"C. Potter" [?]		The Association of Ontario Land Surveyors (983.T-2), Toronto ON	Brooks & Daniels 1993, 1044	
	14	"C. Potter" [?]	*ca.* 1900	private collection	Brooks & Daniels 1993, 1044	
	15	"C. Potter" [?]		Halton Region Heritage Services (977.26.1 File 1 17), Kelso Conservation Area, Milton ON	Brooks & Daniels 1993, 1044	
	16	"C. Potter" [?]		Peel Art Gallery, Museum and Archives (PAMA), Brampton ON	Brooks & Daniels 1993, 1045	

Notes: 1. [?] indicates that the reported form of a signature has not been confirmed by recent physical inspection, or examination of a clear photograph; 2. the location of artifacts is based on reports in the sources—these have been updated in some cases, but it is recommended that institutions be contacted directly to confirm that artifacts are still in their possession.

Table 1 — The known instruments signed by Charles Potter 1853–1899 after he set up shop on his own. It can be expected that their number will increase as more collections come online. Table by R.A. Rosenfeld.

If there is a lesson here it is that the survival of artifacts is radically contingent. History doesn't care about our expectations of what ought to survive. Even if we succeed in adjusting our sense of the numerical reality of the material past to accord with the actual artifactual record, it will not necessarily banish our expectations of what ought to have survived. Our expectations may linger past enlightenment.[3]

Figure 2a — The Potter family obelisk (Alkali feldspar granite) at the Mount Pleasant Cemetery, Toronto. Photograph by R.A. Rosenfeld.

Figure 2b — Inscription panel commemorating Charles Potter, located on the south side of the obelisk. Photograph by R.A. Rosenfeld.

Unlike Galileo or Jean Fusoris, Charles Potter (Figures 1, & 2 a-b) was not a personage of international renown in the scientific world of his day, nor was he destined for posthumous fame in the common cultural narrative of Western science. He was, however, one of the dominant and enduring figures in the trade of scientific instruments in late Victorian Canada. The relative scarcity of his instruments today *is* surprising (Table 1).[4] Admittedly this is an expectation. Future work may reveal that the meagre survival of his identifiable *oeuvre* may be notable, but not wholly exceptional among the artifactual remains of those who were engaged in the 19th-century Canadian scientific-instrument trade. However that may unfold, the examination of the field glasses bearing his name has the potential in the here and now to add to our knowledge of the nature of Potter's trade.[5]

Charles Potter

The first compendious account of Potter (1831–1899) was published by Julian Smith in this *Journal* in 1993. Smith deserves considerable credit for tracking down material prior to its easy availability on the internet, and synthesizing the relevant data to provide a rounded portrait of Potter to replace the previous dim silhouette fleetingly sighted from occasional references. Since then a few corrections and supplements have followed (e.g. Brooks & Daniels 1993, 1040; Wilson 2001; Daniels 2005, 13; Fischer 2023, 347–348). Some previously underutilized sources permit a fuller account of details of Potter's career as a scientific instrument maker to be presented below, and corrections to some statements in previous accounts, but major questions still remain unanswered.

Potter arrived in Toronto in 1853 (Smith 1993, 15; Brooks & Daniels 1993, 1040). According to one secondary source, Potter and his younger brother, Augustus Frederick, were trained by their father, also named Charles, in the craft of scientific instrument making (Brooks & Daniels 1993, 1040, citing "the [Potter] family records" in the possession of the second author). This is in partial agreement with one of the Potter entries in Gloria Clifton's *Directory of British Scientific Instrument Makers* (1995). A mathematical instrument maker Charles (II) Potter (1799–1864) is noted there, who had been apprenticed to George (I) Dollond, and was free of the Grocers' Company in 1847 (Clifton 1995, 221). This Charles (II) Potter also had as an apprentice a son named Charles (III). This may well be the Charles Potter who practiced his trade in Toronto, and whose name is on the field glasses discussed in this paper. Clifton, however, makes no mention of a younger brother in the trade named Augustus Frederick, who had also been trained by the elder Charles (II) Potter. It has to be admitted that neither "Potter," nor "Charles" were unusual names in Dickens's London, and given the present state of knowledge, there is even the possibility that we are dealing with *two* different contemporary families of instrument-making Potters. Further trawling in the London Archives among the Grocers' Company papers, and the apprenticeship indentures of the Dollond family may eventually settle the matter.

In the year of his arrival in Canada, Potter entered into a partnership with William Hearn—it is not clear from the secondary literature whether Hearn's primary formal training was as a watchmaker and jeweller, or as a mathematical instrument maker (Smith 1993, 15; Fisher et al., William Hearn; Fisher et al., Hearn & Potter).[6] If the former, then his partnership with Charles Potter, a trained maker of philosophical instruments, would have made solid business sense, enabling the partnership to confidently commence in trade in more craft disciplines than were available to either of the partners setting up shop alone (eventually, when trading under his own aegis a few years later, Hearn covered all those craft disciplines). It may also have seemed prudent in the small market of a provincial capital in the early 1850s. In the modern secondary literature the partnership is represented as doing tolerably well, chiefly based on the proxy indicator of credit reports compiled by the Mercantile Agency (the ancestor of Dun & Bradstreet).[7]

For the entirety of the Hearn & Potter partnership, *The Globe*, Toronto's Tory broadsheet, was among their favourite advertising venues (and it remained so for Potter after he and Hearn had parted ways).[8] The choice of *The Globe* may have reflected the men's political leanings. Advertisements can sometimes be remarkably useful in establishing the location(s) of a scientific business, its chronological development, which instruments were believed best suited to particular markets, the range of goods and services offered, and the relative ranking of the specialties, instruments, sources, and services offered (or promised). The scarcer are other historical sources, the more valuable advertisements become.

The advertisements in *The Globe* have previously been used to give some sense of the Hearn & Potter stock, establish that the retail of imported goods was part of their trade identity, and discuss a particular claim for craft pedigree (Smith 1993, 15, 17–18; Brooks & Daniels 1993, 1040; Wilson 2001, 8; Clifton 2017, 108). The latter is interesting.

In a series of ads running from late November of 1853 to early February 1854, readers could find "Hearn & Potter (FROM DOLLOND'S)…" (*The Globe* X 166, 1853 November 28, 1; 172, 1853 December 3, 1; 189, 1853 December 24, 3; 193, 1853 December 29, 4; XI, 1854 February 6, 3). The Dollond firm (London 1750–) enjoyed a high reputation due to its early specialization in the commercialization of achromats, and the high standard of its products in general, so much so that the name "Dollond" is more likely to have been known in a colonial provincial capital than others in the trade.[9] The claim in the Hearn & Potter ads for a Dollond association has usually been interpreted as a statement that one of the partners—usually Potter—worked for Dollond's as a journeyman, or might even have served an apprenticeship there (e.g. Smith 1993, 15). This would have been in the days of George (I) Dollond (1774–1852), or George (II) Dollond (1797–1866) (Barty-King 1986, 84–106). Brooks and Daniels have raised mild doubt about the specificity of such claims, not unreasonably wondering: "Was the reference to Dollond, one of London's leading makers and dealers in all types of scientific instruments, to the source of their stock or where one or both of the partners had been apprentices or journeymen? At this point, Astronomical Art & Artifact: we cannot say" (Brooks & Daniels 1993, 1040). Their call for more supporting documentation still stands.

It is possible, however, to cite long-established trade practice in defence of the standard interpretation of the phrasing, that Potter may have been a Dollond apprentice, or journeyman. The formula "from so-and-so's firm" is attested as meaning either "served an apprenticeship under," or "worked as a journeyman for." By way of example, "William Brind, Scale Maker…(From M^r. Read's)…," and "Oliver Combs, (from M^r. Scarlet) Optician…" used the formula on their trade cards, in Brind's case (fl. 1753–1775) to indicate his master, and in Combs's case (fl. 1691–1750) to advertise that he was a journeyman for Scarlet (Calvert 1971, 15 no. 61, pl. 15, & 18 no. 96, pl. 20). And the layout of one of the ads in *The Globe* can be read as applying the formula to Potter, rather than Hearn (*The Globe* XI, 1854 February 6, 3). Furthermore, if Charles (III) Potter is indeed the Toronto philosophical-instrument maker, then there was an existing family connection with the Dollond's, for his father Charles (II) Potter had served his apprenticeship with them. Yet this interpretation would clash with the suggestion that Charles (III) Potter was his father's apprentice (as noted above), unless his apprenticeship were transferred, perhaps starting with the Dollonds and then going to his father, or vice versa.

Hearn & Potter were also alert enough to turn an astronomical event to their advantage (as is done today by vendors of astronomical equipment). In the period leading up to the annular solar eclipse of 1854 May 26, they advertised "Eclipse of the Sun. Telescopes and Dark glasses for viewing the coming Eclipse..." (*The Globe* XI, 62 1854 May 18, 3; XI, 625 1854 May 29, 4).

And they were sufficiently aware of some scientific developments on the continent that four years after Léon Foucault designed and used his gyroscope in experiments to demonstrate the Earth's rotation, they advertised a toy version in time for the Christmas season (*The Globe* XIII, 1310 1856 December 27, 3)!

Despite enjoying what looks like modest prosperity, the partnership only lasted a few years, dissolving in 1857 for reasons yet to be divined.

From 1857–1860 Charles Potter collaborated with his brother, Augustus Frederick Potter (an accomplished craftsman who often appeared as A.F. Potter in trade). It is natural to assume that the Potters operated as a partnership (as in Fisher, Augustus Frederick Potter). Brooks & Daniels, however, perceptively observe that no partnership was possible, "since there were still claims against him [Charles Potter] from the failed Hearn & Potter partnership" (Brooks & Daniels 1993, 1040, confirmed by a Mercantile Agency credit report). The working arrangement between the brothers was sundered in July 1860. It made for vivid reading in the popular press.

Figure 3 — Watercolour by W.S. Hatton of the Rossin House Fire, 1863. Toronto Public Library, Baldwin Collection of Canadiana, Object Number PICTURES-R-1842. Reproduced courtesy of Toronto Public Library.

First A.F. Potter ran ads stating "...that CHARLES POTTER, lately in his employ, is not authorized to receive any accounts due to the said A.F. POTTER, or transact any business for him..." (*The Globe* XVII, 150 1860 July 17, 3; XVII, 151 1860 July 18, 3). Then came the details of the legal case several months later:

> "In the Police Court yesterday...Mr. Augustus Potter, Optician, Rossin Buildings, charged his brother, Mr. Charles Potter, with abstracting several mathematical instruments from his premises. The defence rested on the point that the accused was a partner with his brother, and therefore could not be amenable to the charge. The prosecutor alleged that Mr. Charles Potter was only a journeyman in his employ, and consequently had no right to take away the articles, the theft of which he was now charged with" (*The Globe* XVII, 205 1860 September 21, 3).

And on the subsequent day:

> "In the case of Mr. Charles Potter, after a rather lengthened investigation, the defendant entered into security, himself £100, and a bailsman in a similar amount, to answer the charge at the forthcoming assizes" (*The Globe* XVII, 206 1860 September 22, 2).

£200 was a very sizeable bail. It's possible that the amount reflected the value of the scientific instruments in question, or the magistrate's assessment of Charles Potter as a flight risk, or both. It would appear that the brothers had very different conceptions of their working relationship, at least as presented to the court. Whatever the rights and wrongs of the case, Charles Potter's stratagem to avoid his creditors almost certainly meant that his brother's conception of the relationship was the legally correct one—Charles can only have been a journeyman working for his brother. In a society where social class mattered, Charles's subsidiary position can't have been easy, particularly if he was the older brother, and had earlier enjoyed the status of a master mathematical-instrument maker as part of Hearn & Potter.[10]

After their very public dissociation, the brothers maintained rival establishments in relatively close proximity in the very upscale Rossin House Hotel. Early in the morning of 1862 November 14, fire broke out and eventually gutted the hotel (Figure 3):

> "The many fine stores on the ground floor of the Rossin House Block shared the fate of the rest of the building, but in most cases their contents were got out without any very heavy loss...The stores fronting on King Street were

> occupied by… [among others] Chas Potter, Optician… Mr. Charles Potter, optician, estimates that his loss, both goods and fixtures, will be about $400. He had no insurance. Mr. A.F. Potter succeeded in removing most of his property. He was insured in the Liverpool and London for $1,000, which will more than cover his loss" (*The Globe* XIX, 239 1862 November 15, 2).

Fortunately, only a single fatality resulted, but the scene of that fatality involved more unwelcome publicity for Charles Potter:

> "…a party of men were at work [removing goods and fixtures at risk] in the rooms on the floor above the King-street stores…Suddenly, while some of them were directly over Mr. Charles's Potter's store, the floor on which they stood, to the intense horror of all who witnessed it, gave way with a fearful crash, and they fell through into the store [i.e., Charles Potter's]…" (*The Globe* XIX, 239 1862 November 15, 2).

Clearly Augustus Frederick was a more provident man of affairs than was his brother.

Despite these misfortunes, either of which could have proved terminal to his career as a philosophical-instrument maker, Charles Potter managed to survive and eventually thrive in the provincial trade, to become one of its major figures. For nearly four decades after the Rossin House fire Potter built up a steady trade in retailing and repairing surveying equipment for professionals, institutions (schools and governments), and students (Smith 1993, 24–27). He became one of the main suppliers of varied scientific equipment to educational institutions at all levels, and branched out into textbook and map supply as well (Smith 1993, 25–27; Daniels 2005, 13). He was involved with the development of Toronto's early telephone exchange (Smith 1993, 23). He also marketed hand-painted and photographic lantern slides on a wide variety of subjects: scientific, scenic, and religious (Wilson 2001). It is likely that many more religiously themed lantern slides still bearing "Charles Potter" labels survive than do his signed scientific instruments. The diverse trade that marked his earliest days with Hearn also characterized his mature career.

A few more points can be made about his career.

It was not unusual for mathematical instrument makers and opticians to move their premises from time to time, but usually keeping to the confines of districts where the trade was locally practiced. In 17th- to 19th-century London one such area was The Strand, in Paris it was the Quai de l'Horloge, and in 19th-century Toronto it was centred on King Street, to either side of Young Street (Figure 4). What is remarkable is how often Potter moved within that area (Map 1). At times it may have been to seek larger or otherwise more suitable quarters to accommodate his business as it then was, or as he projected its development, at other times it may have been spurred by necessity, but for most of the moves the precise reasons remain unknown.

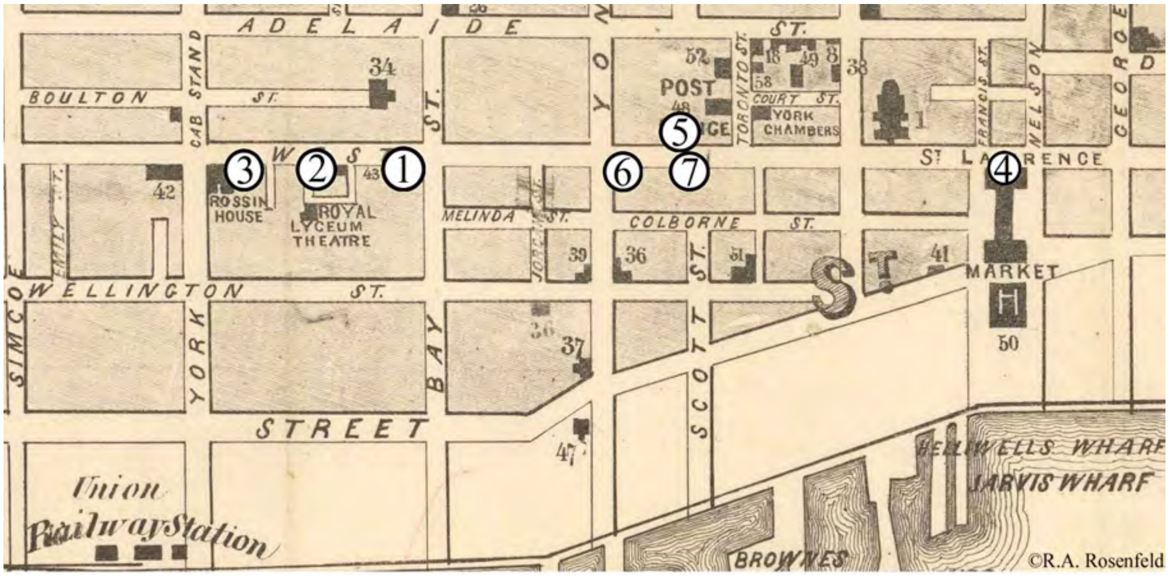
Maker or Importer?

One question inevitably arises with regard to instrument makers in 19th-century Canada: "how much of their trade consisted of retailing instruments made elsewhere, and how much was met by instruments they manufactured on their own premises?" In many cases this can be surprisingly difficult to answer. Daniels (2005) offers some intelligent reflections on this problem, and Brooks & Daniels (1993, 1039) must surely be on the mark to raise the possibility that, as in Europe, much of the manufacturing involved sub-contracting, but that the practice could vary a great deal (even by the same firm). It is also likely that for many scientific instrument makers, even those who were very accomplished craftsmen, their stock was a mix of instruments, some wholly produced in-house by themselves and their staff, others that were only partially so, and yet others that were entirely produced elsewhere, often overseas. And many others who offered scientific instruments, such as jewellers, were only retailers, rather than manufacturers.

What then of Charles Potter?

In the absence of a signature, style in manufacture can be a sort of maker's "signature," or fingerprint, as it were. It can show itself in the choice of a design of instrument with a close association with a particular craftsman, particularly if patented (e.g. Riefler-type *Rundsystem* mathematical tools). Or it may appear in a preference for certain techniques (e.g. tap and die rather than turned on a lathe), or materials (e.g. ivory rather than silver), or decoration (e.g. enamelled rather than plain), or for certain parts over others (e.g. threaded rather than snap backs). Such elements of style aren't infallible markers of maker's identities (they can be shared or copied by competitors or forgers), but when distinctive they can be highly suggestive. Unfortunately (as far as the present author is aware), no one has yet published such an analysis based on the surviving Potter instruments.

Turning to texts, we find in one of Potter's early ads the not unexpected claim that he was both a "maker" and an importer of scientific instruments: "POTTER, PRACTICAL OPTICIAN, MAKER and IMPORTER of…all kinds of MATHEMATICAL and PHILOSOPHICAL INSTRUMENTS…" (*The Globe* XIV, 235 1857 October 2, 3). And by 1872, he could state that he was "MANUFACTURER TO THE Crown Lands Department, Excise and Board of Pubic Works, Ottawa. [And to the] Educational Department, Public Works, Crown Lands, Ontario" (City of Toronto Archives, Notman and Fraser photographs of Toronto, Fonds 1662, Item 14, shown in Figure 4). Are there any more specific textual witnesses to his claim to be a maker of philosophical instruments?



Map 1 — Successive locations of Potter's business 1853–1899 after he set up shop on his own. Map by R.A. Rosenfeld using Charles Unwin's Plan of the City of Toronto *1890 (James Bain: Toronto) as the base.* Note: the dates are approximate and subject to revision, and some additional short-term locations may be uncovered through further research.

1. 1853-ca. 1859 54 King Street East

2. 1859-1860 85 King Street West

3. ca. 1860-ca. 1864 121 King Street West next to the Rossin House, or in the ground floor of Rossin House (depending on the source!)

4. also St. Lawrence Hall 1861-ca. 1862?

5. 1864-ca. 1870 20 King Street East "The Sign of the Spectacles"

6. 1873-1880s 9 King East

7. late 1880s?-1890s 31 King Street East

Both *The Globe* and *The Canadian Journal of Industry, Science, & Art* (house publication of the Canadian Institute) provide the clearest attestation that Potter was more than an importer. They describe the invention of an early photographic ophthalmoscope by Dr. Abner Mulholland Rosebrugh (1835–1914), "the father of ophthalmology in Toronto," for whom Potter was his manufacturer of choice (Opthalmology & Vision Sciences University of Toronto; Connor 1998; Figure 5).[11] The notice Potter received in both the lecture presenting the device to the Canadian Institute, and in the formal paper that followed cannot have hurt either his reputation, or his business. The broad sheet reported on "A VALUABLE SCIENTIFIC INVENTION. At a meeting of the Canadian Institute...Dr. A.M. Rosebrugh, oculist, introduced a new instrument of his invention, the object of which is to photograph and view the deep structures of the living eye... Made by C. Potter, optician, No. 20, King-street East" (*The Globe* XXI, 16 1864 January 19, 2). And Rosebrugh remarked in his paper: "Any good optician can construct this new instrument. The one I exhibit to the Institute was made by Charles Potter, No. 20, King-street East. They can be had complete for $10" (Rosebrugh 1864, 91).

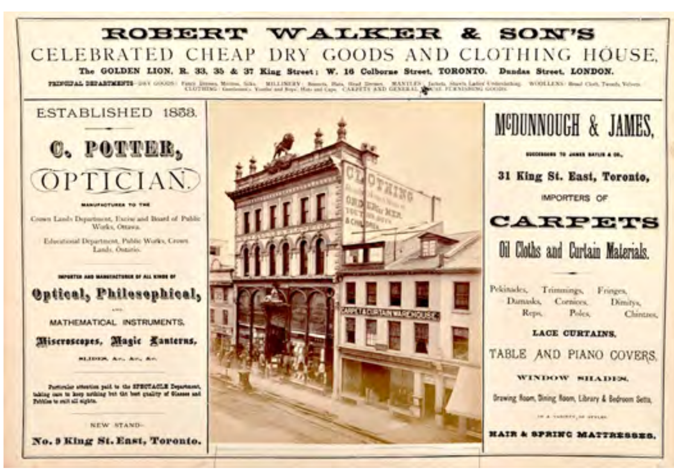


Figure 4 — Potter ad from 1872, and Notman and Fraser photograph of businesses on Queen Street East. Toronto Public Library, City of Toronto Archives, object number OHQ-BOOKS-S-W-163. Reproduced courtesy of Toronto Public Library.

Figure 5 — Woodcut of Dr. A.M. Rosebrugh's photographic ophthalmoscope, as built by Charles Potter. Reproduced after Rosebrugh 1864, 89.

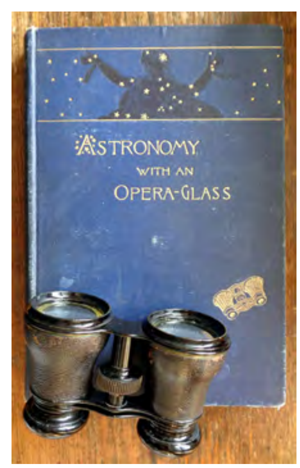


Figure 6 — Charles Potter field glasses, with Serviss, Astronomy with an Opera Glass *(1900). Photograph by R.A. Rosenfeld.*

It seems reasonable, then, to credit Potter's statement that he made scientific instruments as well as imported them. What we can't discern from the material presented here is the proportion of in-house production to subcontracted production, or the proportion of production to importation in his business. It may or may not have varied over the course of his career.

The Potter Field Glasses

The Potter field glasses are a representative of a design popular in Europe, North America, and elsewhere during the period ca. 1870–ca. 1915 (based on the examples in Seeger 1989, 12–16; Watson 1995, 1, 7–8; Figure 6). This style of instrument enjoyed many applications, and was used in the arenas of opera, theatre, and sports, in art galleries and museums, at tourist sites, for occasional espionage and military applications, for nature viewing, and in both recreational and research astronomy.

In regard to recreational astronomy, among the Society's earliest organized observing sections was an Opera-Glass Section:

> "…for the benefit of those members and others who had not taken up a regular course of observing, and also for the study of the constellations and certain of their features, including coloured, variable, and easy double-stars, stellar-clusters, nebula etc., instruments to be field and opera-glasses and portable telescopes" (Lindsay 1892, 21).

The hope was that the section would help members grow from being mere recreational star gazers to scientifically useful observers.[12]

To illustrate the place of field glasses in serious observing, they were employed for magnitude estimates of brighter variable stars by quite experienced observers, who also had access to much more capable instruments (observations by the English amateur and RASC honorary member A. Stanley Williams, and the Harvard Professor Solon I. Bailey in Pickering 1908, 12–13).[13]

The Potter field glasses are a Galilean optical design, with crown and flint achromatic objectives (Figure 7). The diameter of the objectives is 36 mm, with a focal length of 110 mm. The diameter of the eyepiece eye lenses is 18 mm, with a focal length of –55 mm, and a virtual exit pupil of 7 mm (Figure 8). This is a low-power system (magnification ×2). The eyepieces each have a field stop, a not uncommon feature of Galilean field glasses of this vintage (but one that is a little unexpected in an optical system that produces a virtual image; Figure 9).

The body is copper-alloy, as are the threaded objective cells, and only a few components of the field glasses are made of

Figure 7 — Objective end of the Potter field glasses, with reflections from a 532-nm laser showing the boundaries of the contact crown and flint elements. Photograph by R.A. Rosenfeld.

Figure 8 — Ocular end of the Potter field glasses. Photograph by R.A. Rosenfeld.

steel. The interior of the instrument is blackened (Figure 9). The objective barrels of the body are covered in brown leather, while the exposed copper-alloy parts have a Japanned finish (black enamel). The interpupillary distance is fixed at 63 mm (the distance between the optical axes), and there is no provision for dioptre adjustment (the lack was standard at the time). The length of the glasses with the eyepieces fully racked in is 68 mm, expanding to 93 mm when they are fully racked out (Figure 10).

Figure 9 — Objective barrel of the Potter field glasses with objective cell removed, showing internal blackening, and field stop. Photograph by R.A. Rosenfeld.

Figure 10 — The Potter field glasses with the eyepieces fully racked in (left), and fully racked out (right). Photograph by R.A. Rosenfeld.

The field glasses are in working order, and their condition is good, with the exception of an area around the outer edges of the objectives, due to the failure of the Canada balsam (most noticeable in the objective on the right when facing the front of the instrument; Figure 11). There is a slight yellow cast to the objectives, probably resulting from the aging of the Canada balsam. The hand-engraved signatures are placed on the metal eyecup surfaces surrounding the eye lenses, and read "C. POTTER TORONTO" (Figure 12). The effect of engraving through the Japanning to the copper-alloy ground creates the impression of gold letters on a black ground.

The case is sewn out of black pebble-grained leather, and the interior is lined with teal-coloured satin (Figure 13). The lid and the opening of the case are built over a light wooden form, and are joined with copper-alloy hinges (Figure 14). The lid is fit with a short leather carrying handle and has a spring-loaded button-activated latch made of copper-alloy and steel. The satin lining is missing from the interior of the lid, exposing the closing mechanism to view. Besides the pebble-graining, there are some tooled lines on the lid, emphasizing its form.

Even in their present unrestored state, the Potter field glasses offer a not unpleasant viewing experience (although the focus is a bit soft).

Made, or Imported?

Were the Charles Potter field glasses actually made in Potter's shop in Toronto, or did he merely import them and have his trade name placed on them? The latter practice was not at all unusual in the Victorian scientific instrument trade (it was a not infrequent occurrence with watches, and telescopes). No definitive answer can be given at present, but the evidence (such as it is) points to Potter having imported the field glasses.

His ads occasionally mention opera glasses, but do not specify whether they were actually fabricated under Potter's roof, or were imports. The following are typical: "C. POTTER, - OPTICIAN, 31 KING STREET EAST. - MICROSCOPES for Medical use. Also EYE GLASSES, SPECTACLES, OPERA GLASSES, &c., &c., IN GREAT VARIETY" (*The Varsity* 1883 January 13, 132); and "OPERA, Field, AND MARINE glasses; a large and well assorted stock always on hand. CHAS. POTTER, Optician, 9 King-street East, Toronto." (*The Globe* XXXIII, 94 1876 April 12, 1; XXXIII, 96 1876 April 14, 1; XXXIII, 97 1876 April 17, 1; and XXXIII, 230 1876 September 24, 1). They bring us no closer to an answer.

What does bring us closer to an answer are the features of the instrument. In appearance, and optical and physical characteristics it is strikingly similar to field glasses produced by one of the dominant firms supplying the world market, Jumelle Lemaire (Baille-Lemaire). Founded by Armand Lemaire (1821–1885) in 1848 (the date 1846 is sometimes given), the Paris plant was opened in 1860 (the firm relocated to Crosne a little to the south of Paris in the early 1890s), and by the 1880s had 500 employees (Levasseur 1889, 483–485; Figure 15). The firm became well-known for the decorative appear-

Figure 11 — Right-hand objective cell & doublet of the Potter field glasses showing balsam degradation around the edge. Photograph by R.A. Rosenfeld.

Figure 12 — Potter's signature engraved into the metal eyecups of the field glasses. Photograph by R.A. Rosenfeld.

Figure 13 — Exterior of the case for the Potter field glasses. Photograph by R.A. Rosenfeld.

ance of its opera and field glasses, its embrace of mechanized mass-production, and the ubiquity of its products in the shops (Various 1867, 24–25).[14] A reflection of its former market dominance can be found in the frequency of Lemaire field glasses on the current antiques market.

Figure 14 — Interior of the case for the Potter field glasses showing the satin lining, and wooden form and closure of the lid. Photograph by R.A. Rosenfeld.

Many opticians stocked Lemaire products. Even a venerable firm like Dollond sold them to supply the lower and middling reaches of their market, while producing their own optically higher-end versions in-house. Tiffany's of New York also sourced their branded opera glasses from Lemaire.

A simple visual comparison immediately makes the filiation of the Potter field glasses inescapable (Figure 16). If we couldn't see the signature on the eyepieces, we could have no way of telling whether we were looking at a pair of field glasses marked "c. potter," or "lemaire fab^{t} paris." The Potter field glasses are a rebranded product of Lemaire's, manufactured in Paris, but retailed in Toronto. They tell us something about Potter's trade, but nothing about his manufacture.

Opinions on Lemaire's products varied. The year before Potter and colleagues founded the Toronto Astronomical Club (the original of what eventually became the RASC), the 1867 Paris Exposition was held. Among the published reports were several describing the French optical industry. It makes for interesting reading: "M. Lemaire has a very brilliant display when it comes to binocular frames. Unfortunately, his glass does not rise to the level of the frames. It has been said that "With optics it is not enough to have a beautiful frame…" (Various 1867, 10). Another commentator stated that:

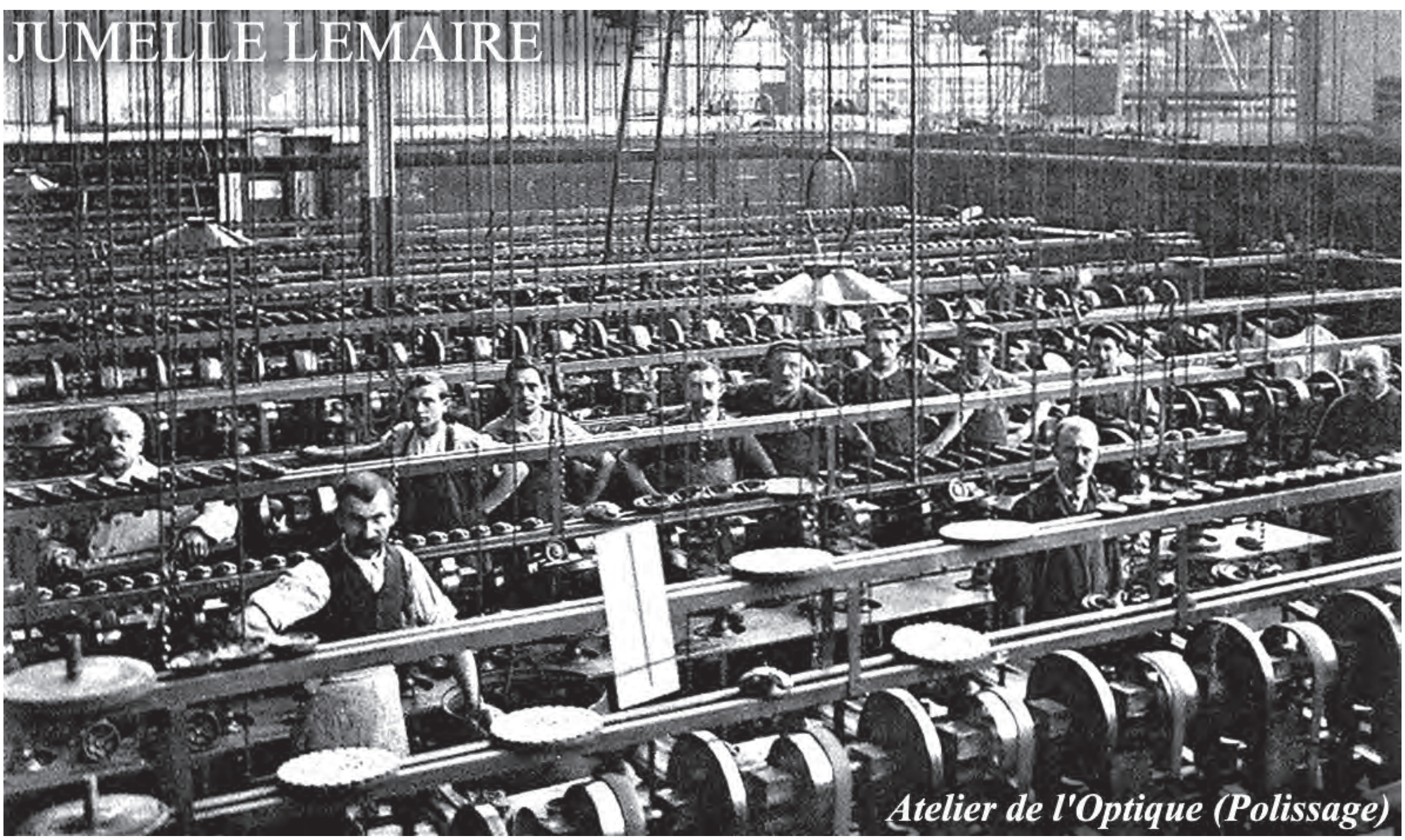


Figure 15 — Photograph of the optical polishing shop at the Jumelle Lemaire works located in Crosne outside of Paris, ca. 1880s–1890s. This image nicely illustrates Lemaire's reputation for mechanized production (note the array of polishing machines in the foreground). Private collection.

Figure 16 — Field glasses signed Lemaire, which are wholly indistinguishable from those bearing the Charles Potter signature. Private collection.

> "I wished to observe and compare binoculars fabricated in a house where the work is done with machines, to those which are made by specialists, who know how to work glass with paper. My comparison took me to the door of the house of Bardou (where glass is worked manually), and on to the house of Lemaire (where glass is worked by machine). I chose at random marine binoculars of the same dimensions from both houses…To avoid accusations of partiality, I asked people unknown to me to observe the letters on a geographical map through both binoculars…and (after having done so) to tell me which binocular provided the best view. The response was unequivocal—they preferred the binocular of M. Bardou. As to the binoculars of M. Lemaire, the observers reported that the view was as through fog, and that the letters on the map were not clear. This test took place in the presence of witnesses, who, if necessary, could testify on how I conducted the comparison. Faced with an examination this conscientious any commentary is unnecessary" (Various 1867, 20).

These are hardly recommendations. Over a decade later, the prominent physicist Alfred Cornu offered a more positive evaluation: "…one ought to mention the house of Lemaire, for the perfection of their binoculars for the theatre, and their marine binoculars" (Cornu 1880, 10). Perhaps their optical quality had improved.

It would be interesting to know to what extent Potter balanced considerations of optical quality against ready availability when he chose to retail Lemaire glasses under the Potter name.

Charles Potter and the "RASC"

As stated earlier, Charles Potter was one of the eight founders of the Toronto Astronomical Society in 1868–1869 (Clare 1868). He was the sole member who could claim to be professionally employed in science, as an optician and maker and importer of mathematical and philosophical instruments (*The Globe* XIV, 235 1857 October 2, 3). He attended meetings, hosted one at his residence, and played an active role in the major project of the group, observing the solar eclipse of 1869 August 7, being in charge of recording the pressure and temperature data (Clare 1869a; 1869b, 38).

Potter's astronomical interests continued after the TAS had withered away after less than a year; he was one of the disappointed Toronto observers hoping to catch the 1882 transit of Venus (Smith 1993, 24–25). He still saw serving astronomical neophytes as part of his trade: "CHEAP TELESCOPES. A Portable Achromatic Telescope that will tell the time of the church clock in Toronto at three miles off, with extra astronomical use. It will show Jupiter's moons, spots on the sun, mountains in the moon, &c. Sent to any address on receipt of $5.50. CHAS. POTTER, Optician. 31 King Street, East, Toronto. [ESTABLISHED 30 YEARS]" (*Wingham Times* 1885 September 4, 6).[15] And, recalling Potter several decades after his death, A.D. Watson, the Society's President said: "Charles Potter was the well-known optician. He helped many a young astronomer to obtain his first instrument, and always took a keen interest in the progress of astronomical sciences in this Dominion" (Watson 1917, 57).

Why then did he not rejoin the revived Society in the 1890s? At the very least resubscribing would have been good for business. It's possible that personal animosities kept him away, but if so, they have thus far left no trace in the historical record. It might simply be that ill health prevented his joining The Astronomical and Physical Society of Toronto (Smith 1993, 27–28). The field glass bearing his signature is exactly the sort of modest instrument that would have fit the observing style of many of the Society members of the 1880s–1890s.

When the Toronto Astronomical Society decided in 1901 that it was time to acquire a capable telescope for its members (a 4-inch Thomas Cooke and Sons refractor, still in its possession), it resolved to do so through one of its own, the optician Charles B. Petry, who just happened to be the new owner of the firm started by Charles Potter. Perhaps some of the users of the new telescope thought back to the earliest antecedent of their Society, and Potter's role in it. ✶

Acknowledgements

The author is grateful to the (anonymous) owner of the Potter field glasses for the opportunity to study them, and the permission to publish the results. Thanks are due to Peter

Broughton for the reference to Potter's ad in the *Wingham Times*, and for discussing some of the issues raised in this paper. The author alone is responsible for any errors in the text. This research has made use of NASA's Astrophysics Data System.

References

Barty-King, H. (1986). *Eyes Right. The Story of Dollond & Aitchison Opticians 1750–1985*. London: Quiller Press

Brooks, R.C. (1992). *Scientific Instruments in Canada*. Ottawa: Canada Science and Technology Museum

Brooks, R.C. & Daniels, W.J. (1993). Surveying Instrument Makers of Central Canada. *Canadian Journal of Civil Engineering 20, 6* (December), 1037–1046

Calvert, H.R. (1971). *Scientific Trade Cards in the Science Museum Collection*. London: Her Majesty's Stationary Office

City of Waterloo Museum, Meet Charles Potter. Retrieved 2025 April 17, from www.instagram.com/waterloomuseum/p/CgZRF1LYLEHs/?img_index+1

Clare, S. (1868). Minutes, Toronto Astronomical Society, December 1, 3–5

Clare, S. (1869a). Minutes, Toronto Astronomical Society, March 2, 13–16

Clare, S. (1869b). Minutes, Toronto Astronomical Society, August 3, 37–40

Clifton, G. (1995). (Ed.) G.L'E. Turner, *Directory of British Scientific Instrument Makers 1550–1851*. London: The National Maritime Museum, & Zwemmer

Clifton, G. (2017). Connections Between the Instrument-Making Trades in Great Britain and Ireland and the North American Continent. In (Ed.) A.D. Morrison-Low, A.D., Schechner, S.J., & Brenni, P., *How Scientific Instruments Have Changed Hands*, History of Science and Medicine Library, volume 56; Scientific Instruments and Collections, volume 5 (pp. 104–118). Leiden–Boston: Brill

Connor, J.T.H. (1998). Rosebrugh, Abner Mulholland, in *Dictionary of Canadian Biography*, vol. 14. Retrieved 2025 July 21, from www.biographi.ca/en/bio/rosebrugh_abner_mulholland_14E.html

Cornu, M.A. (1880). *Exposition Universelle Internationale de 1878 a Paris, Rapports du Jury International, Groupe II. Classe 15. Les instruments de précision*. Paris: Imprimerie Nationale

Daniels, W.J. (2005). Aspects of Scientific Enterprise in Victorian Toronto. *The Ontario Land Surveyor 48, 2* (Spring), 12–13

Del Santo, P., Morris, J. & R., Strano, G., & Van Helden, A. (2008). Galileo's Telescope. In (Ed.) Strano, G., *Galileo's Telescope: The Instrument that Changed the World* (pp. 33–61). Florence: Istituto e Museo di Storia della Scienza–Florence, & Giunti Editore S.p.A.

Fisher, V.J.L. (2023). *Getting Down to Brass & Wax: The Material Culture of Physics at Canadian Universities, 1890-1939* [Unpublished doctoral dissertation]. University of Toronto

Fisher, V.J.L. Augustus Frederick Potter. *Precision Instrument Culture in Canada*. Retrieved 2025 July 21, from omeka.uottawa.ca/instrument-precision/exhibits/show/precision-makers-1857-1918/a-f-potter2

Fisher, V., Carrier, M. & Pantalony, D. Hearn & Potter. *Precision Instrument Culture in Canada*. Retrieved 2025 July 21, from omeka.uottawa.ca/instrument-precision/items/show/2191

Fisher, V., Carrier, M. & Pantalony, D. William Hearn. *Precision Instrument Culture in Canada*. Retrieved 2025 July 21, from omeka.uottawa.ca/instrument-precision/items/show/2190

King, D.A. (2019). European Astrolabes to ca. 1500: An Ordered List. In (Eds.) Rodríguez-Arribas, J., Burnett, C., Ackermann, S., & Szpiech, R., *Astrolabes in Medieval Cultures* (pp. 357–366). Leiden–Boston: Brill

Klever, W.N.A. (2020). Spinoza in de geschiedenis van de optica. Retrieved 2025 June 14, from spinozakringlier.weebly.com/blog/spinoza-in-de-geschiedenis-van-de-optica

Levasseur, E. (1889). Rapport sur le Prix Jules Audéoud (concours de 1889). *Séances et travaux de l'Académie des Sciences Morales et Politiques (Institut de France) compte rendu 32*, 465–501

Lindsay, T. (1892). Eighth Meeting. *Transactions of the Astronomical and Physical Society of Toronto, for the Year 1891*, 21–22

Olsson, G. (*n.d.*). ALS News: Circumferentors—Made in Canada before Confederation. Retrieved 2025 April 17, from www.alsa.ab.ca/Governance/Weekly-News/View/ArticleId/1943/ALS-News-Circumferentors-Made-in-Canada-before-Confederation-1

Opthalmology & Vision Sciences University of Toronto, Abner Mulholland Rosebrugh (1835-1914). Retrieved 2025 September 18, from ophthalmology.utoronto.ca/abner-mulholland-rosebrugh-1835-1914

Pickering, E.C. (1908). *Revised Harvard Photometry: a Catalogue of the Positions, Photometric Magnitudes and Spectra of 9110 Stars, Mainly of the Magnitude 6.50, and Brighter Observed with the 2[-] and 4[-]inch Meridian Photometers*, Annals of the Astronomical Observatory of Harvard College 50. Cambridge MA: The Astronomical Observatory of Harvard College

Potter, A.F. (1861). *Catalogue of optical, mathematical and philosophical instruments and school apparatus, imported, manufactured, and sold by A.F. Potter...* Toronto?: *n.p.*

Poulle, E. (1963). *Un constructeur d'instruments astronomiques au XVe siècle, Jean Fusoris*, Bibliothèque de l'Ecole des hautes études, IVe section, Sciences historiques et philologiques,fasc. 318. Paris: Librairie H. Champion

Rosebrugh, A.M. (1864). A New Ophthalmoscope for Photographing the Posterior Internal Surface of the Living Eye; with an Outline of the Theory of the Ordinary Ophthalmoscope. Er *The Canadian Journal of Industry, Science, & Art, n.s. IX, L* (March), 81–92

Seeger, H.T. (1989). *Feldstcher: Ferngläser im Wandel der Zeit*. Borken: Edition Bresser Optik

Serviss, G.P. (1900). *Astronomy with an Opera-Glass: a Popular Introduction to the Study of the Starry Heavens with the Simplest of Optical Instruments, with Maps and Directions to Facilitate the Recognition of the Constellations and the Principal Stars, Visible to the Naked Eye*, 8th ed. New York–London: D. Appleton and Company

Smith, J.A. (1993). Charles Potter, Optician and Instrument Maker. *JRASC 87, 1* (February), 14–33

Spinoza, B. (2016). (Ed.) E.M. Curley, *The Collected Works of Spinoza*, vol. 2. Princeton–Oxford: Princeton University Press

The Globe (1853–1876)

The Varsity (1883, January 13)

Van Helden, A. (1999). *Istituto e Museo di Storia della Scienza, Catalogue of Early Telescopes*, Cataloghi di raccolte scientifiche 4. Florence: Istituto e Museo di Storia della Scienza, & Giunti Industrie Grafiche S.p.A.

Various (1867). Rapport adressé a la commission d'encouragement par la délégation des Opticiens (opticiens proprement dits). In *Exposition Universelle de 1867, à Paris: Rapports des délégations ouvriéres*…, III (1–44). Paris: Librairie A. Morel

Vermij, R. (2013). Instruments and the Making of a Philosopher. Spinoza's Career in Optics. *Intellectual History Review 23, 1* (March), 65–81

Watson, A.D. (1917). Astronomy in Canada. *JRASC XI, 2* (February), 46–78

Watson, F. (1995). *Binoculars, Opera Glasses and Field Glasses*, Shire Albums no. 317. Princes Risborough

Wellington County Museum & Archives, Collections Catalogue. Retrieved 2025 April 17, from wcma.pastperfectonline.com/webobject/78DC9354-16D8-465F-A92E-218388332017

Wilson, R.G. (2001). Charles Potter: Toronto Optician and Mathematical Instrument Maker. *Photographic Canadiana: Journal of the Photographic Historical Society of Canada 26, 5* (March-April), 8–10

Wingham Times 1885 September 4

Endnotes

1 The Fusoris astrolabes are characterized by an elegant and clear layout, and impressively accurate scale divisions.

2 There may in fact be instruments by both Galileo and Spinoza among unattributed surviving 17th-century instruments. If so, unrecognized instruments by Galileo will be easier to uncover than those by Spinoza, given that there are a few instruments attributed to the former on which to base a comparison, whereas there are none for the latter.

3 It's not that our expectations of what the past should be are irrelevant—they can reveal rather a lot about our understanding of the past. And it is possible that an instinct about what should survive may lead to more discoveries. At the same time care should be taken that it doesn't become a conviction clouding judgement.

4 Daniels 2005, 13 also perceptively noted this dearth with respect to Potter's official position in supplying educational institutions in Ontario (presumably largely primary and secondary institutions) with educational scientific apparatus (of which "…nary a single signed example is known").

5 In the 19th and early 20th century, there were no hard and fast divisions between the terms "opera glasses," "field glasses," and "binoculars." There was tendency to reserve the term "opera glasses" for smaller more decorative versions used in theatres, and "field glasses" for more robust examples for outdoor use, but in practice usage was marked by fluidity, and even inconsistency. The terms were often used as synonyms, and that practice is followed here.

6 *The Precision Instrument Culture in Canada* website has the potential to be extraordinarily useful for those investigating the makers of scientific instruments in Canada, and their surviving output (omeka.uottawa.ca/instrument-precision). In its present state, however, it should be used with caution, due to the frequent errors, and contradictions between entries.

7 The most informative of these are the manuscript Credit Report Volumes, now in the Baker Library of the Harvard Business School, access to which is still controlled by Dun & Bradstreet(!). The much more laconic versions published in their *Reference Books* are also useful.

8 Potter proved canny at indirect advertising as well. From 1868 December 15 to 1869 January 28 *The Globe* reported "Lowest temperature, as registered at Potter's, Optician, King street" at the head of the City News column on the front page. This created the impression of civic engagement through the free provision of scientifically authoritative meteorological data, which implied the reliability of Potter's equipment, and his shop as a place for readers to acquire their own thermometers (e.g. *The Globe* XXV, 299 1868 December 15, 1; XXVI, 24 1869 January 28, 1).

9 Barty-King 1986. This is at best a mediocre work. The Dollonds (1750-1866) are still in need of a historian.

10 I have been unsuccessful in discovering if the case proceeded any further; there doesn't seem to be any mention of it in the *Upper Canada Law Journal*.

11 There was another connection between Potter and Rosebrugh involving technology. It has been said that the first telephone line in Toronto was installed between their residences (Connor 1998)!

12 Unfortunately, the Society's observing sections only lasted a few years, in contrast to those established at the same time within the British Astronomical Association. BAA section heads even offered valuable advice to the Canadian ones when asked for guidance. The BAA sections are still going strong, but the Canadian ones soon died on the vine. It is not at all clear why they didn't persist. This points to a contrast between the Canadian and UK organizations and their respective astronomical cultures, one which is not entirely flattering to the RASC.

13 Prof. David Turner informs me that some very skilled variable-star observers still use low-powered optical aids for quick estimates of brighter targets.

14 Lemaire, however, was criticized from within France for not producing instruments with better optics.

15 I owe this reference to the kindness of R. Peter Broughton.

The Royal Astronomical Society of Canada is dedicated to the advancement of astronomy and its related sciences; the Journal *espouses the scientific method, and supports dissemination of information, discoveries, and theories based on that well-tested method.*

Blast from the Past!

Compiled by James Edgar
james@jamesedgar.ca

The following article appeared in the first RASC Journal in 1907.

Stonyhurst College Observatory, Lancashire, England.

By Rev. I.J. Kavanagh, S.J.

My reason for selecting the Stonyhurst Observatory for my topic is largely a personal one, for I shall be talking about what is my own by many ties. The memory of pleasant years, of hard work done and of petty triumphs achieved, the memory of friends and their helping hands, are fair excuse for the personal note that may sound through my theme. Possibly this very thing may commend my effort to your kindly attention, for the whole world loves a lover. Besides it is encouraging to consider, in the case of the rise and growth of Stonyhurst Observatory, how small beginnings and patient work can culminate in deserved and gratifying success.

The Society of Jesus was early in the field of mathematical science, and, as far as circumstances have permitted, it has striven to maintain its traditions in this respect. Galileo counted the Fathers amongst his friends, and not the least among these was the great Jesuit Cardinal Bellarmine. The names of Boscovitch, Clovius, Hill, Kircher, Scheiner, Grimaldi, and, in our own day, de Vico Secchi and Perry have their place in the honorable annals of astronomy. Even now, in the midst of the strained conditions of the times, the Society counts 22 astronomical observatories, many of them splendidly equipped in men and instruments. Some have fallen from high estate. For instance, little has been done in Rome in recent years. The observatory and equipment that enabled Secchi to do such good work were taken from him and the Jesuits by the Piedmontese invaders. However, the work is started again and is now in the hands of Father Hagan, late of Georgetown Observatory, in Maryland. Elsewhere, as in Havana and Manila, the magnitude and economic importance of the meteorological results have masked the less brilliant but useful monotony of astronomical routine. A case in point is Father Algue's monumental work on the phenomena of cyclones, just about to be published by the U. S. Government. Father Algue is Director of the Havana Observatory. Father Vines, of Manila, on the theory of typhoons has been honored in the same way.

I might mention that both these men, as well as Secchi and one of the native Chinese Jesuits at Zi-ka-wei, and others, received a portion of their training at Stonyhurst Observatory, to which I beg to turn your kind attention. The story of Stonyhurst College goes back to the days when a Catholic College in England lay under the ban of a penal legislation. To meet these unfortunate conditions, the Jesuits founded in 1592, at St. Omer, a college for the education of English Catholic youth. In 1794, after many vicissitudes, the College faculty and the students came over to England, and settled down in Lancashire, on the old-time Sherbourne domain called Stonyhurst, which had been presented to them by one of the old boys, Sir Thomas Weld of Blundel. Curiously enough, the Rector of the College, as lord of the manor, had the right of presentation to the neighboring Protestant parish of Mitton; a right, however, he never exercised.

Perforce the College made haste but slowly. It was only in 1838 that in the quaint old Dutch garden, in the midst of secular yew hedges, the second oldest and finest in all England, there arose the domed roof of the observatory. The principal instrument was a 12 cm. Jones equatorial. Twenty years after, at the instance and under the very friendly advice of Sir Edward Sabine, Father Weld purchased a set of magnetic instruments for eye observations. Thenceforward the record is unbroken. Shortly after, the Board of Trade selected Stonyhurst as one of its seven meteorological stations. Thereupon a full complement of apparatus was installed and the observatory was able to carry on its work with ease and efficiency. The new self-recording instruments for the photographic registration of the magnetic elements were installed in a many walled excavation, in which the equable temperature and the hygrometric conditions have proved most satisfactory, the latter being an important affair in rainy Lancashire. The Mercury Barograph is also installed here. On the occasion of the British Association Meeting at Southport, in 1883 I think, a large party came up to Stonyhurst. Naturally a number of ladies and gentlemen went down to examine the magnetic installation, much to the confusion and consternation of the magnets. These timid creatures thereupon described such extraordinary and eccentric curves, that the graphs had to be rejected from the month's average, but are kept as curiosities. Had a dozen of the old Sherbourne Crusading Knights come up from their marble tombs in Mitton Church, clad in full armor, the behavior of the magnets had scarcely been worse. The arrival of a new 20 cm. equatorial by Carey made it necessary to build a dome some hundred yards away, where the heavy iron mounting would exert no disturbing effects on the magnets. The Jones equatorial was then also removed from the main octagonal building which was becoming inconveniently crowded. Two of the wings still shelter the meridian instruments and the sidereal clocks.

The normal, the wet, and dry bulb thermometers are photographically self-recording. I need no more than mention the anemograph which registers the velocity and direction of the wind by pencil tracings on a clock-driven cylinder. These registers are all the more valuable because the apparatus has never stopped since its first installation, a notable tribute to the maker and to the care of the assistants. Of course, there are also sunshine recorders and automatic registering rain guages. To those who know something of the Lancashire climate I need not suggest which of these two is the harder worked.

Besides the Jones, which is now given over to students' work, there is an 18 cm. Newtonian, a 24 cm. Cassegrain altazimuth, and a 12.5 cm. telescope by Clarke. Upon the death of Father Perry, who was for many years an esteemed and efficient Director, it was resolved by his many friends to set up a fitting monument to his memory. It was decided to erect a 38 cm. equatorial under a new dome. Fortunately the new instrument thus procured has proved equal to all expectations.

Some notes on the life of Father Perry, who did so much for Stonyhurst Observatory, may not come amiss, especially as some years back he came to this country and carried away, amongst other souvenirs, the pleasant remembrance of his visit to the Meteorological and Magnetic Observatory in the neighbourhood of Toronto, then, as now, under the very competent management of R. F. Stupart.

Stephen J. Perry was born in London in 1838 and went abroad for his education to the Benedictine College cf Douai, where he remained seven years. He already manifested exceptional ability along scientific lines. Purposing to be a priest, he entered upon the study of philosophy in Rome at the English College. While here he resolved to seek admission to the Society of Jesus, being, as he says, largely influenced in this action by reading the life of the founder, St. Ignatius of Loyola. He was admitted to the Noviciate at Hodder House in England, and after the two years of probation required before anyone may take upon himself the obligations of the religious state, he took up his studies again, alternating with teaching, as is the custom of the Jesuits, till he had covered the usual 10 years of philosophy and theology preparatory to the priesthood.

Father Perry's mathematical talent was further developed under the teaching of such men as De Morgan in London and Cauchy, Delaunay, and Bertrand in Paris. Among his stories of these days was one about Bertrand, who was not noted for his neat blackboard work. One day he had to be replaced, on account of illness, by an assistant professor, a very competent man. The young professor, having expounded the matter clearly and neatly, had the mortification to see that many of his audience had left the hall. The truth is that these men had come from all parts of Europe to hear the great Bertrand and to note the unexpected and unprepared scintillations of genius, not to witness the commonplace proving of a proposition.

In 1868 he took up the Directorship of Stonyhurst Observatory with which he had had some connection at different times. He also did some teaching at the College. During the vacation months he conducted magnetic surveys of Belgium and the various parts of France. These surveys furnished the first really satisfactory magnetic maps of these regions. He was attached to the Cadiz Eclipse parties in 1870, and was chief of four other Government Eclipse Expeditions. The last was to Isle du Salut off French Guiana (1889), where, through over exertion, he fell a victim to fever. The Jesuit missionaries at Georgetown, in Demerara, who were English, some of them old friends, had the melancholy consolation of giving him a last resting place. He had been in command of two Transit of Venus Expeditions: one to Kerguelen Island, the other to Madagascar. Father Perry was a good, organizer, a patient worker, an observer of the highest class, safe, cool, deliberate, ready for emergencies, most careful and foreseeing in his preparations, and dead sure of his results. He was, moreover, marvellously acute in their interpretation. However, he used to say that his colleague Father Walter Sidgreaves, the present director of the observatory, was the better observer, the best in England.

Though the study of colored and variable stars had been in vogue under Father Weld, the investigation of solar phenomena had not been neglected. Under Father Perry this latter received its greatest development. During all the twenty years of his directorship the drawings by projection of the Sun's surface, in general, and in detail, under low and high power, were made as often as possible. This work is done by W. McKeon, a lay brother of the order, a close observer, a skilful and conscientious draughtsman. Twenty years experience has rendered him exceptionally expert in seeing and portraying the delicate evanescent effects flitting, so to speak, over the paper. In case of a blurred, ill-defined, unseizable image, he tells me that a slight vibration given to the paper unravels, as it were, the jumbled details. It would appear a useful hint. I am convinced that the trained, discriminating eye can secure results far beyond the range of the dead, mechanical photographic lens. The Stonyhurst collection of solar drawings, executed with such accuracy and covering so long a time, has a high value, and, when placed side by side with the contemporaneous magnetic records, throws suggestive lights upon the connection between magnetic and solar phenomena. Father Cortie of the observatory staff for some 16 years has written valuable papers in this relation and recently found himself crossing swords with Mr. A. W. Maunder of Greenwich.

Without in any way cutting in on solar work, under the present director, Father Walter Sidgreaves, Stonyhurst Observatory has done a great deal of stellar spectroscopic work. A Christie Hilger star spectroscope was purchased in 1883, but long before that a Troughton Sims instrument was in use for solar work, as was also a splendid Browing battery of 12 prisms, with a reversing prism, to be attached to the equatorial. Before Father Perry's time some special work had been done on the multiple and the colored stars, but it was he who gave the study of solar phenomena the greatest development. So that Father Sidgreaves' work was not a new departure but a mere natural development assiduously carried on. His studies of the Nova of Perseus and that of Auriga attracted much attention, while his monograph on b Lyrae, richly illustrated with spectrum photographs, is exhaustive. In this work he sometimes used the Hilger spectrograph with a fine Rowland grating (8 cm.) fed from a siderostat. The large equatorial, fitted with a Hilger poly-prism, is used for radiations less refrangible than the violet; for the violet and ultra-violet the 10 cm. Cross equatorial, fitted with a 22°.5 Thorpe prism, is brought into action. Father Sidgreaves finds that shorter exposure and results altogether satisfactory are achieved by doing away with the slit and running the star parallel to the refracting edge of the prism. Of course, this means very fine adjustment.

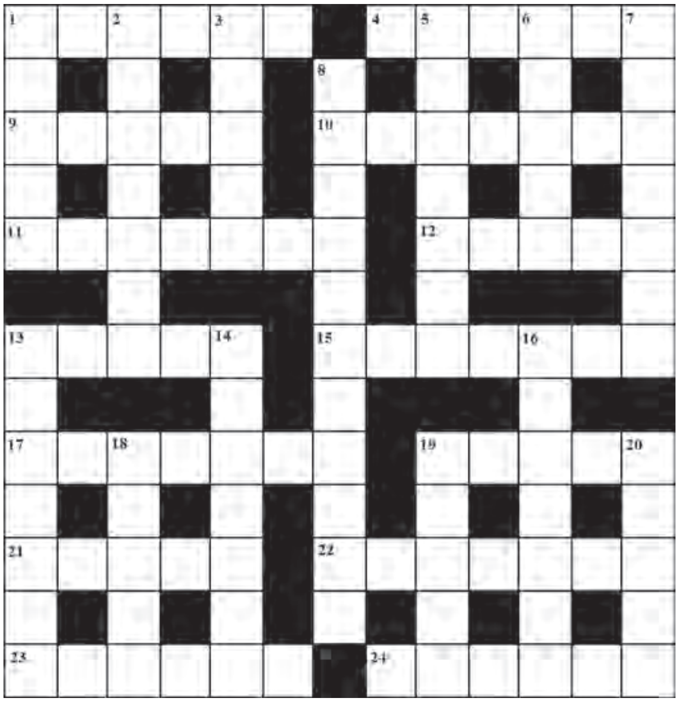
Besides the interest that attaches to the Observatory, there are also attractions for the lover of beautiful scenery and for the antiquarian. I sincerely hope that some of my readers may have an opportunity of realizing how well I am keeping within the bounds of strict truth in singing the praises of Stonyhurst in Lancashire.

Loyola College, Montreal.

[Note: Rev. I.J. Kavenagh was an early contributor to the *Journal* and, in later years, he served on the Society's Council. See also www.rasc.ca/1905-eclipse-35.] ✶

Astrocryptic

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



ACROSS

1. Quebec university assistant with blade in the Kuiper belt (6)
4. How may a body be heard in the Kuiper belt? (6)
9. I need a pointer to find Sagitta (5)
10. Dr. Comet was very loud while around others (7)
11. Transiting north, Helen blindly groped for an eyepiece (7)
12. Follow the recent asteroid in Lyra at first (5)
13. Hubble dined and wined around in California (5)
15. There is something fishy about these falling stars (7)
17. I misheard Gamma Leonis in math class (7)
19. First Greek particle created and destroyed in the Sun (5)
21. Enacted the very best gas law (5)
22. Vote in Randy Attwood as a Pleiad (7)
23. Comet seeker might find one in Orion (6)
24. Assets obtained from neutron star's rotational pulses (6)

DOWN

1. Up or down, making AI gives a quirk of fate (5)
2. A girl dances by Old West night light (7)
3. A comet filter blocks flow in Egypt (5)
5. First sign it returns in relation to a ram (7)
6. Organized Pro-Am tournament at a dish Down Under (5)
7. Its leading syllable describes one of a pair by a stellar apiary (7)
8. Dopey flew a Cessna to Titan but landed on one of these (5,6)
13. I chased myself around in a dragon's belly (7)
14. High clouds ruin an eastern blue sky (7)
16. I set up a refracting telescope to observe a two-toned satellite (7)
18. He turns endless energy into asteroid ephemerides from Harvard (5)
19. Mislabel a cluster of galaxies (5)
20. Dyer and Whitman are part of the final answer (5)

Answers to previous puzzle

Across: **1** COLUMBA (2 def); **5** MIMAS (hid); **8** ALPHA (hid); **9** THOMSON (2 def); **10** TELESTO (Te(le)st+o); **11** SPICA (SP(I)CA); **12** RUBIN (2 def); **14** SCRUB (anag); **16** ATLAS (a(t)las); **18** SCHMIDT (2 def); **20** KINETIC (2 def); **21** DIRAC (anag-o); **22** ADAMS (hid alt); **23** LARAWAG (Lara+wag)

Down: **1** CHARTER (2 def); **2** LAPEL (L+anag); **3** MEAN SUN (2 def); **4** ASTROPHYSICAL (an(trophy)ag); **5** MUONS (mu(on)s); **6** MESSIER (Me(rev)ER); **7** SYNTA (anag); **13** BELINDA (B(E)lind+a); **14** SCHEDAR (anag); **15** BETA CYG (Be+an(CY(ag); **16** ANKAA (a+n+kaa); **17** SITES (hom); **19** IN RAW (anag+w)

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

Index to Vol. 119, 2025

Titles (Research Articles)

Authors

Columns

Pen & Pixel

Feature Articles

Departments

Great Images

By Rob Lyons

The Milky Way is seen rising over a small islet off Mackenzie Beach in Tofino, British Columbia. Rob took the image in the early hours of 2025 July 28, with a Sony A7SIII and Sigma 14-mm ƒ1.4 lens. He shot 20 × 13-second images and stacked them for the sky, and then took a single 180-second image for the foreground.

Journal

Who doesn't like garlic? Shelley Jackson imaged the Garlic Nebula (Abell 85) from Athens, Ontario, under a Bortle 4 sky. Shelley says she noticed the nebula while imaging another wide-field target (200 mm). "I was intrigued, so I looked up the target and saw a lot of wonderful images. I decided to get in a little closer and used my Askar V 80 mm @495 mm [focal length] to capture this beautiful supernova remnant. I spent over 85 hours with my telescope aimed in this area of Cassiopeia." She used an Askar V 80-mm with a flattener, on a SkyWatcher EQ6-R Pro mount, with Player one Poseidon CMOS camera. Stacked with PixInsight (WBPP) and processing and editing was done with PixInsight.