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# Journal

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*Berkeley 59*

# Journal

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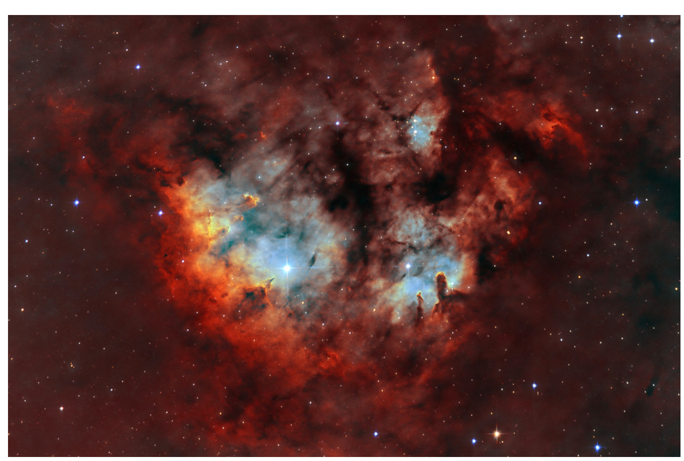

*This amazing image of Berkeley 59 and NGC 7822 in Cepheus was taken by Shawn Neilson from Kitchener, Ontario, in late August. Shawn used a Starfield Optics 8″ astrograph with a Starizona Nexus reducer/corrector at ƒ/3, a QHY268M CMOS camera and filter wheel with Optolong Hα-OIII-SII-RGB filters. He used a Sky-Watcher EQ6 mount on a SkyShed pier. Image was processed in PixInsight for a total of 12 hours.*

Journal

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



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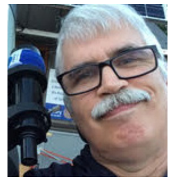
# President's Corner

## Back in Business… With a Difference



*by Charles Ennis, Sunshine Coast Centre (cuhulain@telus.net)*

After two years of shutdown due to the COVID-19 pandemic, my Sunshine Coast Centre is meeting in person again, and it is wonderful.

It's great to be back at the observatory eyepiece, but one night at our observatory, one of our members was at his personal telescope at a distance with a mask on, because he had sniffles and wanted to isolate to protect the rest of us. For the last two years, we've been using our own telescopes in isolation, as have all the Society's members: The Observing Committee has had a record number of people submit their observing records to earn certificates.

Members of my Centre are increasingly using remote telescopes to do astrophotography. Socializing online was a necessity, but now we can do so face to face (having had all our immunization shots). But now we're taking extra precautions to protect one another. People are wearing masks and making a point of washing hands. Hand sanitizer has become an essential piece of outreach equipment. We're meeting again in person, but we're still meeting online as well, as many of our members have discovered the advantages of virtual meetings—no commuting costs (an important issue for many of our members in the current economy), no trips in extreme weather conditions, the ability to attend the meeting even though the person is sick or physically disabled (which an increasing number of our older members are), and even the ability to attend if business has taken them to another part of the world.

Members from other Centres can also easily participate and socialize with us. Our speakers' presentations are recorded and placed on YouTube, so if something has come up in a member's life that prevents them from attending the meeting, they can still enjoy it. Of course, this means we've had to learn how to edit those videos. We've completely switched to the convenience of virtual meetings to conduct the business of our Centre. No more printing costs for agendas, reports, etc. We're emailing those. We've switched from issuing cheques to making payments by e-Transfers. The world situation has driven prices through the roof, so we're all scrambling to find ways to economize. We've been forced to adapt, but that's what life is all about. We're all still in the game but trying to make it a safer one. ✶

# News Notes / En manchette

*Compiled by Jay Anderson*

## Dead stars tell tales

The first map of the "galactic underworld"—a chart of the corpses of once-massive suns that have since collapsed into black holes and neutron stars—has revealed a graveyard that is considerably different from the traditional spiral-arm disk. The new map was created by modelling the evolution of the Milky Way and the effect that the explosive collapse of massive stars would have on the stars' subsequent orbital paths.

When compared to the familiar disk-shape of the Milky Way that is readily visible in the night sky, the distribution of evolved massive stars forms a nearly oval shape in both top and side views instead of a spiral-arm laden disk.

"These compact remnants of dead stars show a fundamentally different distribution and structure to the visible galaxy," said David Sweeney, a Ph.D. student at the Sydney Institute for Astronomy at the University of Sydney, and lead author of the paper. "The 'height' of the galactic underworld is over three times larger in the Milky Way itself," he added.

"And an amazing 30 percent of objects have been completely ejected from the galaxy."

Neutron stars and black holes are formed when massive stars—more than eight times larger than our Sun—exhaust their fuel and suddenly collapse. This triggers a runaway reaction that blows the outer portions of the star apart in a titanic supernova explosion, while the core keeps compressing in on itself until—depending on its starting mass—it becomes either a neutron star or a black hole.

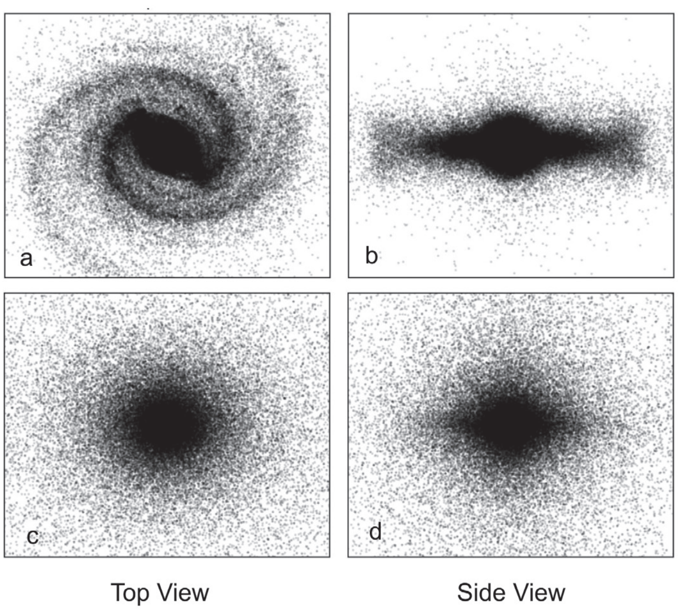



*Figure 1 — Point cloud top-down and side view of the galactic underworld of the Milky Way. The top row shows the visible distribution of stars in general. The bottom row shows the distribution of evolved massive stars. Image: University of Sydney*

In neutron stars, the core is so dense that electrons and protons are forced to combine at the subatomic level into neutrons, squeezing its total mass into a sphere smaller than a city. If the mass of the original star is greater than 25 times our Sun's, the gravity-driven collapse continues until the core is so dense that it becomes a black hole. Both types of stellar corpses warp space, time, and matter around them.

Although billions must have been formed since the galaxy was young, these exotic carcasses were flung out into the darkness of interstellar space by the supernova that created them, and hence slipped beyond sight and knowledge of astronomers—until now.

By carefully recreating the full life cycle of the ancient dead stars, the researchers have constructed the first detailed map showing where their corpses might lie.

"One of the problems for finding these ancient objects is that, until now, we had no idea where to look," said Sydney Institute for Astronomy's Professor Peter Tuthill, co-author on the paper. "The oldest neutron stars and black holes were created when the galaxy was younger and shaped differently, and then subjected to complex changes spanning billions of years. It has been a major task to model all of this to find them."

Newly formed neutron stars and black holes conform to today's galaxy, so astronomers know where to look. But the oldest neutron stars and black holes are like ghosts still haunting a house demolished long ago, so they are harder to find, even though they make up about 1 percent of the Milky Way's mass.

"It was like trying to find the mythical elephant's graveyard," said Professor Tuthill, referring to a place where, according to legend, old elephants go to die alone, far from their group. "The bones of these rare massive stars had to be out there, but they seemed to shroud themselves in mystery."

He added, "The hardest problem I had to solve in hunting down their true distribution was to account for the 'kicks' they receive in the violent moments of their creation. Supernova explosions are asymmetric, and the remnants are ejected at high speed—up to millions of kilometres per hour—and, even worse, this happens in an unknown and random direction for every object."

But nothing in the Universe sits still for long, so even knowing the likely magnitudes of the explosive kicks was not enough: the researchers had to delve into the depths of cosmic time and reconstruct how they behaved over billions of years.

"It's a little like in snooker," said Sweeney. "If you know which direction the ball is hit, and how hard, then you can work out where it will end up. But in space, the objects and speeds are just vastly bigger. Plus, the table's not flat, so the stellar remnants go on complex orbits threading through the galaxy.

"Finally, unlike a snooker table, there is no friction—so they never slow down. Almost all the remnants ever formed are still out there, sliding like ghosts through interstellar space."

The intricate models they built—together with University of Sydney Research Fellow Dr. Sanjib Sharma and Dr. Ryosuke Hirai of Monash University—encoded where the stars were born, where they met their fiery end, and their eventual dispersal as the galaxy evolved.

The final outcome is a distribution map of the Milky Way's stellar necropolis.

"It was a bit of a shock," said Dr Sharma. "I work every day with images of the visible galaxy we know today, and I expected that the galactic underworld would be subtly different, but similar in broad strokes. I was not expecting such a radical change in form."

In the maps generated, the characteristic spiral arms of the Milky Way vanish in the "galactic underworld" version. The arms are entirely washed out in part because many of these stellar remnants were created when the Milky Way was much more extended than is currently the case, and because of the blurring effects of the energetic kicks from the supernovae that created them. The modelling team found that 30 percent of the stellar remnants—40 percent of neutron stars and 2 percent of black holes—received a kick sufficiently strong to send them out of the galaxy. The team estimates that about 0.4 percent of the Milky Way's mass has been lost to intergalactic space over its lifetime

Even more intriguing, the side-on view shows that the galactic underworld is much more "puffed up" than the Milky Way—a result of kinetic energy injected by supernovae, elevating them into a halo around the visible Milky Way.

"Perhaps the most surprising finding from our study is that the kicks are so strong that the Milky Way will lose some of these remnants entirely," said Dr Hirai. "They are kicked so hard that about 30 percent of the neutron stars are flung out into intergalactic space, never to return."

Added Tuthill, "For me, one of the coolest things we found in this work is that even the local stellar neighbourhood around our Sun is likely to have these ghostly visitors passing through. Statistically our nearest remnant should be only 65 light-years away: more or less in our backyard, in galactic terms."

*Compiled with material provided by the University of Sydney.*

## Mars underground

An in-situ survey of Martian subsurface structure has revealed that a basin on the red planet has a dry and multi-layered shallow subsurface. The results are based on a ground-penetrating radar survey in a southern marginal area of the Utopia Basin conducted by China's Mars rover Zhurong of the Tianwen-1 mission.

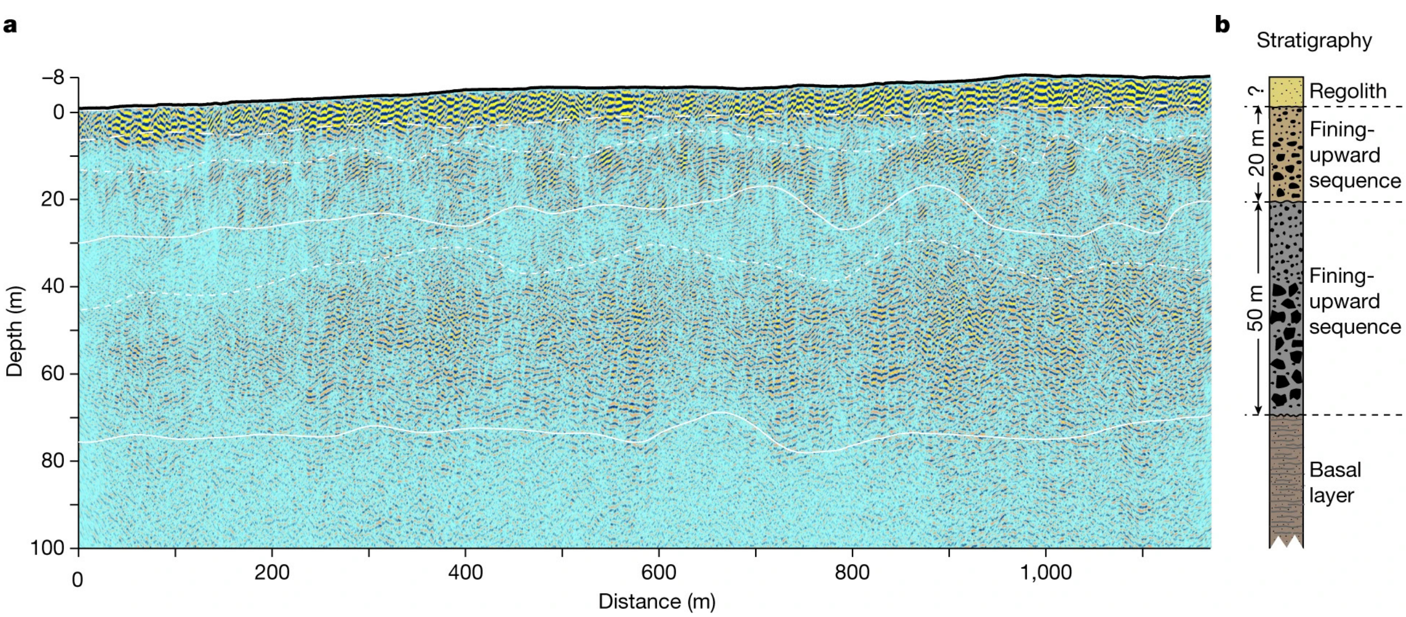



*Figure 2 — a, The low-frequency radar imaging profile, with the uppermost thick black line denoting the topography relative to the landing site. The dashed line above 10 m denotes the estimated bottom of the top layer presumably containing mainly regolith. The two solid lines at depths of around 30 and 80 m represent the contacts between the second and third layers and the base of the third layer, respectively. The two dashed lines at around 10 and 40 m deep roughly separate finer- and coarser-grained rocky blocks within the second and third layers, respectively. b, The interpreted lithologic stratigraphy based on radar imaging. Image: Chinese Academy of Science.*

Utopia is the largest impact basin on Mars with an estimated diameter of 3,000 km. It has a heavily wind-eroded, hard surface crust formed from upward-moving solutions of minerals that have subsequently evaporated at the surface. The basin where Zhurong landed is believed to have hosted an ancient ocean.

A 21-member research group from the Chinese Academy of Sciences, lead by Chao Li, Yikang Zheng, Xin Wang, and Jinhai Zhang, constructed a detailed, high-resolution subsurface profile using the Zhurong rover's ground-penetrating radar, collected along a roughly 1,171-metre traverse over 113 Martian days. The profile revealed a 70-metre-thick multi-layered structure beneath a 10-m-thick regolith. The researchers found no direct evidence for the existence of liquid water within the radar detection depth range. A thermal simulation suggested that the Martian soil 100 metres deep could not stably contain liquid water, nor sulfate or carbonate brines, although the presence of saline ice cannot be ruled out, according to the study.

The top layer, no thicker than 10 metres, is interpreted as the Martian regolith, though multiple reflections between the rover and the ground surface have contaminated the signal with strong artefacts, making it difficult to distinguish its base from underlying sediments.

The second layer, extending from 10 to 30 metres, is shown to contain rocky blocks (clasts), presumably having taken shape in approximately the past 1.6 billion years; clast sizes increase with depth. The study authors suggest that this layer is formed from the resurfacing of the original layer either by repeated meteor impacts or by long-term weathering, or a combination of the two. They also suggest that flooding and sedimentation may have occurred after an impact fractured the surface and underlying ice layers.

The third layer, within the depth range of 30 to 80 metres, is composed of larger rocky blocks, distributed more evenly and representing an older, probably more substantial geological event that happened as early as 3.5 to 3.2 billion years ago. The absence of any strong reflections between the second and third layers indicates that no substantial volcanic flow is present to the depth of the sampling transit.

*Composed in part with material provided by the Chinese Academy of Sciences.*

## Cardiac surgery on the Milky Way

In a paper enticingly titled "The Poor Old Heart of the Milky Way," a team of astronomers lead by Hans-Walter Rix of the Max-Planck-Institut für Astronomie has used data from a multitude of sources to discover an ancient, metal-poor, and centrally concentrated stellar population that they identify as the "heart" of the Milky Way. Using orbital, spectral, and

*Figure 3 — A section of the Sagittarius star cloud imaged by the* Hubble Space Telescope*. The colours of the stars reveal their temperature and give clues to their age. Blue stars are young and hot. Red stars may be dwarfs or giants. Red dwarfs are small cool stars that are often difficult to see at a large distance. Red giants are the size of our Sun or larger, swollen in size as they reach the latter stages of their life cycle. Such stars are easily visible at large distances, even beyond the galactic core. Image: NASA*

distance data from the *Gaia* spacecraft and spectra from the Sloan Digital Sky Survey (SDSS), the investigators selected a subset of low-metallicity red-giant stars in a 30-degree region around Sagittarius A*, the designation given to the galactic core. This initial collection consisted of over two million candidate stars, each with less than 3 percent of the solar abundance of "metallic" elements, the collective name given to those atomic species heavier than hydrogen and helium.

From this two-million-star sample, the research team further used *Gaia* measurements to select those stars that had orbits closely tied to the galactic centre—stars with nearly circular orbits that didn't stray far into the galaxy. Stars with large eccentricities were identified as interlopers passing through Sagittarius in extended orbits that took them out into the deeper reaches of the Milky Way.

The final sample revealed a core of ~18,000 stars with metallicities ranging from 3 percent to 0.2 percent of the solar abundance. The team labelled this core of old stars as the Milky Way's proto-galaxy. After correcting for obscuration of background stars by dust, Rix projected a total of 50 to 100 million solar masses are likely tied up in the proto-galaxy.

In order to conduct the survey, the team had to identify bright red-giant stars and gather their spectral measurements in the neighbourhood of Sagittarius A* for which radial velocities, proper motion, parallaxes, and orbital velocity were known or calculable. Because their sample extended beyond the limits of previous studies, metallic abundances were re-calculated and compared to known values from other direct measurements. This selection process reduced the number of candidates to about 1.5 million. After orbital calculations were completed, largely using *Gaia* data, the sample was winnowed to the 18,000 candidate stars with orbits closely coupled to the galactic nucleus—the initial core of the Milky Way.

According to the team's *Nature* paper, "The metal-poor stars exhibit a striking central concentration relative to the metal-rich sample, suggesting a spheroidal population in the inner galaxy." More revealing was the measure of orbital rotation: the most metal-poor stars barely revolved around the core while those with increasingly larger metallicities showed more prominent velocities. This was interpreted as reflecting the initial spin-up of the Milky Way, with stellar metallic content revealing how rotation increased with the ages. According to the research team, "Such a relation is expected if star formation occurs—as time goes on—in gas that has increasingly settled into a disk…."

## New details in the Orion Nebula

Hot O and B stars embedded in giant molecular gas clouds produce energetic ultraviolet (UV) photons that ionize hydrogen in the surrounding nebula, producing glowing HII regions that are favourite targets for amateur telescopes and cameras. Lower-energy far-ultraviolet (FUV) photons, however, pass through the HII region and go on to interact with the more distant parts of the gas cloud where the composition is largely in molecular form or in dust grains. In this zone, known as a Photo-Dissociation Region (PDR), the FUV radiation is capable of photo-dissociating molecules and ionizing more delicate atoms such as carbon, sulfur, and silicon, heating the nebula, which is then cooled by the emission of infrared radiation. The PDR is a complex region in which significant chemical and physical processes determine the character of a large part of the nebula. Its importance is reflected in the fact that PDR emission dominates the infrared (IR) spectra of star-forming galaxies. Within the nebula, FUV radiation produces warm regions of dust and gas embedded in neutral atomic and molecular gas, creating interfaces that have an important influence on the formation of new stars.

Recently, astronomers using the W.M. Keck Observatory on Hawai'i Island have captured the most detailed and complete images of the PDR in the constellation Orion, which gets zapped with UV radiation from several massive young stars, particularly the four Trapezium stars. When viewed with a telescope, the photogenic nebula is seen as a glowing gaseous stellar nursery located 1,350 light-years from Earth. The irradiated neutral zone is located in a structure known as the Orion Bar that lies within the Orion Nebula. The boundary or transition zone between ionized and neutral parts of a giant molecular cloud often forms a sharp "ridge" of emission that is sometimes described as a "reef" in photographs.

"It was thrilling being the first, together with my colleagues of the 'PDRs4All' *James Webb Space Telescope* team, to see the sharpest images of the Orion Bar ever taken in the near infrared," said Carlos Alvarez, a staff astronomer at Keck Observatory and co-author of the study.

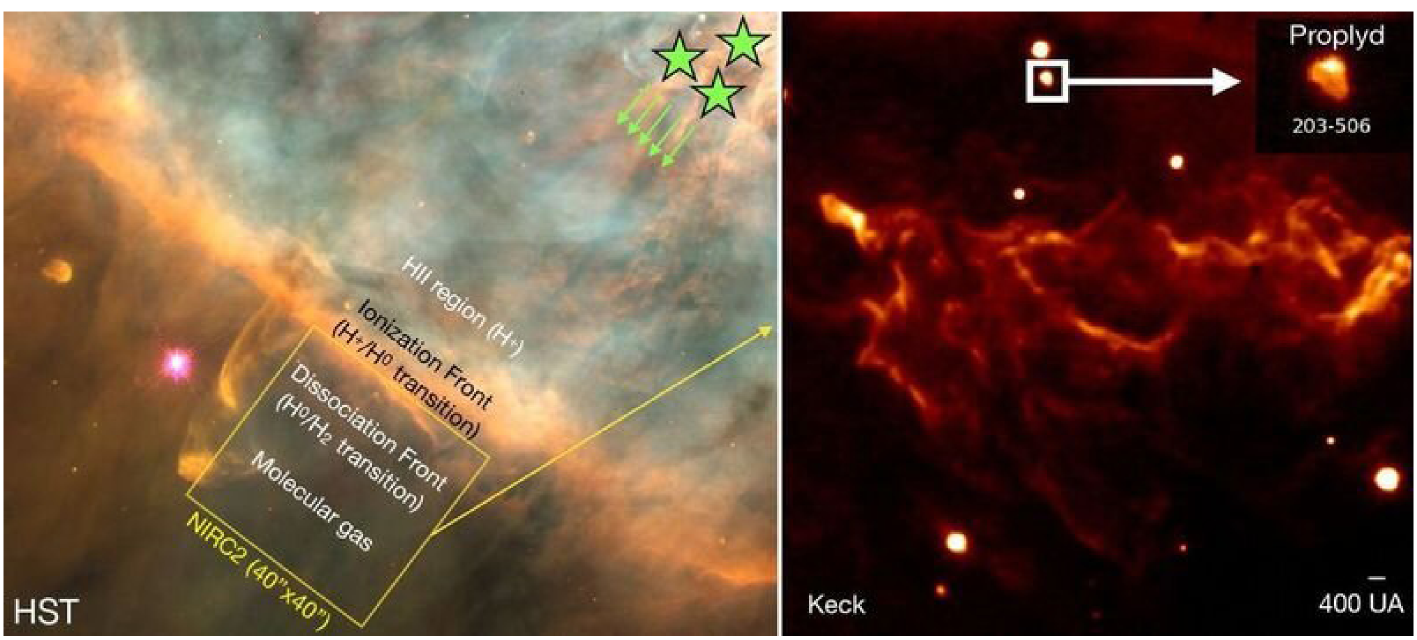



*Figure 4 — Left:* Hubble Space Telescope *mosaic of the Orion Bar. The green star icons show the location of the hot blue stars of the Trapezium. Credit: NASA/STScI/Rice Univ./C.O'Dell et al. The NIRC2 wide camera field of view is shown in the yellow square. Right: Infrared heat map of the Orion Bar obtained with Keck Observatory's NIRC2 instrument reveals substructures such as proplyds. Credit: Habart et al./W.M. Keck Observatory*

Because the Orion Nebula is the closest massive star-formation region to us and may be similar to the environment in which our Solar System was born, studying its PDR—the area heated by starlight—is an ideal place to find clues as to how stars and planets are created.

"Observing photo-dissociation regions is like looking into our past," said Emilie Habart, an Institut d'Astrophysique Spatiale associate professor at Paris-Saclay University and lead author of a paper on this study. "These regions are important because they allow us to understand how young stars influence the gas and dust cloud they are born in, particularly sites where stars, like the Sun, form."

To probe Orion's PDR, the PDRs4All team used Keck Observatory's second-generation Near-Infrared Camera (NIRC2) in combination with the Keck II telescope's adaptive optics system. They successfully imaged the region with such extreme detail that the researchers were able to spatially resolve and distinguish the Orion Bar's different substructures—structures such as ridges, filaments, globules, and proplyds (externally illuminated photo-evaporating disks around young stars)—that formed as starlight blasted and sculpted the nebula's mixture of gas and dust.

"Never before have we been able to observe at a small scale how interstellar matter structures depend on their environments, particularly how planetary systems could form in environments strongly irradiated by massive stars," said Habart. "This may allow us to better understand the heritage of the interstellar medium in planetary systems, namely our origins."

Massive young stars emit large quantities of UV radiation that affect the physics and chemistry of their local environment; how this surge of energy the stars inject into their native cloud impacts and shapes star formation is not yet well known.

The new Keck Observatory images of the Orion Bar will help deepen astronomers' understanding of this process because they reveal in detail where gas in its PDR changes from hot ionized gas, to warm atomic, to cold molecular gas. Mapping this conversion is important because the dense, cold molecular gas is the fuel needed for star formation.

*Composed in part with material provided by W.M. Keck Observatory*

## What slows the rotation of accretion disks?

The motion of a tiny number of charged particles may solve a long-standing mystery about thin gas disks rotating around young stars, according to a new study from Caltech. These features, called accretion disks, last tens of millions of years and are an early phase of Solar System evolution. They contain a small fraction of the mass of the star around which they swirl and are called accretion disks because the gas in these disks spirals slowly inward toward the star.

Scientists realized long ago that when this inward spiraling occurs, it should cause the inner part of the disk to spin faster, according to the law of the conservation of angular momentum. To understand conservation of angular momentum, think of spinning figure skaters: when their arms are outstretched, they spin slowly, but as they draw their arms in, they spin faster.

Angular momentum is proportional to velocity times radius, and the law of angular momentum conservation states that the angular momentum in a system stays constant. So, if the skater's radius *decreases* because they have drawn their arms in, then the only way to keep angular momentum constant is to *increase* the spin velocity.

The inward spiral motion of the accretion disk is akin to a skater drawing their arms in—and as such, the inner part of the accretion disk should spin faster. Indeed, astronomical observations show that the inner part of an accretion disk does spin faster. Curiously, though, it does not spin as fast as predicted by the law of conservation of angular momentum.

Over the years, researchers have investigated many possible explanations for why accretion disk angular momentum is not conserved. Some thought friction between the inner and outer rotating parts of the accretion disk might slow down the inner region. However, calculations show that accretion disks have negligible internal friction. The leading current theory is that magnetic fields create what is called a "magnetorotational instability" that generates gas and magnetic turbulence—effectively forming friction that slows down the rotational speed of inward spiraling gas.

"That concerned me," says Paul Bellan, professor of applied physics. "People always want to blame turbulence for phenomena they do not understand. There's a big cottage industry right now arguing that turbulence accounts for getting rid of angular momentum in accretion disks."

A decade and a half ago, Bellan began investigating the question by analyzing the trajectories of individual atoms, electrons, and ions in the gas that constitutes an accretion disk. His goal was to determine how the individual particles in the gas behave when they collide with each other, as well as how they move in between collisions, to see if angular momentum loss could be explained without invoking turbulence.

As he explained over the years in a series of papers and lectures that were focused on "first principles"—the fundamental behaviour of the constituent parts of accretion disks—charged particles (i.e. electrons and ions) are affected by both gravity and magnetic fields, whereas neutral atoms are only affected by gravity. This difference, he suspected, was key.

Caltech graduate student Yang Zhang attended one of those talks after taking a course in which he learned how to create simulations of molecules as they collide with each other to produce the random distribution of velocities in ordinary gases, such as the air we breathe. "I approached Paul after the talk, we discussed it, and ultimately decided that the simulations might be extended to charged particles colliding with neutral particles in magnetic and gravitational fields," Zhang says.

Ultimately, Bellan and Zhang created a computer model of a spinning, super-thin, virtual accretion disk. The simulated disk contained around 40,000 neutral and about 1,000 charged particles that could collide with each other, and the model also factored in the effects of both gravity and a magnetic field. "This model had just the right amount of detail to capture all of the essential features," Bellan says, "because it was large enough to behave just like trillions upon trillions of colliding neutral particles, electrons, and ions orbiting a star in a magnetic field."

The computer simulation showed collisions between neutral atoms and a much smaller number of charged particles would cause positively charged ions, or cations, to spiral inward toward the centre of the disk, while negatively charged particles (electrons) spiral outward toward the edge. Neutral particles, meanwhile, lose angular momentum and, like the positively charged ions, spiral inward to the centre.

A careful analysis of the underlying physics at the subatomic level—in particular, the interaction between charged particles and magnetic fields—shows that angular momentum is not conserved in the classical sense, though something called "canonical angular momentum" is indeed conserved.

Canonical angular momentum is the sum of original ordinary angular momentum plus an additional quantity that depends on the charge on a particle and the magnetic field. For neutral particles, there is no difference between ordinary angular momentum and canonical angular momentum, so worrying about canonical angular momentum is unnecessarily complicated. But for charged particles—cations and electrons—the canonical angular momentum is very different from the ordinary angular momentum because the additional magnetic quantity is very large.

Because electrons are negative and cations are positive, the inward motion of ions and outward motion of electrons, motions caused by collisions, increases the canonical angular momentum of both. Neutral particles lose angular momentum as a result of collisions with the charged particles and move inward, which balances out the increase in the charged-particle canonical angular momentum.

It is a small distinction, but makes a huge difference on a Solar System-wide scale, says Bellan, who argues that this subtle accounting satisfies the law of conservation of canonical angular momentum for the sum of all particles in the entire disk; only about one in a billion particles needs to be charged to explain the observed loss of angular momentum of the neutral particles.

Furthermore, Bellan says, the inward motion of cations and outward motion of electrons results in the disk becoming something like a gigantic battery with a positive terminal near the disk centre and a negative terminal at the disk edge. Such a battery would drive electric currents that flow away from the disk both above and below the plane of the disk. These currents could power astrophysical jets that shoot out from the disk in both directions along the disk axis. Indeed, jets have been observed by astronomers for over a century and are known to be associated with accretion disks, though the force behind them has long been a mystery. ✶

*Composed with material provided by Caltech.*

*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.*

# Research Articles / Article de recherche

## Some Notable Solar Storms

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### Abstract

This is a short history of powerful solar storms that have affected the Earth by either energetic particles or geomagnetic pulses. For recent magnetic ones, including the failure of Hydro Québec in 1989 and the Carrington flare of 1859, we have direct observational evidence, while our knowledge of earlier particle events in 993, 774 CE, and 660, 5259, and 7176 BCE depends on records of pulses in the radioactive nuclides of carbon 14 in tree rings and beryllium 10 and chlorine 36 in ice cores. The event of 993 CE was key to determining the date of 1021 CE for the Viking settlement at L'Anse aux Meadows in Newfoundland. These solar storms are rare but powerful and unpredictable, so they present a serious danger to the electrical, electronic, and satellite systems that now are essential for our daily lives.

### 1. Introduction

Our Sun is a remarkably stable star. Its luminosity integrated over all wavelengths, known as the total solar irradiance or TSI, varies by only 0.1% over the 11-year sunspot cycle, being brightest when the dark spots are most numerous because of extra radiation from the surrounding areas. However, geomagnetic storms and spectacular auroral displays from time to time remind us of other solar influences. We attribute these phenomena to instabilities that develop as the magnetic fields from multiple sunspots of opposite polarity intermingle resulting in flares, X- and gamma rays, coronal mass ejections (CMEs) with associated magnetic fields and solar cosmic rays, now called solar energetic particles (SEPs). If the ejection is toward us, it can be measured by Earth-based magnetic and particle sensors as well as satellite instruments. The X- and gamma rays are absorbed high in the Earth's atmosphere, where they can affect radio transmission. The varying strength of the Sun's general magnetic field strongly influences the flux of galactic energetic particles (galactic cosmic rays) that reach us, permitting more when the field is weak.

### 2. 2022 February 4

A geomagnetic storm from a moderate coronal mass ejection hit 49 communication satellites on February 4 this year, the day after they were launched by SpaceX for its Starlink project to provide better internet connections worldwide. (www.space.com/spacex-starlink-satellites-lost-geomagnetic-storm). The increase in atmospheric drag of approximately 50% prevented most of the satellites from leaving their low preliminary orbit used for system testing, so eventually they will burn up on re-entry. At higher altitudes, stronger storms can be serious problems for both orbital lifetime and satellite electronics.

### 3. Québec in 1989

Older readers from Québec will remember the 1989 winter morning of Monday, March 13, with no electricity. A strong coronal mass ejection had reached the Earth, where interaction with the magnetosphere induced currents in the lengthy transmission lines of Hydro Québec and caused a system-wide failure. Most of the province was without electricity for ten hours and some rural parts had to wait days for restoration. Boteler (2019) has summarized the problems that occurred at many other power facilities across Canada and northern United States.

Staff at Canada's Department of Energy, Mines and Resources (EMR), which had the responsibility to alert facilities of possible dangers from solar storms, had issued a warning on Friday, March 10, based on information from international solar monitors. That afternoon the 10.7-cm solar radio telescope at the Algonquin Radio Observatory of the National Research Council (NRC) recorded the exceptionally strong event shown in Figure 1. About 16:00 EST, Paul Gagnon at the observatory notified solar astronomer Vic Gaizauskas at NRC in Ottawa. He immediately tried to contact EMR, but both members of the relevant staff had departed for the day. It

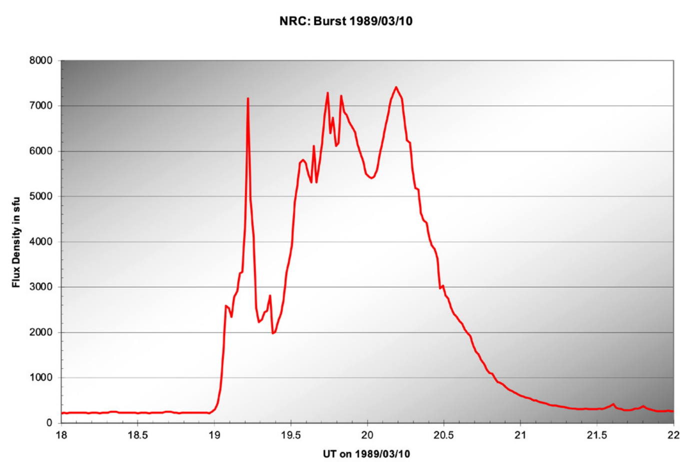


*Figure 1 — The radio signal from the 1989 March 10 solar flare. This is the strongest signal seen since Arthur Covington began monitoring the 10.7 cm solar radio emission at the National Research Council in 1947. Normally the strength varies between 75 solar flux units (sfu) at sunspot minimum and 150 to 280 at maximum. This radio signal travels at the speed of light, giving us a warning hours to days before the dangerous effects arrive. (Image courtesy of Ken Tapping.)*

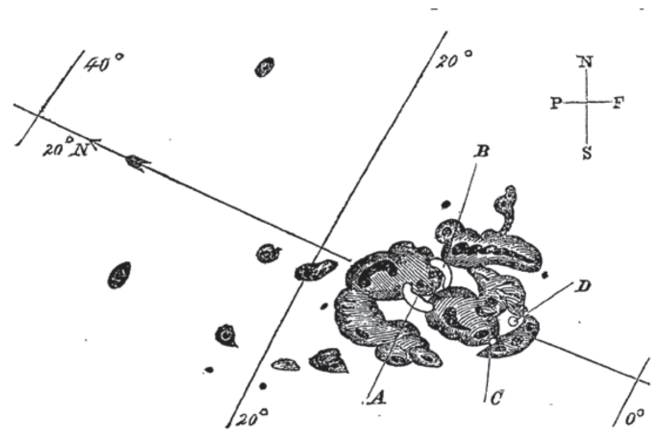


*Figure 2 — Carrington's sketch of the 1859 solar flare. It appeared first as two parts in the positions marked by the white patches A and B above the large spot. During about 5 minutes, they moved approximately 30,000 miles over the solar surface toward C and D and disappeared.*

is unclear whether the additional warning would have helped because Hydro Québec, along with other power suppliers in Canada and the United States, did not expect a magnetic storm could be so devastating. Now, Hydro Québec, along with other generators, have better procedures for dealing with solar events; the NRC solar radio monitor is based at the Dominion Radio Astrophysical Observatory near Penticton, B.C., and the communication of dangerous events by Natural Resources Canada, the successor to EMR, is no longer constrained by weekends. In fact, Richard Coles, the responsible EMR manager at the time, had just received budgetary approval to include weekend forecasting beginning on 1989 April 1!

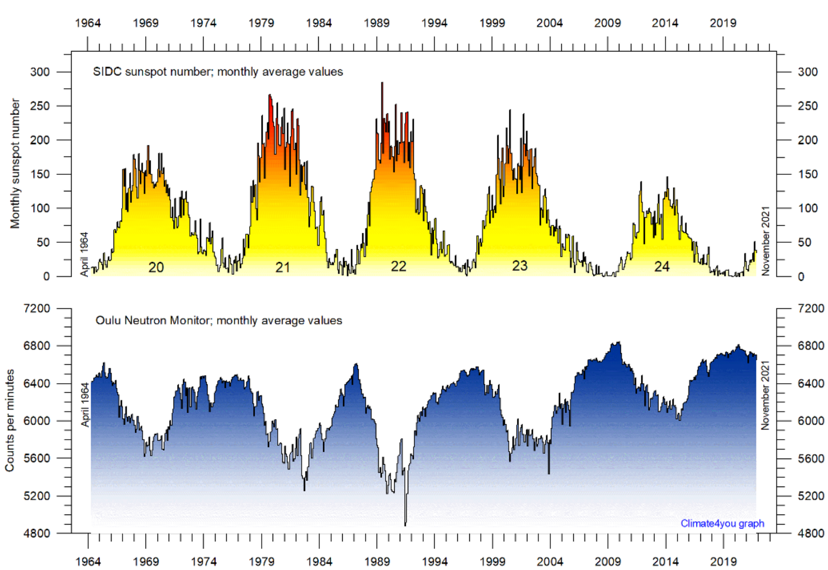


*Figure 3 — This record from the Oulu neutron monitor in Finland shows that the incidence of galactic cosmic rays is antiphase with sunspot number. Figure courtesy of Ole Humlum www.climate4you.com*

Guillon et al. (2016) have described how Hydro Québec had pioneered the use of 735 kV extreme-high-voltage transmission lines a thousand kilometres long to bring electric power from the generating stations east of James Bay and in Labrador to the populated south. Since both lines were located in the auroral zone, reasonable protective options were in place but were overwhelmed by this exceptional geomagnetic storm.

According to Boteler (2019), this storm resulted from two CME's from strong flares in a large active region of sunspots as it approached the centre of the disk and alignment with the Earth. The first magnetic disturbance reached us in 54h 30m on March 12 at 20:27 EST, resulting in some disturbances in power systems in northern United States and the second in 31h 27m on March 13 at 2:43 EST causing the Québec failure, affecting many systems in Sweden and the United Kingdom, as well as North America, throughout the day.

Lengthy electrical transmission lines as well as telephone lines and pipelines at high geomagnetic latitudes are particularly at risk from induced electric currents. Other strong magnetic storms were 1972 August 4, which detonated sea mines off the Vietnam coast (Knipp et al. 2018) and the New York Railroad storm of 1921 May 13–16, which disrupted telegraph and telephone systems worldwide and is presumed to be the cause of fires at a station in Brewster, north of New York City, and at a control tower in the city (Love et al. 2019).

## 4. The Carrington Event of 1859

Richard Carrington was a meticulous independent observer in England with a telescope in Redhill, Surrey. According to Prosser (2018), he received the Gold Medal of the Royal Astronomical Society in 1859 for his contributions to a catalogue of circumpolar stars. He also discovered the differential rotation of sunspots, noticed that they form closer to the equator as a cycle progresses and started the counting of solar rotations, which began with No. 1 on 1853 November 9.

On 1859 September 1, Carrington (1859) was recording the forms and positions of spots using a projected image of the Sun 11 inches in diameter when he saw,

> "… within the area of the great north group (the size of which had previously excited general remark), two patches of intensely bright and white light broke out, in the positions indicated in the appended diagram by the letters A and B, and of the forms of the spaces left white."

He added that the event began within 15 seconds of 11:18 GMT, faded gradually, shifted an estimated 30,000 miles over the huge sunspot and was gone after 5 minutes as shown in Figure 2.

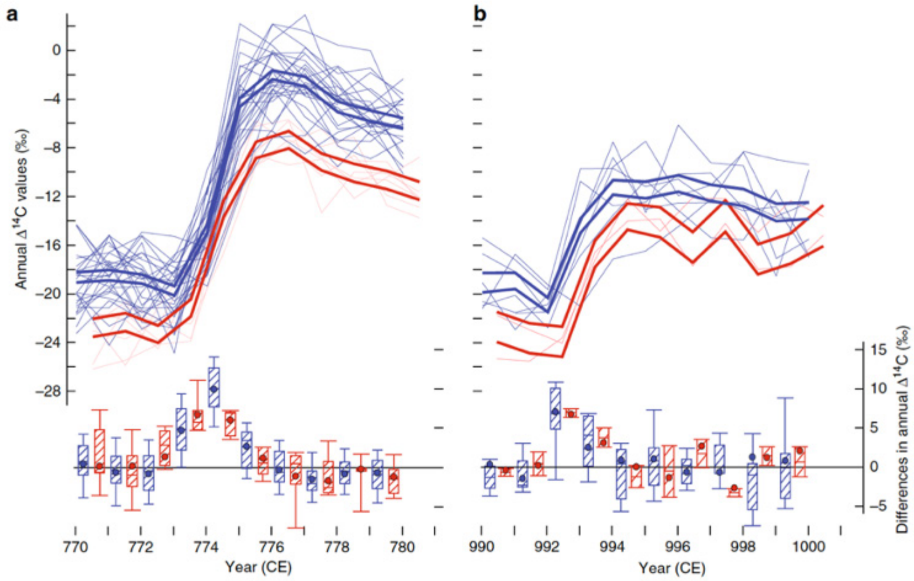


*Figure 4 — Measurements of ¹⁴C in tree rings by Buntgen et al. (2018) showing the discontinuities for 774 and 993 CE with blue for Northern Hemisphere sites and red for Southern ones. In each case the thick lines bracket the standard uncertainties. Reproduction according to creativecommons.org/licenses/by/4.*

His observation was confirmed by the independent report of this flare by the London observer Richard Hodgson (1859) in an adjoining note in the *Monthly Notices of the Royal Astronomical Society*. This was the first observation of what we now call a white-light flare.

Fortuitously, the Kew Gardens Observatory in London had recently installed a photographic recorder of geomagnetic activity. Carrington's report to the Society noted "that a moderate but very marked disturbance took place at about $11^h\ 20^m$ A. M., Sept. 1st, of short duration; and that towards four hours after midnight there commenced a great magnetic storm, which subsequent accounts have established to have been as considerable in the southern as in the northern hemisphere." However, at the time, Carrington was hesitant to conclude there was a connection with the flare.

The global effects of this event are summarized in several papers in an extensive discussion of the Carrington event edited by Clauer and Siscoe (2006). Exceptional auroral displays and telegraph failures showed that there were two major magnetic storms, first on August 28–29 and then on September 2–3. Red aurorae reached low geomagnetic latitudes ~25° for several hours in both hemispheres the first time and ~18° the second time. All auroral colours were observed below 50° for ~24 h on August 28–29 and for ~18 h on September 2–3. At some places they were bright enough that one could read a newspaper. Large portions of the world's 200,000 km of telegraph lines were unusable for these intervals and some fires occurred. Reproduction of the records at the Kew Observatory by Boteler (2006) show the first magnetic pulse arriving on Sunday, August 28, at 22:55 UT and continuing until 10:30 the next day, and a second on September 2 at 05:00 UT that lasted until September 7. During the second phase, American telegraph operators in the Boston area and between Philadelphia and Pittsburgh were able to send brief messages when disconnected from their batteries.

Shea & Smart (2006) reprinted the report of Prof. G.P. Kingston, Director of the Toronto Magnetic Observatory.

"Prior to the morning of Sept. 2, the instruments occasionally gave evidence of a disturbed condition of the magnetic elements but not to such an extent as to lead to any systematic reading of them excepting at the regular hours of observation. The Aurora first appeared about 7:40 P.M. of Sunday Aug. 28. From which time through the night the whole sky was covered with a brilliant mass of streamers, patches and luminous bands, which rose from all points of the horizon, the predominant colour being yellow intermixed with patches of crimson."

He continued with brief descriptions of faint aurora on August 29, overcast sky August 30, no aurora August 31, overcast till near midnight then auroral streamers and a corona September 1, aurora through clouds September 2, streamers and imperfect corona September 3, streamers September 4 and faint aurora September 5.

Kingston included magnetic readings for only September 2 and 3 with some off scale during the evening of the first day. Thus Toronto had aurora during both magnetic storms, but the observatory missed measuring the signals on August 28 because it was not staffed on Sundays.

Hudson (2021) compared all these observations with what we now know about super flares on the sun and other slow-rotating G-type stars. He noted that none of the radioisotope signatures discussed below have been found for the Carrington flare of 1859 and concluded that it "did not significantly exceed the magnitudes of the greatest events observed in the modern era."

## 5. Cosmogenic Radionuclides

During the sunspot cycle, a decreasing solar magnetic field permits an increase in galactic cosmic rays (mainly protons and

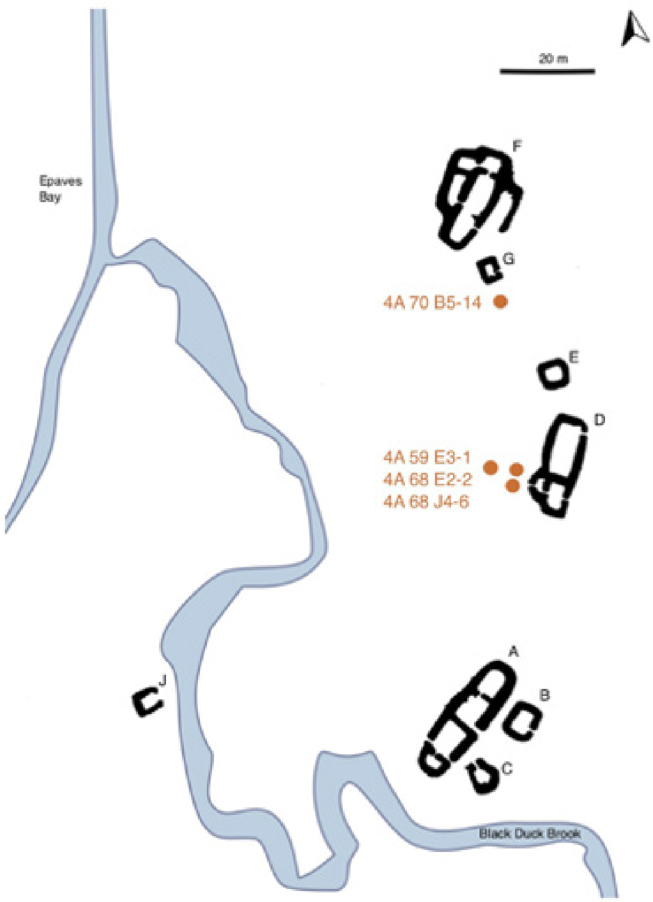


*Figure 5 — Map of the excavations at L'Anse aux Meadows from Kuitems et al. (2021) showing the locations of the three wood samples near Hall D used to date the Norse site. The fourth sample from near hut G did not have enough rings to include the calibrating signal of 993 CE. Reproduction according to creativecommons.org/licenses/by/4.*

alpha particles) to reach our earth's upper atmosphere where interactions with atmospheric molecules produce neutrons that are detected as shown in Figure 3. These energetic particles also produce the radioactive nuclei of carbon 14 ($^{14}C$), beryllium 10 ($^{10}Be$) and chlorine 36 ($^{36}Cl$) as listed in Table 1. The $^{14}C$ combines with atmospheric $^{16}O_2$ to form $^{14}C^{16}O_2$, which circulates for about 5 years before photosynthesis deposits as $^{14}C$ in annual tree rings. The $^{10}Be$ and $^{36}Cl$ isotopes attach to liquid or solid aerosol particles suspended in the air that precipitate after about a year. In polar regions the snow becomes compressed into annual layers of ice that can be examined with cores. Similarly, a sufficiently energetic burst of solar particles can add a pulse to the formation of these isotopes.

The radioactive nuclei decay at known rates, so their abundance relative to the stable counterpart can give the age of a sample after correction for atmospheric variations in their generation. However, for the present purpose we are just interested in any spikes in the concentration of these radioactive nuclei in the annual rings of a tree trunk or ice core that can indicate the addition of a solar particle event to the background of galactic cosmic rays. On time scales of a few years, the $^{14}C/^{12}C$ ratio varies by less than a few percent from year to year, so anything significantly stronger can be attributed to a burst of solar particles. If a definite calendar year can be attached to a specific ring such as the outermost one for the date the tree was cut down or evidence of a known volcanic eruption in an ice core, a date for the solar event can be obtained simply by counting the intermediate rings.

## 6. The Events of AD 993 and AD 774 and the Vikings in Newfoundland

Miyake *et al.* (2012, 2013) found such abrupt changes in $^{14}C$ in Japanese tree rings for the years 774/5 CE and 993/4 CE. Mekaldi *et al.* (2015) confirmed these detections with $^{10}Be$ spikes in two Greenland ice cores and one from Antarctica, as well as a $^{36}Cl$ detection from Greenland. Buntgen et al. (2018), in a worldwide study of tree rings, eliminated the slight uncertainty in the years with their measurements of events in 774 CE in 27 Northern Hemisphere sites and 7 Southern Hemisphere ones and the weaker event in 993 CE, with about half the strength, in 8 Northern and 2 Southern sites as shown in Figure 4. Uusitalo et al. (2018) found that the strength of the 774 CE signal increased with geomagnetic latitude as expected for a solar source of the energetic particles.

The 993 CE anomaly provided a key marker for an international team of Kuitems et al. (2021) from the Netherlands, Germany, and Canada investigating the Viking site at L'Anse

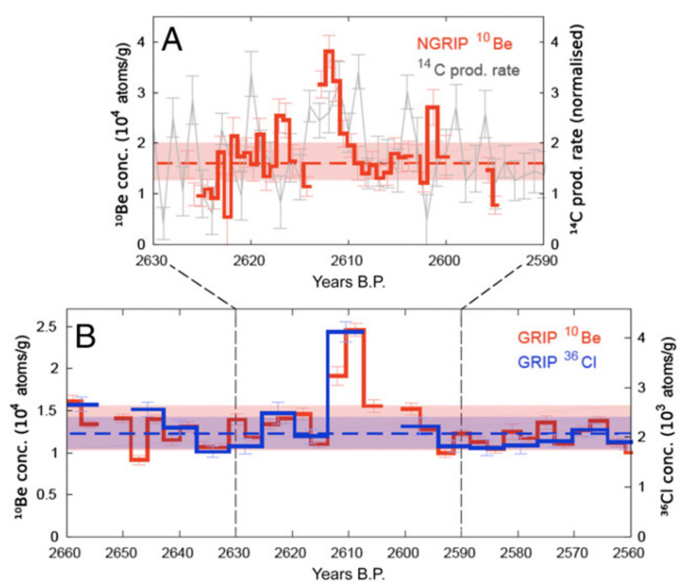


*Figure 6 — Measurements of the $^{10}Be$ and $^{36}Cl$ peaks at 660 BCE in two Greenland ice cores by O'Hare et al. (2019). Here and in the next figure B.P. means Before the Present era defined as 1950 CE, so the difference from BCE dates is 1951 years because year 1 CE is the year following 1 BCE. Reproduction according to creativecommons.org/licenses/by/4.*

aux Meadows on the northmost tip of Newfoundland. (The site was named after the village on the next bay to the east.) The analysis of three wood samples from the locations noted in Figure 5 showed the $^{14}C$ spike as well as the waney edge where growth stopped when the tree was felled, so a simple counting of the annual rings in each gave the same date of 1021 CE. The edge of one sample indicated felling in the spring and another for the summer or autumn, while the third was indeterminate. All showed the clean cuts expected from the use of metal tools, which would not have been available to any indigenous inhabitants. From a study of the *Saga of the Greenlanders* and the *Saga of Erik the Red*, Kuitems et al. concluded that the Vikings occupied the site for at least 3 winters and at most 7 over an interval of 13 years around 1021 CE.

In the cyclic changes of the Earth's climate, the Medieval Warm Period from about 900 to 1400 CE permitted the Vikings to establish settlements with supporting farms and livestock in Greenland and explore to the west and south. Then, as temperatures fell during the Little Ice Age, the settlers fled to Iceland or died in their villages, trapped by the sea ice. When temperatures rose again in recent times, farming again became possible by the people who had repopulated the coasts.

Wallace (2006) has described the artifacts found at L'Anse aux Meadows, a soapstone spindle whorl, a fragment of a bone needle, a glass bead, and a bronze pin with a ring that definitely established the Norse presence, but the best estimates from carbon dating gave only a range from 990 to 1050 CE. She identified the site as Straumsfjordr in the sagas with the fiord being the Strait of Belle Isle. From this base during summer weather, the Vikings explored the coastal areas surrounding the Gulf of St. Lawrence, which they called Vinland. They collected wild grapes and wheat and traded with natives in skin canoes. Later they had to defend themselves from a concerted attack. The sagas mention a particular location they called Hop, which in Old Norse means a shallow tidal lagoon protected by sand bars, rather like the estuaries of rivers on the Gulf Coast of New Brunswick. Along with grapes and wheat, butternuts grow there but not in Newfoundland, explaining the butternuts found at L'Anse aux Meadows.

## 7. 660 BCE (2609 BP)

In the rings of German, Irish, and California trees, Park et al. (2017) found a $^{14}C$ enhancement about 660 BCE, preceded by 3 years of reduced strength implying a time near solar maximum when the galactic cosmic ray flux would be low. Later O'Hare et al. (2019) examined two ice cores. Figure 6 shows the $^{10}Be$ and $^{36}Cl$ results from the Northern Greenland Ice Core Project (NGRIP) and the lower-resolution Greenland Ice Core Project (GRIP). The authors attributed these signals to solar particle events 10 to 20 times stronger than the strongest modern one of 1956 February 23 and comparable with those of 774 and 993 CE.

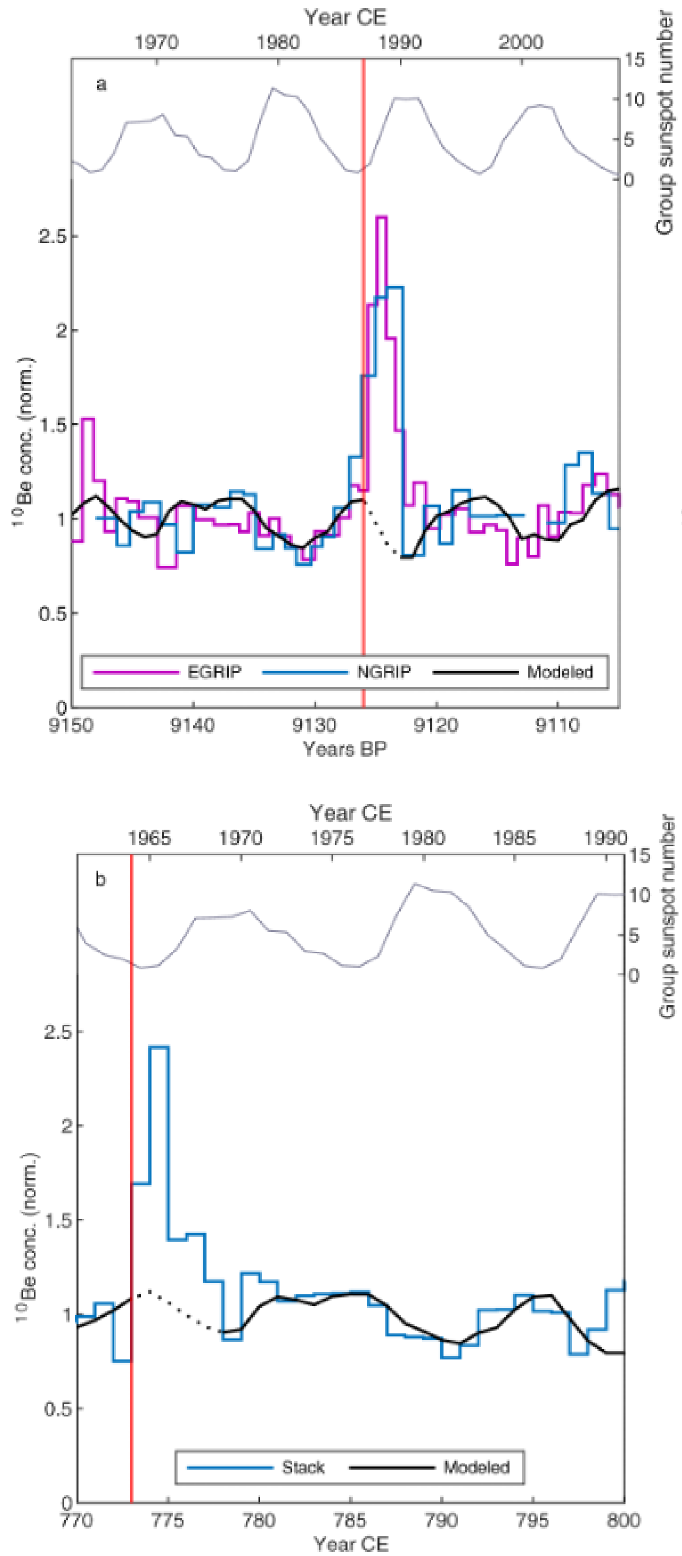


*Figure 7 — Measurements by Paleari et al. (2022) of $^{10}Be$ and $^{36}Cl$ for 7176 BCE and $^{10}Be$ for 774 CE from Greenland ice cores showing coincidences near the minima in the solar cycle. The peak in glacial deposition occurs about a year after the arrival of the solar energetic particles that create the extra $^{10}Be$. Reproduction according to creativecommons.org/licenses/by/4*

## 8. 5259 BCE and 7176 BCE (7208 BP and 9125 BP)

In four sets of absolutely dated tree rings from the European Alps, Ireland, Siberia, and the United States, Brehm et al. (2022) found an enhanced $^{14}C$ concentration for the year 5259 BCE and in three such sets from the Alps, Germany, and the United States they found similar excesses for 7176 BCE. Then Paleari et al. (2022) identified the 7175 BCE event with a $^{10}Be$ spike in three dated Greenland ice cores and one from Antarctica and $^{36}Cl$ in one of the Greenland cores. Also, they were able to see the 11-year solar cycle in their $^{10}Be$ records from two of the northern cores and concluded that the solar emission occurred during a minimum in activity, contrary to our expectations. As shown in Figure 7, a similar examination of cores from Greenland and Antarctica revealed that the 774 CE event also occurred during a solar minimum.

## 9. Present Danger

Table 2 from Brehm et al. (2022) compares the above five SEP events by their estimated increase in atmospheric $^{14}C$ along with three more weaker ones also found in tree rings. Out of 12,460 years of dendrochronology records, these 8 are from only the 16% that have been scanned with adequate 1- or 2-year resolution to be confident of an event detection. Ancient auroral records, such as those mentioned by Buntgen et al. (2018), have been inconclusive, so we do not know whether any of these events also had large geomagnetic effects. Nevertheless, a recurrence of one of these rare particle storms would have disastrous consequences for astronauts and electronics in space.

The resolution for the 19th-century tree rings and ice cores is adequate, but any energetic particles in the Carrington magnetic storm were too weak to be detected. However, modern storms, either particle or geomagnetic, such as those summarized in Table 3, do happen and can have serious effects on the ground and in space. Now that our present society depends critically on lengthy power lines, electronic controls, and communications with satellites, the devastation by a strong SEP shower or geomagnetic storm would be immense. In our adaptation and mitigation plans for other dangers, we must include protection from these solar surges. We must not ignore the warnings we have had from past events.

I wish to thank David Boteler, Vic Gaizauskas, and Ken Tapping for helpful contributions to this report. ✶

| Reaction | Half life (y) |
|---|---|
| n + $^{14}N$ —> p + $^{14}C$ | 5730 |
| Spallation of $^{14}N$, $^{16}O$ —> $^{10}Be$ | 1.387 × 106 |
| Spallation of $^{40}Ar$ —> $^{36}Cl$ | 3.08 × 105 |

*Table 1 – The Cosmogenic Radionuclides*

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| 7176 BCE | 5410 BCE | 5259 BCE | 660 BCE | 774 CE | 993 CE | 1052 CE | 1279 CE |
|---|---|---|---|---|---|---|---|
| 28.7±0.9 | 9.0±1.1 | 29.2±0.9 | 19.2±2.1 | 26.2±1.0 | 14.0±1.2 | 10.1±2.0 | 9.2±2.7 kg |

*Table 2 – Atmospheric increase in kilograms of the mass of $^{14}C$ by strong solar particle events according to Brehm et al. 2021.*

| |
|---|
| **2022 Feb. 4** |
| A modest magnetic storm increased the atmospheric drag on *Starlink* satellites preventing them from reaching the desired orbit. (www.nytimes.com/2022/02/09/science/spacex-satellites-storm.html). |
| **2017 Sep. 10** |
| The relatively weak magnetic storm that followed the coronal mass rejection and strongest flare of solar cycle 24 disabled high-frequency aviation and maritime emergency radio bands for up to 8 hours. (Zhu et al. 2021). |
| **2003 Oct. 29–30** |
| One of the strongest coronal mass ejections and associated magnetic storms was followed by another less than a day later. Astronauts on the *International Space Station* took protective cover from the energetic particles, several deep-space missions went into safe mode or shut down, a radiation experiment on a Mars orbiter failed, and communications with Antarctic research stations were out for 130 hours. (www.ncei.noaa.gov/news/great-halloween-solar-storm-2003) |
| **2000 Apr. 6** |
| Four satellites of the U. S. Defence Meteorological Program encountered intense field-aligned currents much stronger than expected from ground observations. (Burke et al. 2006). |
| **1989 Mar. 12–13** |
| The first magnetic pulse disturbed power systems in northern United States and the second disrupted Hydro Québec as well as causing voltage fluctuations and alarms across Canada and the United States (Guillon et al. 2016; Boteler 2019). |
| **1972 Aug. 4** |
| In the shortest recorded transit time of 14.6 h after a flare and coronal mass ejection, a magnetic pulse detonated dozens of sea mines the U.S. Navy had placed off the coast of North Vietnam. (Knipp et al. 2018). |
| **1956 Feb. 23** |
| This is the strongest directly observed solar energetic particle event. Usoskin et al. (2020) have estimated that it was a factor ~30 below the detection limit for a single ice-core or tree-ring proxy, but combining multiple sources could help. |
| **1921 May 13–15** |
| Fires at railroad facilities in New York City and in a nearby town have been attributed to this exceptionally strong magnetic storm. (Love et al. 2019). |

*Table 3 – Some of the Serious Solar Storms of the 20th and 21st Centuries.*

# Astronomy in Philately: "Happy 30th Anniversary Roberta Bondar!"

*by Rick Stankiewicz*
*RASC National Member and Peterborough Astronomical Association member*
*Royal Philatelic Society of Canada member*

Even in uncertain times and during pandemics there can be occasions to celebrate, and this year was one of those occasions. This year marked the 30th anniversary of when Dr. Roberta L. Bondar became only the second Canadian, the first Canadian woman, and the world's first neurologist in space (Figure1). This extraordinary Canadian is not only an astronaut and physician, but a scientist, photographer, pilot, writer, speaker, and champion for the environment. Witnessing the Earth from space tends to have this effect on people.

Bondar's groundbreaking space flight is documented on this silk cachet "Day of Launch" cover (Figure 2), using a stamp (Scott #2575) from the 1991 U.S. Postal Service (USPS) series on "Space Exploration," which depicts the *Voyager 2* spacecraft flying by Uranus. The cancel was applied 1992 January 22, at the Kennedy Space Center, Florida, to mark the successful launch of *Space Shuttle Discovery* STS-42 and its crew of seven astronauts, into low-Earth orbit. On board was a payload that included the first International Microgravity Laboratory (IMT-1). The cachet on this envelope is an official National Aeronautics and Space Administration (NASA) image of this international crew (L to R) Stephen Oswald (Pilot), Roberta Bondar (Payload Specialist 1, CSA), Norman Thagard (Mission Specialist 1), Ronald Grabe (Commander), David Hilmers (Mission Specialist 3), Ulf Merbold (Payload Specialist 2, ESA-West Germany) and William Readdy (Mission Specialist 2). This was only the second Shuttle mission to carry astronauts from three nations.


*Figure 1 — Autographed Canadian Space Agency portrait of Dr. Roberta Bondar in flight suit.*


*Figure 2 — Launch Cover for launch of* Discovery *STS-42, at the Kennedy Space Center, Florida, 1992 January 22.*

Eight days later, this "Day of Return" cover is cancelled 1992 January 30, as the *Discovery* craft landed at Edwards Air Force Base, California, completing a successful mission (Figure 3). During the mission the *Space Shuttle* averaged an altitude of 299 km and completed 129 orbits while travelling over 5.4 million km. Bondar conducted more than 40 scientific experiments in space, including the effects of microgravity on the human body and its ability to recover. The cachet on this cover depicts Bondar and Thagard during the mission.


*Figure 3 — Return Cover for landing of* Discovery *STS-42, at Edwards AFB, CA, 1992 January 30.*

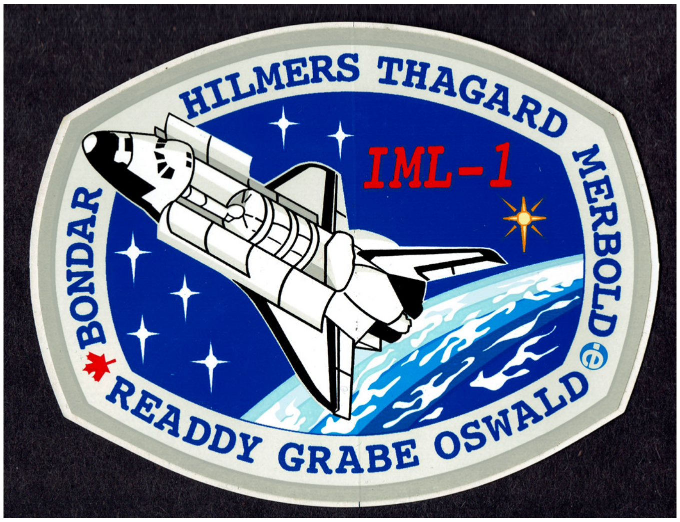


*Figure 4 — Official NASA Mission Patch for STS-42 IML-1*

One of the easiest ways to identify which space mission an astronaut is associated with is by their Mission Patch. There is a tradition of Mission Patches being created for every NASA mission since 1965, and they are typically designed by the crew members, which makes every Mission Patch unique to that crew and their mission. For STS-42 (Figure 4), the design shows the *Space Shuttle Discovery* in orbit with an open cargo bay exposing the Spacelab module, which would have included the IML-1. Around the perimeter are the last names of all seven crew members. Five of the crew members were from the U.S.A., but Bondar is noted as Canadian and Merbold as from the European Space Agency. The white stars on either side of the Shuttle represent the "4" and "2" of the STS-42 delineation. The gold star on the far right is in memory of astronaut Captain Manley "Sonny" Carter, who was slated to have been a Mission Specialist on this mission, but was killed in a plane crash eight months earlier.


*Figure 5 — Bondar's Personal Mission Patch for STS-42 IML-1*

On the other hand, the Personal Mission Patch (Figure 5), which would have been designed solely by Bondar, embodies the many elements of her mission, from the year (1992) to the mission purpose (IML-1). Also included is the caduceus, to represent her medical credentials and background. The red maple leaf mirrors the orientation of the *Space Shuttle* in a quiescent, tail-to-Earth position, floating over the Great Lakes, oriented in such a way that Bondar's hometown of Sault Ste. Marie is centrally located.

Not every astronaut that goes into space has a postage stamp issued for them, but Canada Post was quick to recognize Bondar's—and other Canadian accomplishments in space—with a setenant pair of postage stamps issued on 1992 October 1. (Figure 6) This issue celebrated "Canada in Space," through some achievements up to that point, like Marc Garneau's trip to space in 1984, but the most current was Bondar's trip to space just eight months earlier. The timing was right for recognizing her contributions. The stamp showing the *Space Shuttle* flying over Canada (Scott #1442) was Canada's first use of a holographic stamp design. The other stamp in this set (Scott #1441) and the design of the First Day of issue Cover (FDC) cachet, illustrate the ANIK E2 satellite, to represent Canada's history and lead in communications technology.

Many countries have recognized individual astronauts and cosmonauts; however, it was not until 2003 October 1, that Canada Post released a series of postage stamps to celebrate "Canadian Astronauts." Each of the eight stamps carries an image of one of our Canadian heroes. The FDC shown here (Figure 7) is the first half of the series (Scott #1999 a–d), which includes arguably most of Canada's famous astronauts (Marc Garneau, Roberta Bondar, Steve MacLean, and Chris Hadfield) and autographed by three of them (Garneau, Bondar, and Hadfield). The stamp design combines a coloured foreground image of each astronaut in an official Canadian Space Agency (CSA) portrait and the backgrounds are black and white images from each of their respective NASA missions. The cancellation is shown as St-Hubert, Québec, which comes as no surprise, given that it is home of the CSA. The series is numbered and presented in the chronological order that each astronaut travelled into space. This was the last commemorative stamp issue to celebrate our Canadians in space.

Years later, after hanging up her spacesuit, Dr. Bondar created The Roberta Bondar Foundation, a registered not-for-profit charity in 2009.

The Mission Statement for the Foundation sums up Bondar's love of the environment and humanity: "The Roberta Bondar Foundation connects people to the natural

*Continues on page 224*

# Urania's Gallery

*by Phil Mozel, Mississauga Centre*

*. . . men who have been instructed of her she raises aloft to heaven (ouranos), for it is a fact that imagination and the power of thought lift men's souls to heavenly heights.*
(Diodorus Siculus, 1st century BCE).

Look through any RASC publication and you will come across the seal of the Society: a representation of the ancient Greek muse *Ourania* (Latin *Urania*). Urania was the daughter of Zeus (chief of the Greek gods) and Mnemosyne (or Memory) who was, in turn, the daughter of Uranus (The Sky) and Gaea (The Earth). She is one of the (usually) nine muses and represents astronomy. She may be considered the muse of those reading this *Journal*.

The origin of the RASC seal has been well described in earlier issues of the *Journal* (Rosenfeld 2009, 2013) where we also learn something of the attributes of this muse. Urania, to be identified clearly as such, is generally depicted with a representation of the heavens in the form of a globe or armillary sphere and, sometimes, a pointer, compass, or callipers. A glance at the Society's seal shows that these attributes have always been absent during the several iterations of the seal during the more than 100 years of the Society's existence. This was a conscious decision at least for the 2004 revision (Grey 2004).

This is not unprecedented. For example, the Francois Vase, ca 570 BCE, shows a wedding procession consisting, in part, of Zeus and his wife Hera plus the muses Urania and Calliope. Names appear above the respective individuals but Urania is otherwise without attributes as has often been the case over the last two-and-a-half millennia. (www.khanacademy.org/humanities/ancient-art-civilizations/greek-art/greek-pottery/a/the-francois-vase-story-book-of-greek-mythology). On some occasions the reverse is true and the attribute is depicted without the muse! A first century BCE Greek mosaic currently displayed at the Archaeological Museum of Elis depicts only the names and attributes of the muses. Urania is represented simply by a colourful globe (theoi.com/Gallery/Z20.4).

Herewith, then, a small gallery of the muse Urania highlighting her appearance over the last 25 centuries.

## Classical Representations

*Figure 1 — The author with a 1st century BCE or 2nd century CE reworking of a Greek original of the 2nd century BCE. Urania is depicted holding a globe. The largest representation of Urania he has seen! Naples Archaeological Museum. Photo by Debbie Mozel.*

*Figure 2 — Urania seated and contemplating a globe. Roman, 1st century CE. Discovered in Churriana, Spain. National Archaeological Museum, Madrid. Courtesy of Carole Raddato. www.flickr.com/photos/carolemage/15540589738*

*Figure 3 — Fresco of Urania pointing to a globe mounted on a square base. From the peristyle of the House of the Vettii, Pompeii, before 79 CE. Photo by Peter Stewart. www.flickr.com/photos/peterstewart/736924495*

*Figure 4 — Fresco of Urania on pedestal with pointer and celestial sphere with coordinate lines. Pompeii, before 79 CE. Courtesy of Paul McClure. www.flickr.com/photos/paul-mcclure/25155412346.*

*Figure 5 — Fresco showing a seated Urania with pointer and globe. From the house of Julia Felix, Pompeii, before 79 CE. The chair, particularly the back, is reminiscent of certain styles of sundial. Urania as gnomon? Now in the Louvre, Paris. Courtesy Carol Raddato. www.worldhistory.org/image/3937/fresco-with-urania/*

*Figure 6 — A Roman sarcophagus of the mid-2nd century CE depicting the nine muses. Urania, bottom right, is shown pointing to a globe that may be rendered with coordinate lines. Louvre Museum, Public domain, via Wikimedia Commons https://commons.wikimedia.org/wiki/File:Muses_sarcophagus_Louvre_MR880.jpg*

*Figure 7 — Detail from a 60 m² mosaic from the Roman villa in Vichten, Luxembourg, ca 240 CE. Urania is shown seated and pointing to a globe with coordinate lines.The complete mosaic depicts all nine muses. Courtesy of Musée national d'histoire et d'art Luxembourg.*

*Figure 8 — A mosaic pavement from the triclinium of a Roman villa showing a bust of Urania holding what is described as an armillary sphere. 3rd century CE.* Courtesy Lexicon Iconographicum Mythologiae Classicae. *In the collections of the Bardo Museum, Tunis.*

*LIMC-France resources: LIMCicon ID 1607 (A.-V. Szabados) URL http://www.limc-france.fr/objet/1607. Creation 1976/09/01. Update 2015/01/26. https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode*

*Figure 9 — Urania with globe with coordinate lines. From a mosaic of the nine muses, Cos, Greece. Roman imperial period. Archaeological Museum of Cos. https://commons.wikimedia.org/wiki/File:Palazzo_dei_gran_maestri_di_rodi,_sala_delle_muse,_mosaico_delle_nove_muse_da_kos_08_urania.JPG Courtesy Sailko. Reproduced under licence https://commons.wikimedia.org/wiki Commons:GNU_Free_Documentation_License,_version_1.2*

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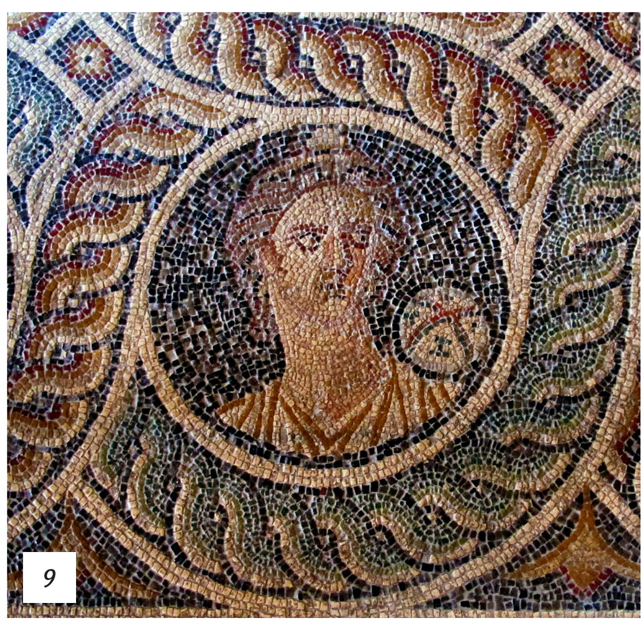
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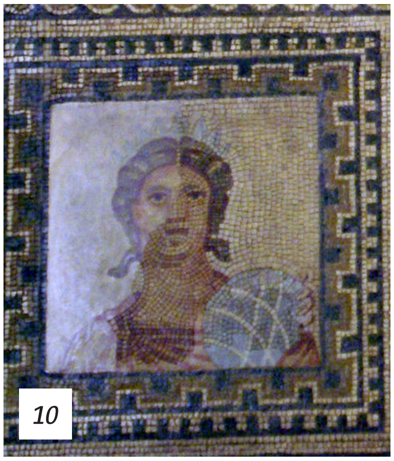
*Figure 1 – After a year and a half of trying under Bortle 4 skies in Athens, Ontario, Shelley Jackson finally managed to reel in the Dark Shark Nebula, found in Cepheus. Shelley says, "The shark swims in a sea of cosmic treasures; dusty regions, dark nebulae, reflection nebulae and colourful stars." Shelly used an Askar 200-mm FL astrograph lens, a 30-mm guide scope, a ZWO 120 mono guide camera, a ZWO ASI294MC pro one-shot colour CMOS cooled to –0 °C on a Sky-Watcher AZ EQ5 pro mount. Stacked and processed with PixInsight with a total integration time of 24 hours and 40 minutes.*

*Figure 2 – Andrea Girones imaged our Solar System giant, Jupiter, on September 24, just two days before its opposition with Io. Andrea used a Celestron C11 Edge HD SCT and an ASI 462MC camera.*

*Figure 3 – This beautiful image of the Cave Nebula together with star cluster NGC 7419, which can be found in Cepheus, was imaged by Adrian Aberdeen from Mount Forest, Ontario. He used a Sky-Watcher Esprit 80MM, ZWO ASI071 camera on a Celestron CGEM mount. The final image was processed with PixInsight.*

*Figure 4 – Katelyn Beecroft captured the Bubble Nebula (NGC 7635) and open cluster M52 using an Askar FRA400 telescope with the ZWO ASI533MC camera and L-extreme filter on an HEQ5 mount. The image was guided using the ASI 120-mm mini and ZWO 30-mm ƒ/4 guidescope. Total integration was 3.5 hours.*



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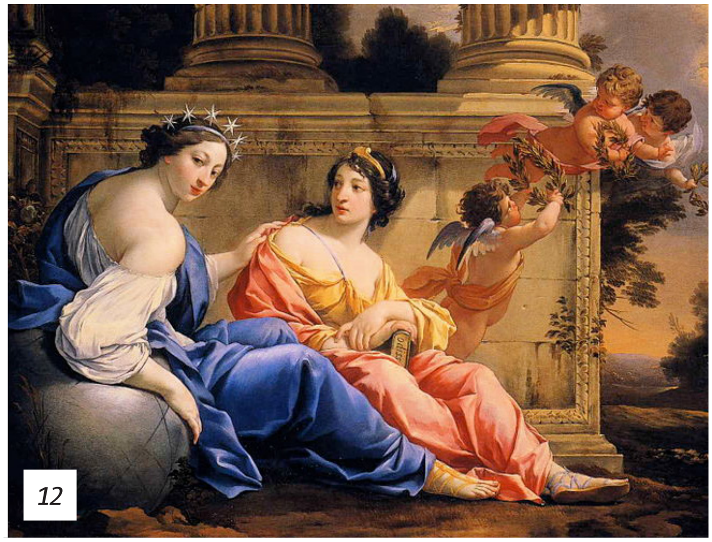

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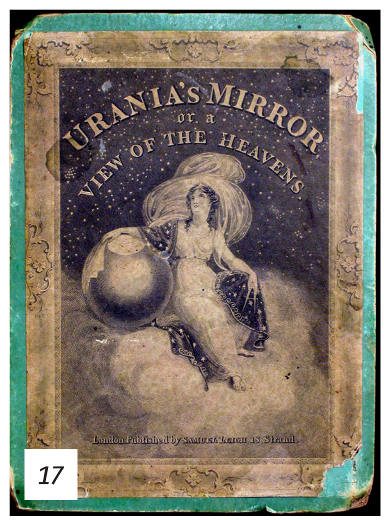


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*Figure 10 — Urania from a Roman portrait mosaic of the nine muses. 3rd/4th century CE. Urania is seen holding a globe with coordinate lines. Found in Trier, Germany (Roman Augusta Treverorum). Rheinisches Landesmuseum. Courtesy of Elena. www.flickr.com/photos/autumnal-fires/3818183175/. Reproduced under licence https://creativecommons.org/licenses/by-nc-nd/2.0/*

## Post-classical Representations

*Figure 11 —* Urania XII, *Andrea Mantegna (artist) and Johann Ladenspelder (printmaker), ca 1550. This is one print from the so-called Tarocchio Cards of Mantegna. Urania holds a globe and callipers. The Miriam and Ira D. Wallach Division of Art, Prints and Photographs: Print Collection, The New York Public Library. https://digitalcollections.nypl.org/items/7cbc52a0-067d-0135-1431-739454e15a61*

*Figure 12 —* Urania and Calliope, *Simon Vouet, French, ca 1634. Urania, with starry diadem, in the company of the muse Calliope is resting her arm on an exercise-ball-sized sphere with coordinate lines. National Gallery of Art, Washington, D.C., Samuel H. Kress Collection. www.nga.gov/collection/art-object-page.46160.html.*

*Figure 13 —* An Allegory of Peace and the Arts, *Orazio Gentileschi, ca 1636–8. Urania, in the company of the muses Calliope and Melpomene, is diademed with stars while holding a celestial globe on which are stars and the signs of the zodiac. The perspective is that of an observer looking from "outside" the heavens, i.e. the constellations appear backward to one viewing the painting. The zodiac is highlighted by a pair of golden lines. A rather scorpion-looking crab precedes Leo. Originally decorating the ceiling of the Great Hall at the Queen's House, Greenwich. Now at Marlborough House, London. www.rct.uk/collection/themes/Trails/an-allegory-of-peace-and-the-arts/the-muses-urania-calliope-and-melpomene*

*Figure 14 —* Uranie et Melpomène, *Louis de Boullogne, ca 1680–1681. Urania is seen holding an armillary sphere in one hand and callipers or compass in the other while a surveying compass lies at her feet. See https://catalogue.museogalileo.it/object/Proportional-SurveyingCompasses.html. The meaning of the figures on the scroll is unknown. From the collection of Louis XIV. From the collection of the Louvre Museum. On long-term loan to National Estate of Versailles, Versailles. https://collections.louvre.fr/en/ark:/53355/cl010236721.*

*Figure 15 —* Urania. Uranie. *Cesare Ripa, ca 1757–1772. Hand-coloured engraving. Published originally in 1608. Urania wears a crown of stars and holds a globe depicting the constellations. The Miriam and Ira D. Wallach Division of Art, Prints and Photographs: Art & Architecture Collection, The New York Public Library. (1757–1772). Urania. Uranie. https://digitalcollections.nypl.org/items/510d47e4-81d6-a3d9-e040-e00a18064a99.*

*Figure 16 —* Johann Elert Bode. *Paul Malvieux (German, 1763–1791). Below a portrait of Johann Bode, Urania wears a halo of stars, holds a celestial globe in her left hand and a unique rod in her right. This is possibly a distaff, used in weaving, and a symbol from antiquity indicating a "good worker in wool" i.e. an upstanding woman. The artist perhaps included it to emphasize Urania's femininity. More than likely, however, the artist simply made a mistake (Morden 2022). Bode was a popularizer of the so-called Titius-Bode Law. Engraving on paper. Plate: 16 × 9.5 cm. Purchase 1967. McMaster Museum of Art, McMaster University, Hamilton, Ontario. Courtesy McMaster Museum of Art. https://emuseum.mcmaster.ca/emuseum/view/objects/asitem/search@/0?t:state:flow=11c2217b-33a1-4f2a-b403-c34113358ef8*

*Figure 17 — The front of the box of* Urania's Mirror, *a set of 32 cards depicting the constellations. First published in 1824, subsequent sets had holes punched in the cards so that, when held up to the light, a shining representation of the constellations could be seen. The charts are based very closely on Alexander Jamieson's* A Celestial Atlas *of 1822. On the box, Urania, in a diaphanous gown, holds callipers in her left hand and rests her right arm on a globe with at least two coordinate lines visible. https://en.wikipedia.org/wiki/Urania%27s_Mirror*

Quo ducit Urania. *Where Urania leads. Clearly, she leads in various guises. But she always has our attention.*

### Acknowledgements

Many thanks to those who gave permission to reproduce their images as noted above. Thanks also to Julie Bronson, Collections Administrator, McMaster Museum of Art; Chris Gainor, Phil Groff, Betty Robinson, and Doug Welch, RASC; Aris Polyzois; Sarah Scott and Bill, Kosmos Society. Special thanks to my personal muse and comrade in history, Meg Morden.

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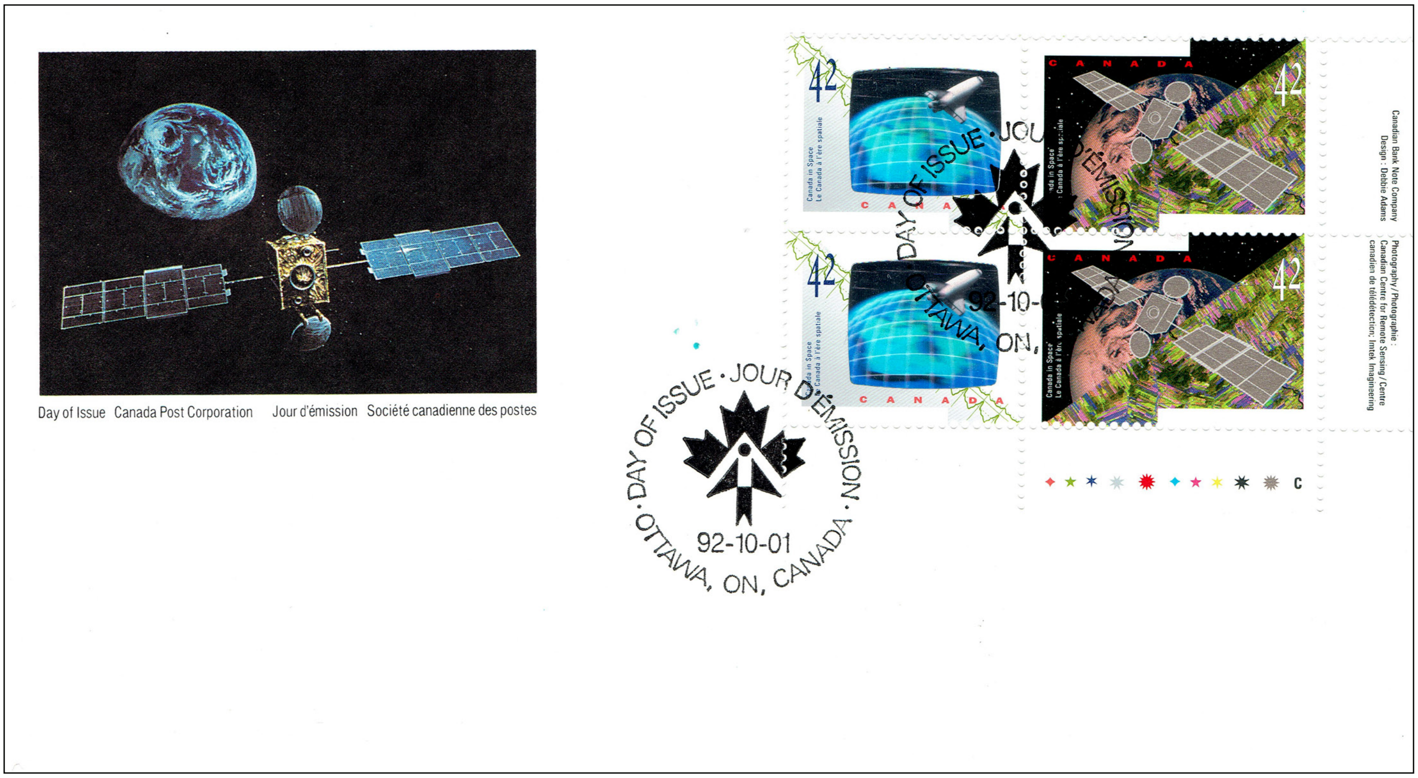


Figure 6 — First Day Cover issued 1992 October 1 (Scott Cat. #1441-2)

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world, inspiring curiosity, respect for and conservation of the environment while building healthier lives."

She was clearly inspired by not only her flight in space, but also her love of photography and concern for the environment. She is a very accomplished woman with many honours bestowed upon her over the years, but this year is special for the mark she has left in the history books and the world, that she circled 192 times back in 1992. Happy 30th Anniversary Roberta Bondar!

Keep looking up…to one pretty amazing Canadian! ✶


Figure 7 — First Day Cover issued 2003 October 1 (Scott Cat. #1999a-d)

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*Rick has been a lifetime philatelist who collects Canada, Poland, U.S., U.N., and topically – astronomy and space. He enjoys combining and sharing his passions for astronomy, photography, philately, numismatics, and the outdoors (hunting, fishing, travelling). He is a retired Conservation Officer and lives in Keene, Ontario, and he can be contacted at stankiewiczr@nexicom.net*

# AAVSO

## Your Monthly Guide to Variable Stars – Series Two

*by Jim Fox, AAVSO*

### **R Aquarii (R Aqr)** (November)

When originally discovered by Karl Ludwig Harding in 1811, R Aquarii was thought to be a normal, long-period variable. At the time, Harding was searching for a "missing" planet between Mars and Jupiter, and he did discover 3 Juno, a main-belt asteroid, in 1809. R Aqr is now classified as a symbiotic variable after a spectrogram taken in 1922 showed the complex spectrum having both emission and absorption lines.

Symbiotic variables have at least 3 components: a cool red giant star, a small hot (often dwarf) star, and a nebula surrounding both stars. All 3 components may contribute to the light curve of the star. In the 1970s, astronomers found the first ever optical jets streaming from R Aqr in opposite directions.

When in its "normal" state, R Aqr varies between visual magnitude 6 and 11 with a period 387 days. But occasionally, the maximum dims to about magnitude 8 and the minimum brightens to about magnitude 9. This seeming anomaly persists for several years until the system returns to "normal" variation. Two theories have been advanced to explain the anomaly. One theory suggests that swelling of the cooler star causes more mass to transfer into the other star's accretion disk, causing either the disk or star to brighten. Another theory postulates a large, semi-transparent cloud around the brighter star and its accretion disk and that the entire cloud-disk-star system periodically eclipses the dimmer star. Continuing observations may help to elucidate which, if either, is correct.

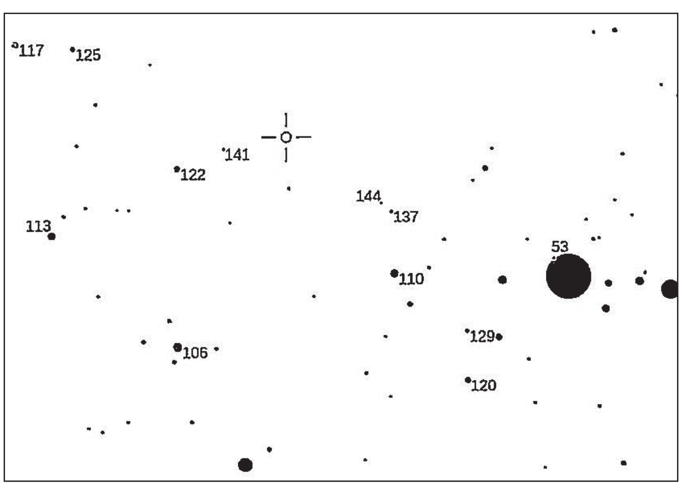


*Figure 1—R Aquarii (R Aqr)*

R Aqr can be found 48′ southeast of Omega-2 Aquarii at 23h 43m 49s, –15°17′04″. The star labelled 53 in this chart is SAO 165841, 21′ southwest of R Aqr. Given the R Aqr's southern declination, it is conveniently placed for observers in both Northern and Southern Hemispheres. Chart is not inverted with north up and east left. R Aqr is the highlighted open circle. Chart courtesy AAVSO.

### **X Persei (X Per)** (December)

Before the introduction of photography, all stellar observations were visual. In the mid-19th century, Italian astronomer Father Angelo Secchi used a *visual* spectroscope to study several thousand stars. Most of the stars showed the usual characteristic absorption line spectra, but a few showed *emission* lines, mainly of the hydrogen Balmer series. The first such star discovered, Gamma Cassiopeiae, was found by Father Secchi in 1866. Today, many stars have been found to show emission lines, but some of those stars of spectral class B are known to be variable, known as Be stars, or Gamma Cassiopeiae stars. X Persei is one of the Be stars.

Be stars rotate so rapidly that they throw off material from their equatorial region into a surrounding disk. It is thought that the emission lines originate in this disk of material, and the stars can change between Be and B classes as the disk dissipates and reforms. These stars vary in brightness as well as spectrum. Several modes of variation may be present: periods of several years may relate to disk formation and dispersal, shorter periods may be due to pulsation or interactions with a binary component.

X Per is a Be binary system that varies between visual magnitudes 6 and 7 with a period of 250 days. In 1989–1990, the star's spectrum changed from Be to "normal" B, and its magnitude faded, probably due to dispersal of the excretion disk. As the disk reformed and the spectrum returned to Be, the magnitude also brightened.

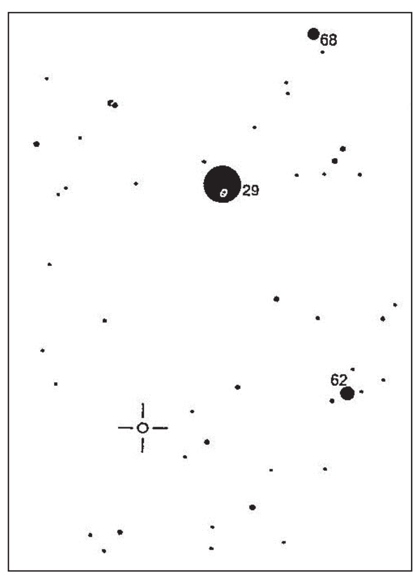


*Figure 2—X Persei (X Per)*

The secondary star of the X Per system is a neutron star that is also a strong X-ray pulsar. The pulsar has a period of 837 seconds, but period changes may be associated with transfer of mass from the primary.

You can watch X Per as it varies at 3h 55m 23s, +31°02′45″, just under a degree south of magnitude 2.9 Zeta Persei (SAO 56799) labelled 29 on this chart. The stars labelled 62 and 68 on this chart are SAO 56762 and SAO 56775, respectively. Chart is not inverted with north up and east left. X Per is the highlighted open circle. Chart courtesy AAVSO. ✶

*Jim Fox has owned many telescopes in his astronomical journey—he's even ground a few mirrors for his own. Jim has been a long-standing Astronomical League member and served as President from 1990–1994, as well as serving on the Board of the Astronomical Society of the Pacific. He was awarded the Leslie C. Peltier Award by the Astronomical League in 2014 and he has served several years as the AAVSO Photoelectric Photometry Coordinator. The IAU named asteroid 2000 EN138 "(50717) Jimfox" to honour his many achievements.*

# John Percy's Universe

## Donald Fernie: An Appreciation

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

John Donald Fernie (1933–2022), astronomer, historian, educator, author, university administrator, and RASC National President from 1974 to 1976 passed away on 2022 June 27. He was my teacher, Ph.D. co-supervisor, research collaborator, colleague, friend, fellow music lover, and role model.

He was not nearly as well-known as he deserved to be. He made no "gee whiz" discoveries. But his research on Cepheid pulsating variable stars was fundamental to establishing the distance scale of the Universe, and for understanding stellar structure and evolution. His historical studies led to authoritative and widely read books and articles for both specialists and the general public. Through these, and his many public lectures, and his service to the RASC, he contributed significantly to public education, outreach, and communication, as well as to university teaching and research. He helped in many ways to build the University of Toronto astronomy group into one of the best in the world. He received the coveted Fellowship in the Royal Society of Canada. Asteroid *Fernie* is named in his honour, for perpetuity.

Don was born and raised in South Africa. He received his M.Sc. degree from the University of Cape Town, then he and his wife Yvonne went to the U.S., where Don received his Ph.D. from Indiana University, supervised by Bob Kraft. They moved back to Cape Town for three years, where Don had a faculty position, and he published prolifically, then they came to Toronto where Don took up an assistant professorship in 1961 at the University of Toronto. That year, he gave a fourth-year course for our small class of astronomy majors, which is where I first met him. I particularly remember a gathering where Don and Yvonne played recordings of South African folk music (folk music was the "in thing" for the younger generation in those days). After a short diversion into school teaching, I became one of his graduate students.

*Figure 1 — Don Fernie FRSC, astronomer, historian, educator, author, university administrator, and RASC National President 1974–1976.*

He was based at the University's David Dunlap Observatory (DDO) in Richmond Hill, north of Toronto, where he immediately set about to revitalize the DDO's hand-made 48-cm telescope, and to use it for photometry and to study variable stars, especially Cepheid pulsating variable stars, whose period-luminosity relation is crucial to understanding the distance scale in our galaxy and in the Universe. In those days, observational astronomers had to understand their telescopes and instruments, and be able to repair or even build them if necessary. No "black boxes" back then!

Don rose quickly to become Chair of the Department of Astronomy and Director of DDO, from 1978 to 1988. Those were not easy times. Science and university budgets were stagnating—or worse. The astronomy department was geographically dispersed, on three campuses and with observatories in Richmond Hill and Chile. The use of DDO for research was decreasing. The department was not as cohesive as it is now. With his thoughtful, transparent leadership style, he played an important part in building the Toronto astronomy group into what it is today—one of the largest and most important centres of astronomy research and education in the world.

And the DDO survives! The land around it was sold to a developer in 2008, and the proceeds were used to establish and endow the Dunlap Institute of Astronomy and Astrophysics, thanks to the generosity and vision of the Dunlap family and the university. The observatory was then run by members of the Toronto Centre from 2008 to 2015; it is now owned by the municipality of Richmond Hill and operated by the Toronto Centre and other science outreach groups.

Don also served the international astronomical community in many ways, including as President (1979–1982) of the International Astronomical Union's Commission (interest group) on Variable Stars. I followed him in that role, a few years later. He travelled the world to conferences, to present his research, and meet with research collaborators and other kindred spirits. Those were the days before email and Zoom.

With his rapidly growing interest in the history of astronomy, Don also played an important role in the department's curriculum. He became an Associate of the university's Institute for the History and Philosophy of Science and Technology and launched a very popular and well-received undergraduate course in *Astronomy through the Ages.* Among the messages on his memorial guestbook (1) are glowing reviews from former teaching assistant Judith Irwin and former student Katharine Hayhoe—both now distinguished professors and educators. Don's course has continued, in various guises, in the two decades since his retirement. He wrote the short but authoritative history of astronomy at the University of Toronto, which appears on our website (2).

His interest in the history of astronomy did not develop late in his career, as is often the case. Within the first decade of coming to Toronto, he published two authoritative historical reviews, on the Cepheid period-luminosity relation (Fernie, 1969) and on the quest for the nature of the spiral nebulae (Fernie 1970). These perfectly illustrated the linkage between his interests in astronomical research, teaching, history, and writing.

His first book was *The Whisper and the Vision: The Voyages of the Astronomers*, published in 1976 by Clarke, Irwin, in Toronto. He was encouraged to publish this by our late colleague, Professor Bill Clarke, of Clarke, Irwin. His second book, *Setting Sail for the Universe*, published in 2002 by Rutgers University Press, was based on 28 of his best "Marginalia" columns in the influential journal *American Scientist.* These books are notable in the way that they bring the story of astronomers to life. After all, astronomy is done by people, not by articles and books!

In 1972, he became First Vice-President of the RASC, and continued as National President in 1974–1976. As was the custom at the time, he travelled from coast to coast to visit almost all the RASC Centres. He served the RASC in other roles, as well, including Book Review Editor of this *Journal*, and as Assistant Editor of the *National Newsletter*, to which he contributed many delightful articles.

According to the Astrophysics Data Service, Don published 48 papers in the *Journal*, ranging from short reports, to reprints of his engaging columns in the *David Dunlap Doings* newsletter, to scholarly book reviews, to major review papers on photometric research (Fernie, 1982), on the historical search for stellar parallax (Fernie, 1975), and on biography—of our late colleague and former RASC National President Jack Heard (Fernie, 1979). His RASC Presidential Address (Fernie, 1977) was on "Quasars: The Continuing Enigma."

He published 270 papers in total. His last (Fernie, 2006) was in *Nature*, arguably the most prestigious of all science journals. Coincidentally, his last research paper was co-authored with me (Percy *et al.* 2004). It is a reminder that Don's data and his publications live on, far beyond his retirement and death.

What was Don like as a person? There is no better source of information than those who knew him best—his family, friends, colleagues, and former students. In the messages left in his memorial guestbook (1), we hear that he was: "a wonderful, kind, intelligent, generous, and loving soul. He cared deeply for his family and his community" (that from his long-time family doctor), "generous and affable," "a quiet and thoughtful man who loved his music and a good read," "a model to follow … all embedded in good humour and happiness," "a working example of a good man," "BBQ'd a mean steak!" "a wonderful storyteller," "a lecture style to aspire to," "his talent as a teacher and a researcher was an example to us all," "a wonderful writing style," "a unique and inspiring individual," "my first impression of Don as a friendly, helpful, and cheerful person only strengthened with time," "that sweet smile says it all" (see Figure 1). What words to be remembered by!

Don leaves his daughters Kim (Ian) and Robyn (Stephen) and his grandchildren Nicholas and Krysten. His wife Yvonne passed away in 2008. ✶

*John Percy FRASC is Professor Emeritus, Astronomy & Astrophysics and Science Education, University of Toronto, and a former President (1978–1980) and Honorary President (2013–2017) of the RASC.*

## Endnotes

1 mountpleasantgroup.permavita.com/site/JohnDonaldFernie.html

2 www.astro.utoronto.ca/about

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# An Obituary for Donald Edward Machholz

*by David Levy, Kingston & Montréal Centre*

Dear Don,

You left us far too soon, my friend. From your home in California and later in Arizona, you lived quietly and well, with a passion for stargazing that dominated your life.

As the English poet Gerard Manley Hopkins wrote, "I am like a slip of comet,/ Scarce worth discovery."

He wrote his poem in 1864, but it might have been composed with you in mind. You were born on October 7, 1952, in Portsmouth, Virginia. I first heard of you during the 1970s, when you were popularizing a program to observe all (or almost all) the Messier objects in the sky in a single night. I did not take the idea seriously for a long time. I have seen all the Messier objects, but I found them over a relaxing period of five years, from Messier 45 (The Pleiades star cluster) during the summer of 1962, to the distant and ethereal galaxy Messier 83, in the spring of 1987. Your idea was to learn the sky far more thoroughly than I did, and catch all the clusters, clouds of gas and dust, and distant galaxies that Charles Messier carefully recorded. (Messier himself was an 18th century hunter of comets, but he is known more for his catalogue.)

Thank you for inspiring me. By the mid–1980s, I was more proficient in observing than I was in earlier decades. One clear night in the early spring of 1983, I successfully observed all but one of the Messier objects. Messier 30 was the only one I missed that night.

By that time, Don, you were already famous. In 1978, after some 1,700 hours of searching, you discovered your first comet using your simple telescope. (You never gave up, did you?) I thought of your success on that beautiful quiet night. In 1985, on the final night of the Riverside Telescope Maker's Conference that year, you discovered a second comet after another 1,700 hours. You used a beautiful 10-inch cardboard and glass telescope for that second comet. (You really never gave up, did you.) Luck began to go your way after that. Your third comet arrived in 1986. You used a pair of 29x130 binoculars for that one. Right in between the passages of your second and third comets, Comet Halley, the most important and famous comet of them all, rounded the Sun on February 9, 1986. I like to

*Figure 1 — Donald Edward Machholz. Credit: Michele AnneLouise Machholz/Wikimedia Commons*

think that as the great Halley's comet made its pass through the inner solar system, it was guarded by these two other comets discovered by you.

Don, you never ever quit. No one would have criticized you if you had. Instead, you spent the remaining years of your life searching the sky. You spent almost *nine thousand* hours over the course of your life comet hunting. Through it all, you never lost your passion for watching the sky. You and I share that one important aspect, Don. As many comets as you and I might have found, it was the search that was so important, for "in no better way," as Leslie Peltier wrote, "can we come face to face, night after night, with such a wealth of riches as old Croesus never dreamed of."

In recent years the professional astronomers have taken over comet discoveries. But still you kept on searching. Despite their great big telescopes, you kept going, always searching, with a series of small telescopes. You found two new comets in 1994, one of which broke apart into several pieces.

By the start of the new millennium, amateur astronomers had pretty much given up. Visual comet hunting was passé. No more. Only not for you. You discovered not one, not two, but three comets since the year 2004 and as of August 2022, you were the leading discoverer of comets by visual means in the world.

Don, I wish I had known you better. I do know I shall miss you, and our friendship which has evolved over the years, very much. I conclude this letter, this obituary, with the end of the Hopkins poem:

*"But then her tether calls her. She falls off*
*And as she dwindles sheds her smock of gold…*
*So I go out. My little sweet is done.*
*I have drawn heat from this contagious sun,*
*To not ungentle death now forth I run.*

Rest in peace my friend.

David H. Levy

## Goodbye, Wendee

Dear readers:

What follows is the most difficult article I have ever written. On Friday, September 23, 2022, my wife Wendee died. She had been suffering from metastatic breast cancer for over a decade, but this past summer she was truly and clearly suffering. We had an oncologist who was good clinically but who had no bedside manner, and a nurse practitioner who was very good, but a bit of a Pollyanna. Therefore, when Wendee began to destabilize by the hour near the end of September, I was just not prepared for it.

Wendee and I were together for more than thirty years, and we were married for the last 25 of them. We got together as the result of a fix-up. When Wendee's Mom, Annette Wallach, and my mom—Edith Pailet Levy—resumed their childhood friendship in 1985, my father had just died from Alzheimer's Disease. They got together in Montreal and immediately shared stories about their children. Wendee, it turned out, had just separated from her first husband, and I was long since divorced from my "practice wife." They decided to try to bring us together. Wendee was the first to reject the idea: "I am a dog person; he is a cat person," she said; "I am an athlete, and he is a couch potato." (I could say that over time I became a dog person and Wendee became a couch potato, but I won't.)

I just ignored my mom's suggestion. Every year or two Mom would repeat her idea. After seven years, Mom asked again, and when I still had not done anything, she annoyingly chastised me and said, "forget the whole thing. Forget I ever asked you."

That was a challenge. On March 23, 1992 (one year to the day before I took the two photographs that led to the discovery of Comet Shoemaker-Levy 9 that would strike Jupiter in 1994), I typed out a post card to her in Las Cruces. She replied, and we finally met that summer. After lunch and a conversation with her and her two sisters, I returned to Clyde and Patsy Tombaugh's house, where I was staying. When Patsy answered the door, she asked, "Well, how did your date go?" I looked at her and replied, "Patsy, I have just spent time with the three most beautiful women I have ever met!"

*Figure 2—Wendee, and the author's first telescope, Echo.*

Early in our relationship, we were driving near Las Cruces. It was a clear dark night and we got out of the car. Wendee looked up and asked me, "What star is that?"

"That bright star," I answered her, "is Vega."

Just then, Wendee recalled that her first husband, long since divorced, had warned her that he would never answer her questions more than once. Wendee then inquired of me, "David, if I were to ask you every night, looking at that same star, the same question, 'What star is that?' what would you do?"

"I would explain to you, every night," I replied, "that star is Vega. And I would never, ever, tire of it."

On another evening, I was driving Clyde and Patsy Tombaugh back from a dinner engagement. Clyde was sitting up front with me and Wendee was in the back seat with Patsy.

"Clyde, I am going to take you home first, and then I will take Wendee home."

"David," why not just drop Wendee off on the way? It would be faster."

"Clyde I may want to hug her and give her a big kiss."

"That's okay. We'll wait!"

The group in the car got silent. I looked back towards Wendee, then to Clyde, and I said, "Clyde, I am taking you and Patsy home first."

As Wendee and Patsy giggled in the back seat, Clyde said, “OK. Now that you explain it!”

Wendee and I were married in the Flandrau Science Center on March 23 (that magic date again) 1997. The reception at our home featured Comet Hale-Bopp and a lunar eclipse. Our first few months were difficult. Gene Shoemaker was killed in a car accident in Australia that July, and I had two cancer surgeries (prostate and right kidney) later that year. But as I recovered, our marriage became fun and interesting. We travelled everywhere. Possibly her favourite trip was to the outback near Alice Springs, where we observed more than two thousand meteors on a single night in November 2001. Because for a short period we saw one meteor per second, I considered the Leonids that year a meteor storm.

We took three trips to Israel together, the last two of which were part of my doctoral work at the Hebrew University on the night sky in Shakespeare’s time. I loved that particular period in my life, and Wendee and I had a lot of fun navigating the multitude of rules and regulations that the University appeared to make up as we went along. Near the end of that process, I wrote a routine question about the dimensions of the European paper I needed to use. The next morning, I found Wendee looking at her email. “I need for you to read this message now,” she said. “Is it good news?”

“I do think so.” The letter was from the Hebrew University, announcing that the University Senate had just awarded my PhD, and that they hoped we would come to Israel to receive the degree in person. We spent the remainder of that happy day making flight arrangements.

Wendee served as director of our Jarnac Observatory, and I served as her assistant. I used it every clear night. During the 26 years we lived in our Vail home, I discovered only one comet, in 2006. The comet was confirmed by the Central Bureau for Astronomical Telegrams just as we returned home from the Yom Kippur services. I was so overwhelmed by the message that I printed it, and then without a word, cried as I walked back to the house and showed it to Wendee.

Wendee’s greatest joy was not so much me, but our daughter Nanette and our grandchildren Summer and Matthew. One night, when she was a college student, our granddaughter Summer contacted us to inquire of a bright red star she noticed high in the southern sky. What followed was a wonderful conversation about Mars, Percival Lowell, and the possibilities of life somewhere on that distant world. Our grandson Matthew provided us with golden opportunities to show how, when he looks at the stars, he can escape the chatter of the nightly news and appreciate the big picture of the night sky and the Universe at our doorstep.

Our marriage gave me an opening to write some books, but my favourite book began when, one morning, I found Wendee reading intently.

“You never told me you wrote a book about your dog when you were ten years old.” She found that crazy old book the most delightful she had seen, and she wanted me to revise it.

By this time, around 2013, she had received her diagnosis of breast cancer. For years, she did very well, until the end of last summer when she needed surgery to remove her ovaries. After that she began chemotherapy, which worked for a few months.

By the spring of 2022 all the treatments stopped working. Wendee insisted that I go to this year’s Adirondack Astronomy Retreat, but she was obviously suffering. We made a 911 call in mid-September, and a second one two weeks later. In between, I presented her with the first copy of Clipper, my new book for children. She was able briefly to hold it up and examine the front and back covers. With that second 911 call, I was pretty certain she would never be coming home. Wendee died on Friday evening, September 23. She was 73 years old.

The night before her funeral, our son-in-law Mark, our grandson Matthew and I were enjoying an evening in the observatory. Matthew saw a bright meteor, and as I questioned him on its direction, I saw a faint one. Mark saw a third meteor. I like to think that this minor outburst of the October Cygnid meteor shower—three meteors within a period of about five minutes—were Wendee’s goodbye.

Rest in peace, my sweet Wendee. ✶

*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.*

# CFHT Chronicles

## A Watery World

*by Mary Beth Laychak, Director of Strategic Communications, Canada-France-Hawaii Telescope (mary@cfht.hawaii.edu)*

After a summer of conference travel and computer woes at precisely the wrong time, the CFHT Chronicles returns with a new director and exciting science news.

CFHT's new executive director, Jean-Gabriel Cuby, started July 15. Dr. Cuby's long history with CFHT spans more than 25 years. He joined the French Time Allocation Committee in 1995, serving as committee chair in 1998, and subsequently served on the CFHT Science Advisory Committee and CFHT Board of Directors. Until the time of his appointment as director, he served as one of the French agency representatives on the MSE Management Group.

Dr. Cuby began his career working at the European Southern Observatory, rising to the head of the VLT-VLTI instrument program at Paranal Observatory in Chile. He stayed engaged in the ESO community upon moving to Laboratoire d'Astrophysique de Marseille (LAM), serving on various ESO committees and instrument teams. While at LAM, he played an active role in the European Extremely Large Telescope project and in the *Euclid Space Mission*, led the AMU participation to the development of the DESI spectrographs, and led the LAM-CNES contribution to the Grism-Prism Data Processing System for the *Roman Space Telescope*. After leaving the director position at LAM, Dr. Cuby served as the chargé de mission to the deputy director, head of the Astronomy & Astrophysics division of the Centre National de la Recherche Scientifique (CNRS). In that role, Dr. Cuby represented CNRS and ultimately coordinated a European Commission program bringing together many optical and radio astronomical observatories and institutes (Opticon-RadioNet Pilot).

Since moving to Waimea, Jean-Gabriel has worked to learn more about his new home and his new staff. He recently started testing the waters of outrigger canoe paddling with one of the local canoe clubs. From his office windows, Jean-Gabriel sees Maunakea daily, a sight that causes invigoration in his efforts to run CFHT and continue to develop our Maunakea Spectroscopic Explorer project. He also finds continued reflection in the mauna while working toward greater understanding of its deeply significant role in Hawaiian culture.

Welcome Jean-Gabriel! And *mahalo* to Andy Sheinis, our director of engineering who acted as CFHT's interim director over the past year.

### A Watery World

The remainder of the column is based on a news release written in large part by the iREx team, led by Mari-Ève Naud. The iREx version of the release can be found on their website and contains a wealth of information about the role played by Observatorie du Mont-Megantic.

In August, a team of researchers led by Charles Cadieux, a Ph.D. student at the Université de Montréal and member of the Institute for Research on Exoplanets (iREx), announced the discovery of an exoplanet orbiting TOI-1452, one of two small stars in a binary system located in the Draco constellation about 100 light-years from Earth. The exoplanet could be completely covered in water and is a target the team hopes to observe soon with the *James Webb Space Telescope*. CFHT's very own SPIRou played a critical role in the research.

The exoplanet, known as TOI-1452 b, is slightly greater in size and mass than Earth and is located at distance from its star where its temperature would be neither too hot nor too cold for liquid water to exist on its surface. The astronomers believe it could be an "ocean planet," a planet completely covered by a thick layer of water, similar to some of Jupiter's and Saturn's moons.

In an article published in August in *The Astronomical Journal*, Cadieux and his team describe the observations that elucidated the nature and characteristics of this unique exoplanet.

NASA's TESS mission put researchers on the trail of TOI-1452 b. TESS surveys the entire sky in search of planetary systems like our own using the transit method of observation. TESS monitors the sky looking for decreases in brightness of stars with a regular cadence, a potential sign of an exoplanet blocking the light from its host star. TESS observed a slight decrease in the star TOI-1452's brightness every 11 days, leading astronomers to predict a planet about 70 percent larger in diameter or roughly 5 times the volume of the Earth.

TESS identifies candidate planets for further observations; an exoplanet is not the only reason why a star decreases in brightness. Charles Cadieux belongs to a group of astronomers who use ground-based telescopes to conduct follow-up observations of TESS candidates to confirm their planet type and characteristics. Cadieux observes with PESTO, a camera installed on Observatoire du Mont-Mégantic (OMM) Telescope and developed by Université de Montréal Professor David Lafrenière and his Ph.D. student François-René Lachapelle.

"OMM played a crucial role in confirming the nature of this signal and estimating the planet's radius," explained Cadieux. "This was no routine check. We had to make sure the signal detected by TESS was really caused by an exoplanet circling TOI-1452, the largest of the two stars in that binary system.

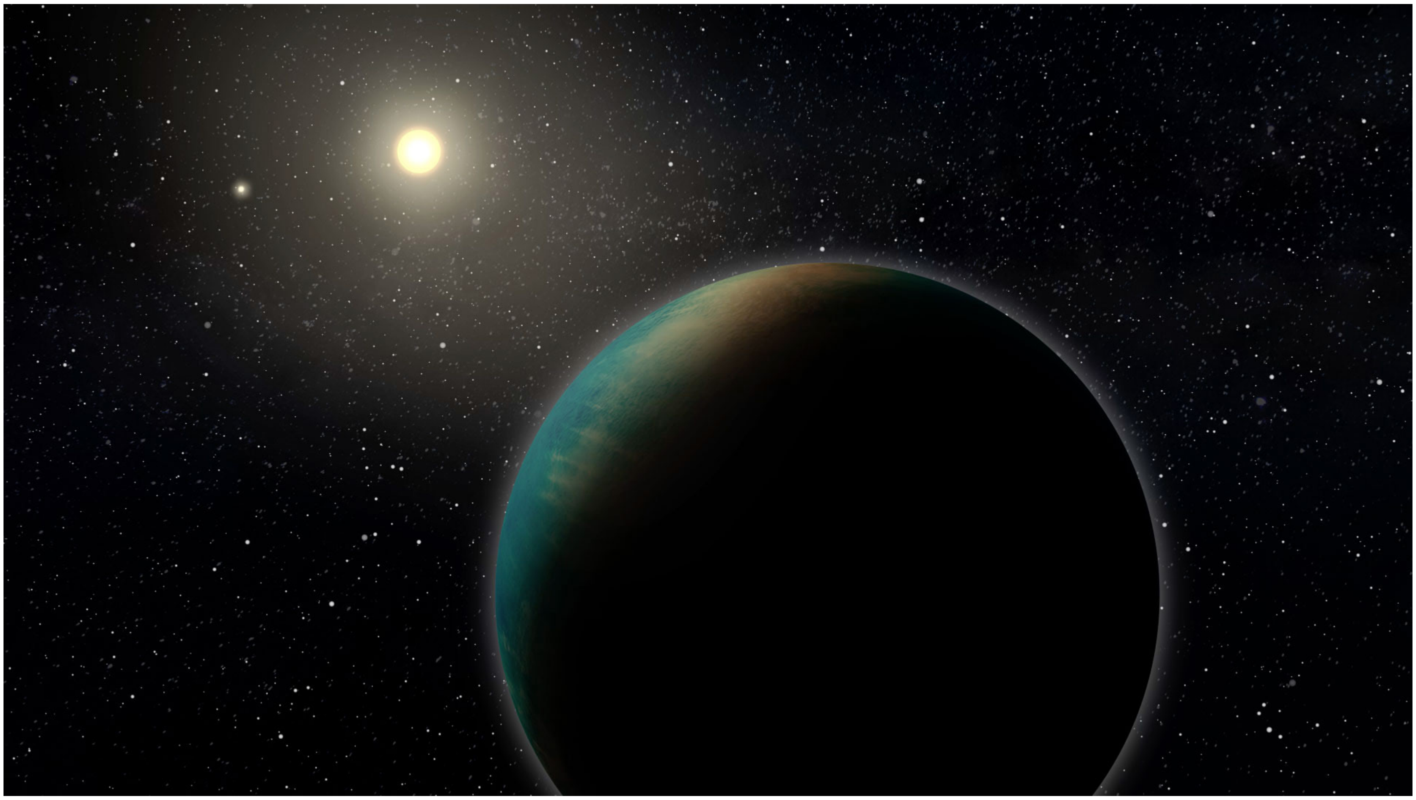

*Figure 1 — Artistic rendition of the exoplanet TOI-1452 b, a small planet that may be entirely covered in a deep ocean. Credit: Benoit Gougeon, Université de Montréal.*

The host star TOI-1452 is much smaller than our Sun and is one of two of similar size stars in a binary system. The two stars orbit each other and are separated by such a small distance—97 astronomical units, or about two and a half times the distance between the Sun and Pluto—that the TESS telescope sees them as a single point of light. But PESTO's resolution is high enough to distinguish the two objects, and the images showed that the exoplanet does orbit TOI-1452, which was confirmed through subsequent observations by a Japanese team.

To determine the planet's mass, the researchers then observed the system with CFHT's SPIRou instrument. Designed in large part in Canada, SPIRou is ideal for studying low-mass stars such as TOI-1452 because it operates in the infrared spectrum, where these stars are brightest. Even then, it took more than 50 hours of observation to estimate the planet's mass, which is believed to be nearly five times that of Earth.

Researchers Étienne Artigau and Neil Cook, also with iREx at the Université de Montréal, played a key role in analyzing the data. They developed a powerful analytic method capable of detecting the planet in the data collected with SPIRou.

"SPIRou was built to enhance our understanding of exoplanets and star systems far from the Earth by monitoring the tiny shift or wiggle in a star's spectra over time. We observed TOI-1452 for four months every possible night SPIRou was on the telescope, capitalizing on the extreme stability and reliability of the instrument," said Luc Arnold, SPIRou instrument scientist at CFHT. "The discovery by Cadieux and the team is the first of many strange new worlds SPIRou will help to uncover."

The February 2023 *Journal* deadline for submissions is 2022 December 1.

See the published schedule at

rasc.ca/sites/default/files/jrascschedule2022.pdf

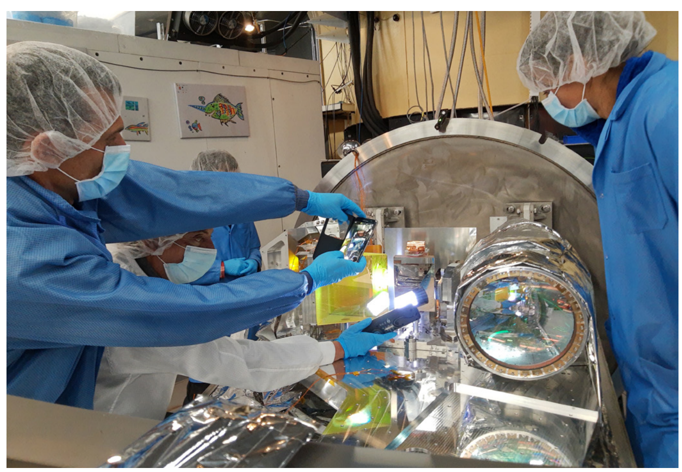

*Figure 2 — The interior of SPIRou and members of the SPIRou team.*

*Figure 3 — Artistic rendition of the exoplanet TOI-1452 b, a small planet that may be entirely covered in a deep ocean. Credit: Benoit Gougeon, Université de Montréal.*

The team also includes Quebec researchers Farbod Jahandar and Thomas Vandal, two Ph.D. students at the Université de Montréal. Jahandar analyzed the host star's composition, which is useful for constraining the planet's internal structure, while Vandal was involved in analyzing the data collected with SPIRou.

TOI-1452 b is probably rocky like Earth, but its radius, mass, and density suggest a world very different from our own. Earth is essentially a very dry planet: even though we sometimes call it the Blue Planet because about 70 percent of its surface is covered by ocean, water makes up only a negligible fraction of its mass—less than 1 percent.

Water may be much more abundant on some exoplanets. In recent years, astronomers have identified and determined the radius and mass of many exoplanets with a size between that of Earth and Neptune (about 3.8 times larger than Earth). Some of these planets have a density that can only be explained if a large fraction of their mass is made up of volatiles such as water. These hypothetical worlds have been dubbed "ocean planets."

"TOI-1452 b is one of the best candidates for an ocean planet that we have found to date," said Cadieux. "Its radius and mass suggest a much lower density than what one would expect for a planet that is basically made up of metal and rock, like Earth."

The University of Toronto's Mykhaylo Plotnykov and Diana Valencia are specialists in exoplanet interior modelling. Their analysis of TOI-1452 b shows that water may make up as much as 30% of its mass, a proportion similar to Jupiter's moons Ganymede and Callisto, and Saturn's moons Titan and Enceladus.

An exoplanet such as TOI-1452 b is a perfect candidate for further observation with the *James Webb Space Telescope*. It is one of the few known temperate planets that exhibit characteristics consistent with an ocean planet. It is close enough to Earth that researchers can hope to study its atmosphere and test this hypothesis. And, in a stroke of good fortune, it is located in a region of the sky that the telescope can observe year-round.

"Our observations with the *Webb Telescope* will be essential to better understanding TOI-1452 b," said René Doyon, Université de Montréal Professor and Director of iREx and of the Observatoire du Mont-Mégantic (OMM), who is also the Principal Investigator of NIRISS, one of the four science instruments of the *James Webb Space Telescope*. "As soon as we can, we will book time on the Webb to observe this strange and wonderful world." ✶

*Mary Beth Laychak has loved astronomy and space since following the missions of Star Trek's* Enterprise. *She is the Canada-France-Hawaii Telescope Director of Strategic Communications; the CFHT is located on the summit of Maunakea on the Big Island of Hawaii.*

# Binary Universe

## *Our Galaxy*

*by Blake Nancarrow (Toronto Centre)*
*(blaken@computer-ease.com)*

### Where Things are Two-point-oh

In February 2016, I reviewed the simple application called *Where is M13?* (or WIM for short). I thought it an intriguing tool for getting a better sense of where deep-sky objects were in three-dimensional space even though the program only presented a top-down and side view of the Milky Way Galaxy. That old software application, if you can find it, still works.

There's a new version by the original developer and it is significantly different. Different enough that I felt it deserved a full examination rather than a brief mention in the Bits and Bytes section of this column.

### A New Name

First things first. Author Bill Tschumy renamed the application *Our Galaxy* (OG). You can certainly still use the standalone tool to determine the location of M13. And like the predecessor, you can explore beyond the Milky Way.

### More Platforms

The old WIM program only worked on Windows, Macintosh, and Linux machines with the Java virtual machine software installed. Now, OG works on all the computer operating systems plus mobile devices. It no longer depends on Java. You can use it essentially everywhere including your iOS or Android slate.

I performed the bulk of my testing with *Our Galaxy* 2.0 on a Microsoft Surface Laptop Go running Windows 10 with a 1536 x 1024-pixel display.

Tschumy says it can also work in a web browser, but I did not try that.

### A New Interface

*Our Galaxy* sports a rather different interface compared to *Where Is M13?* The dual-pane view with top-down and elevation perspectives of our home galaxy is gone. The table below the two views is gone.

Instead, we are immersed in a 3-D display (see Figure 1), which allows panning and zooming. This new view in fact simulates the effect of floating in outer space and enhances the three-dimensional nature of our celestial neighbourhood.

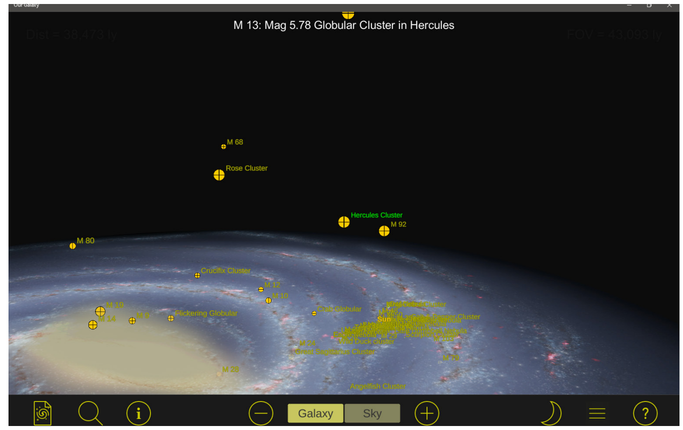


*Figure 1 — Our Galaxy showing the location of Messier 13 high above the plane of the Milky Way.*

Alas, I miss the tabular component. You could compare attributes of objects and sort the list in different ways. All the particulars of objects are still available but must be summoned up individually with the Information button in the bottom toolbar.

Another subtle enhancement is revealed in the 3-D views: object icons or stars are shown in different sizes by distance. In other words, they appear bigger when closer to your imaginary spacecraft.

### More Lists

WIM included many pre-defined lists for the user. We still have the categorical views such as Open Clusters, Planetary Nebulae, Globular Clusters, Galaxies, etc. (Figure 2)

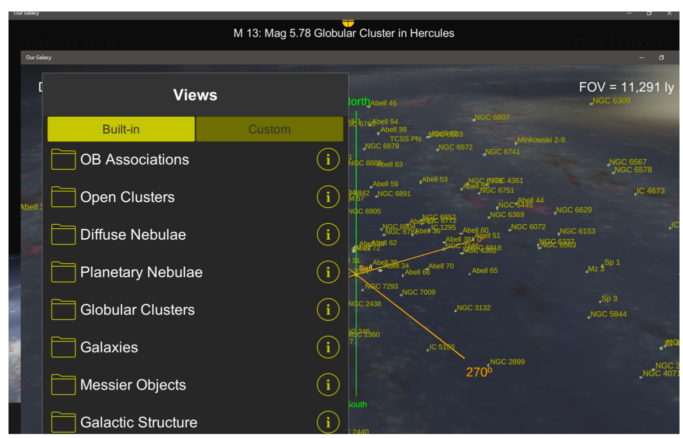


*Figure 2 — Menu showing the many pre-defined selections, with planetary nebula active.*

But there exist a couple of new views to emphasize the Milky Way's structure (e.g. Stellar Halo and Dark Matter Halo).

A user can still create their own custom views as well. And like before, the user can easily search for an object.

## Get Dark Adapted

A welcome update to the software is red-light mode (Figure 3).

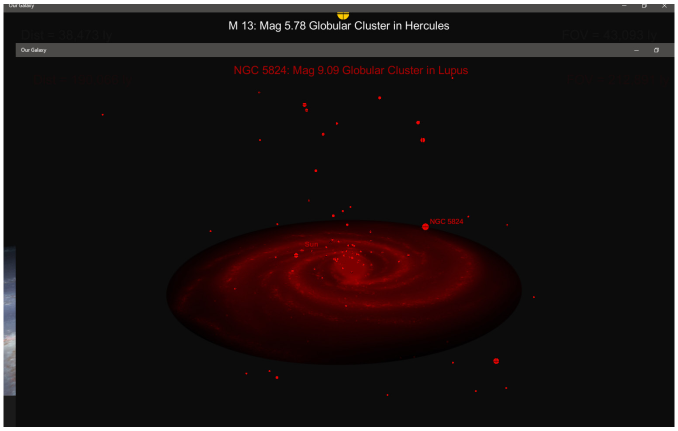


*Figure 3 — Using red mode while viewing globular clusters surrounding our home spiral.*

This will prove particularly useful when viewing in the field at night, perhaps on a phone or tablet.

## More Control

The menu in the app (Figure 4) offers many controls for adjusting things such as your position or orientation relative to the galaxy, the density of labels, and the visibility of galactic structures.

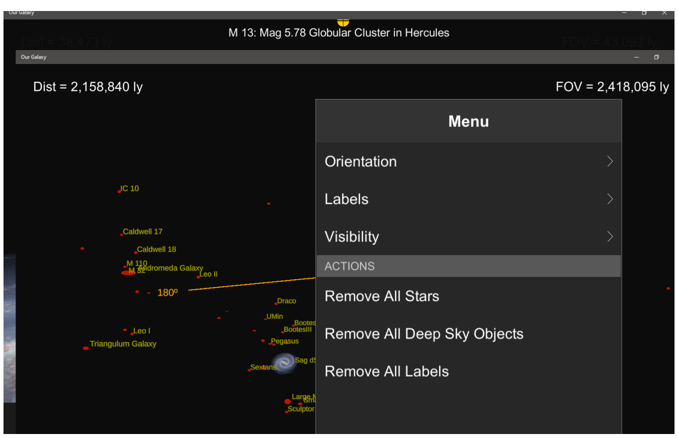


*Figure 4 — The settings menu of* Our Galaxy *with various view and reset controls.*

The orientation commands are particularly useful if you induce a nauseating spin in the display which I somehow did more than once (also halted with a keyboard shortcut if you know it!).

## New Irksome Qualities

While *Our Galaxy* is markedly better than the old *Where Is M13?*, there are lingering problems from the previous product as well as some new issues.

The alternate view called Sky, while useful, is still a little frustrating. The cylindrical projection of the celestial sky is highly distorted at the top and bottom edges. No other projections like Aitoff or Mollweide are available. The Sky view is busy with the gridlines and is not zoomable. I'd like to be able to toggle off the constellation names and stick figures.

I wished for a right-click option (on Windows) or long-press (on Android) to allow me to quickly centre on a selected object.

OG no longer offers object images. That said, old WIM only showed deep-sky objects with disappointingly low-resolution photos.

As I ran OG on my Motorola phone, I noted it did not work in portrait orientation. Not a big deal to me. The app lagged on the Android when I zoomed in to a deep level.

I reported a minor bug to the author: when you enter text that is all capital letters (e.g. NGC) it is changed to initialized case.

And that smaragdine font colour... leaves a bit to be desired. Ugh.

## Good Help

There is good support within the *Our Galaxy* tool with general astronomy information, tips on using the application, and a list of handy keyboard shortcuts for those running on a PC or Mac. The developer is easily reached on Cloudy Nights.

## Bottom Line

The free app *Our Galaxy* for all computers and mobile devices is a great tool for learning (or conveying) the location of deep-sky objects, inside and beyond the galaxy. Visualization is easier now, more than ever before, with the immersive three-dimensional display.

Visit the website to learn more about the *Our Galaxy* version 2.0 software.

www.otherwise.com

## Bits and Bytes

*Stellarium* is no longer beta! Very recently, the developers released the 1.0 version of the computer-based application. Now that said, I don't think that means we should expect it to be 100% bug-free... ✶

*Blake's interest in astronomy waxed and waned for a number of years but joining the RASC in 2007 changed all that. He is a member of the national observing committee. In daylight, Blake works in the Information Technology industry.*

# Dish on the Cosmos

## Protoplanetary Disks

*by Erik Rosolowsky, University of Alberta (rosolowsky@ualberta.ca)*

The Atacama Large Millimetre/submillimetre Array (ALMA) has been operating for 10 years. The most iconic set of results with ALMA have been the observations of protoplanetary disks around forming stars. These disks are a ubiquitous feature of star formation, where the disk geometry is a natural consequence of how material flows onto the developing star. The protoplanetary disks provide good conditions for assembling planets, and the ubiquity of these disks around young stars is one of many lines of evidence that exoplanets are common. How planets themselves form remains poorly studied. There is a strong set of theoretical physics ideas that we use to study formation but there is little in the way of direct observation of forming planets. However, new observations with ALMA are now starting to see the hints of planetary formation within the disks around stars.

Figure 1 shows one of the most iconic images from ALMA's first decade: the protoplanetary disk around the protostar HL Tauri. The disk is circular, and we see it from an inclined perspective. Hence, it appears like an oval when projected onto the plane of the sky. The light in this image is long wavelength emission with a wavelength of approximately 1 mm. The light comes from warm dust around the protostar that is giving off a smooth spectrum of light at a range of different wavelengths. This emission is like the broad spectrum of sunlight, which has a comparable amount of light in the red and blue parts of the optical band. The rings visible in the image are gaps in the disk where the gravitational tug of protoplanets elsewhere in the disk pulls material out from that specific radius. Thus, we know that there are planets in this disk, just not at the locations where the gaps are seen.

Overall, we have a hard time seeing the planets themselves inside protoplanetary disks. The main reason is that planets are forming close to their stars, so we need high resolution observations to see them near the light of the protostar. The image in Figure 1 is one of the highest resolution modes of ALMA, seeing fine details in the disk. However, the planets suspected in this system are all located in the bright inner region where we can't see them as distinct objects separate from the central star. Planets are also relatively faint in these conditions and the light resulting from the heating of the young star swamps the light from planets.

Figure 2 shows another way we have studied protoplanetary disks. This image looks quite similar to Figure 1: it shows an inclined disk of light seen around a protoplanetary star observed with ALMA. However, the actual data are subtly different. Where Figure 1 showed the light from warm dust, this image shows the emission from hydrogen cyanide (HCN), a specific molecule commonly found in protoplanetary disks. Unlike warm dust emission, the HCN molecule only emits light at very specific wavelengths of emission that correspond

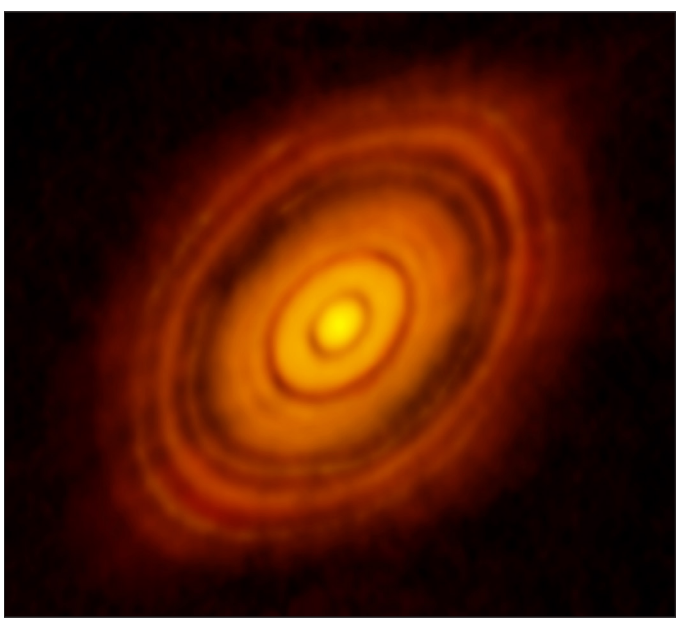

*Figure 1 — Dust emission from protoplanetary disk around the nearby protostar HL Tau as observed with ALMA. The image shows the inclined disk with rings that have been created through the interaction with the orbital motion of protoplanets seen elsewhere in the disk. Credit: ALMA(ESO/NAOJ/NRAO); C. Brogan, B. Saxton (NRAO/AUI/NSF)*

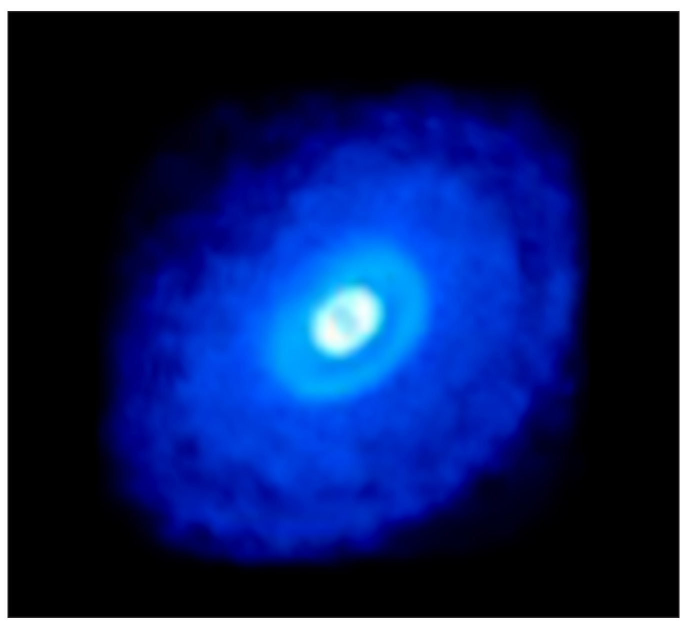

*Figure 2 — Molecular line emission from the star HD 163296. The image shows the light seen from the hydrogen cyanide molecule. While this shows similar structure to the dust emission (Figure 1), the image can be used to measure the chemistry and the motion of protoplanetary disks. Credit: ALMA (ESO/NAOJ/NRAO)/D. Berry (NRAO), K. Öberg et al (MAPS)*

to that specific molecule. Each type of atom and molecule has a unique set of spectral lines that allows astronomers to unravel the chemistry of an object. They examine which spectral lines are present in the light from the system and the relative strength of that emission.

In addition to chemistry, spectral lines also give insight into how the gas is moving around the protostar. Because of the Doppler effect, when gas is moving toward us or away from us, the motion of that material will create a small shift in the wavelength of light that we observe. By knowing the true or "rest" wavelength for the emission, we can use this shift to deduce how fast the gas is moving toward us or away from us. In the case of protoplanetary disks, like the one seen in Figure 2, we can determine which side is moving toward us and which side is moving away. We can also measure these motions across the disk and use that to determine how quickly the disk is spinning at different distances from the star. We can't do this with the dust emission because there are no unique spectral features (i.e. no lines) that we can latch onto and use in the Doppler calculations.

When we observe the motions of the gas around protoplanetary disks, we usually see that the pattern in which it is rotating around the central star is smooth. This is expected because the mass of the forming star is larger than anything else in the system, so the gravity from that star dominates the motions of the material. This is the same type of pattern we see in our own Solar System, and it follows the same general rules: objects closer to the star are moving faster than objects farther away. This trend follows a specific mathematical form set by Newton's law of gravity and the protoplanetary disks we observe also follow that pattern in general.

When we see deviations from this standard pattern of motion, we start to pay attention. In recent observations of a different protostar, AS 209, astronomers appear to have detected gas that can be linked to the formation of an individual planet. The main results from the paper by Jaehan Bae and collaborators are shown in Figure 3. This complicated figure illustrates the spectral in-line emission from carbon monoxide orbiting around this star. The left panel shows rings of the dust continuum emission as circles, showing the general shape of the disk. The colour image in the background shows the emission from the CO molecule, but it has been restricted to only look at a narrow range of velocities in the disk. There is much more light found at different velocities, but this has been restricted specifically to the emission associated with gas moving away from us at a relative velocity of 5 km/s. In examining this emission, the notable feature is that the light is asymmetric. Above the star, the emission is smooth, as we would expect from orbital motion; but in the bottom emission, there is a "kink" in this light, showing that the motions of the gas have been disturbed. If we zoom in on that disturbed region (right panel), we see a bright feature that stands out in other molecules that is illustrated in the blue contours in that panel. The research team exploring these data argues that this is the signature of a "circumplanetary" disk.

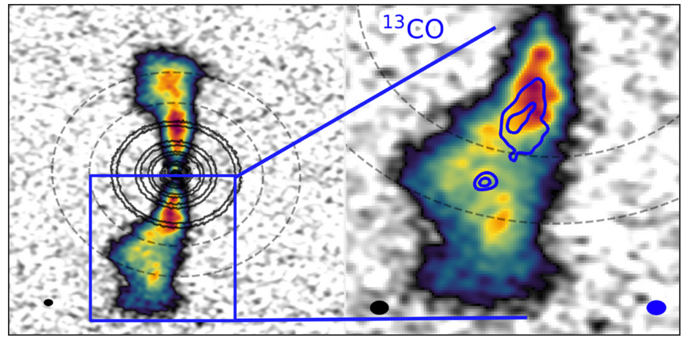

*Figure 3 — Light from carbon monoxide molecules in orbit around the protostar AS 209. The colour image shows the narrow range of velocities where we can see the disturbed structure from the presence of a planet in the disk. The right panel shows a zoom in that highlights the presence of a small bump that shows the gas in a circumplanetary disk around a young planet. Credit: ALMA (ESO/NAOJ/NRAO), J. Bae (U. Florida)*

These circumplanetary disks are expected around planets during their process of formation. They are the exact analogue of the protoplanetary disks seen around forming stars and they arise for the same reason. When material flows onto a forming planet, it naturally channels into a disk-like geometry before flowing onto the growing planet. Like the disk around the star, these are also natural places for even smaller objects to form, such as the moons of these systems. We specifically think that these circumplanetary disks are part of the formation for gas-giant planets like Jupiter. The Galilean moons (Io, Europa, Ganymede, and Calisto) are thought to have formed in these disks and their relatively large size can be explained by forming in a circumplanetary disk around the forming Jupiter. The new ALMA observations seem to have found the first evidence for one of these circumplanetary disks. The kink in the emission is also consistent with this picture. The kink arises because of the gravitational effects of the forming planet, disturbing the otherwise smooth motions of the gas and dust flowing around the star.

Finding these and other circumplanetary disks is important because we can start to measure the masses of the material in the forming disks and measure how the flows of material move out of the overall gas moving around the star to get trapped into the forming planets. We are now starting to see the direct formation of planets with ALMA and can finally study this process with new detail. ✶

*Erik Rosolowsky is a professor of physics at the University of Alberta where he researches how star formation influences nearby galaxies. He completes this work using radio and millimetre-wave telescopes, computer simulations, and dangerous amounts of coffee.*

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*Compiled by James Edgar*

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## Columns

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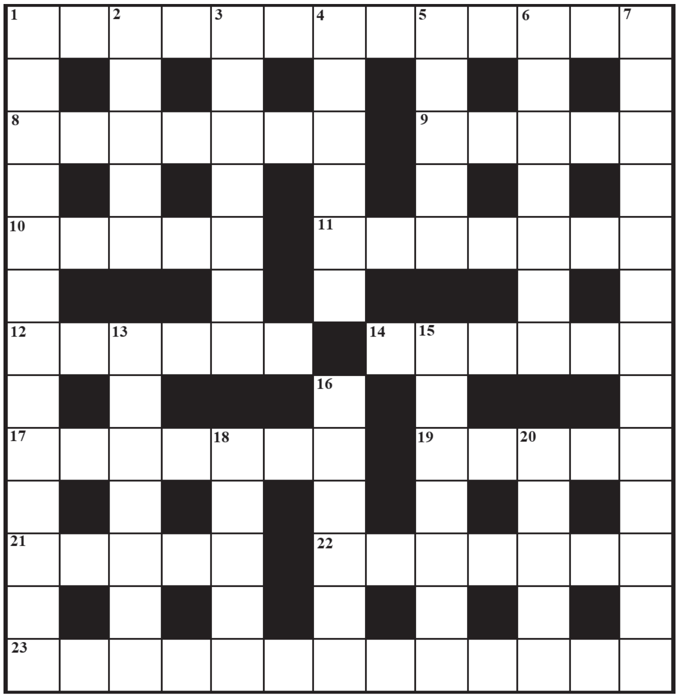
# Great Images

*by James Edgar*

*This "Cool Moon" was captured on a very cold winter evening in 2010 February 15 by James Edgar from his home in Melville, Saskatchewan. The view is looking over a neighbour's roof; the exhaust from their furnace is blown straight out by a strong south wind. James used his Canon 50D DSLR with a stock zoom lens at 90-mm focal length, ISO 500, ƒ/5.6 for 4 seconds.*

# Astrocryptic

*by Curt Nason*



## ACROSS

1. Vega appears in polite illumination (5,8)
8. Go right in a lab to study twinkler in a crow's wing (7)
9. They ain't resolving a pair of stars in a bear's paw (5)
10. Artemis arose here with a TeleVue eyepiece (5)
11. Garlands for the Spanish in relation to the hare (7)
12. Mother gets in a car to drive to the south of the river (6)
14. What Libra and Pisces have in common (6)
17. Increasing chaos by revising northern poetry (7)
19. Dark matter candidate detected in Almach or Mirach (5)
21. He had odd lust after hydrogen was seen at 21 cm (5)
22. Determined, Amanda danced around to Tombaugh's lead (7)
23. Use giant moron to make a crater south of Purbach (13)

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1. He limited white dwarfs with wobbly handcar shaker (13)
2. Stellar spectroscopist spread love around capital of Germany (5)
3. Rail about a fool in retrograde around Neptune (7)
4. Polestar precession described by Bob and Lew (6)
5. Had a smoke and created light pollution (3,2)
6. For example, learn about what's in our new catalogue (7)
7. Oddly seen are some thin stars in the Martian uplands (7,6)
13. 100 is one of two circulating at login (7)
15. Dense galactic disc does not play music (7)
16. Monday turns out to generate a magnetic field (6)
18. Little planetary eyepiece or hot mess? (5)
20. Self-sustaining reaction to Markarian's fame (5)

### Answers to previous puzzle

**Across**: **1** PYXIDIS (an(rev)ag); **5** RIGEL (rev); **8** NEAR EARTH (syn+anag); **9** NEW (2 def); **10** TESLA (anag); **11** ALBERTA (Al+Bert+a); **13** REMOTE (anag); **15** COOLED (Co+0+LED); **18** SETTING (an(ET)ag); **20** DENEB (an(E)ag); **22** LEO (rev); **23** ALEXANDER (2 def);**24** SISSY (2 def); **25** STETSON (stet+son)

**Down**: **1** PAN-STARRS (an(r)ag); **2** X-RAYS (2 def); **3** DUE EAST (2 def); **4** SIRRAH (rev); **5** REHAB (anag); **6** GENERAL (anag); **7** LOW (2 def); **12** ALDEBARAN (anag); **14** METEORS (anag+s); **16** OLD DATE (syn); **17** EGRESS (hid); **19** ITALY (anag); **21** NODES (N(ode)S); **22** LOS (rev)

# Great Images

*by Gary Stone*

*Garry Stone caught STEVE — Strong Thermal Emission Velocity Enhancement — about 100 km south of Saskatoon near the Gardner Dam. Gary used his D700 Nikon with a 50 mm ƒ.2 lens at ISO 3200 for 1/3 of a second. STEVE is known to many aurora chasers and is mostly associated with the Northern Lights.*

# Journal

*The Tarantula Nebula is a spectacular target in the Southern Hemisphere, and accomplished astrophotographer Ron Brecher managed to beautifully capture the detail in this active star-forming region with data acquired by Carlos Sagan at Copiapó in Atacama, Chile, in a Bortle class 2 sky. Sagan used a Takahashi FSQ106-EDX at ƒ/5 with QHY9 camera. Acquisition, focusing, and control of iOptron CEM60-EC mount was done with Sequence Generator Pro. Focus with ZWO Pegasus Focus Cube v2. Guiding with PHD2. Acquired All pre-processing and processing in PixInsight. Total integration was 11 hours and 30 minutes.*