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Journal

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PROMOTING ASTRONOMY IN CANADA

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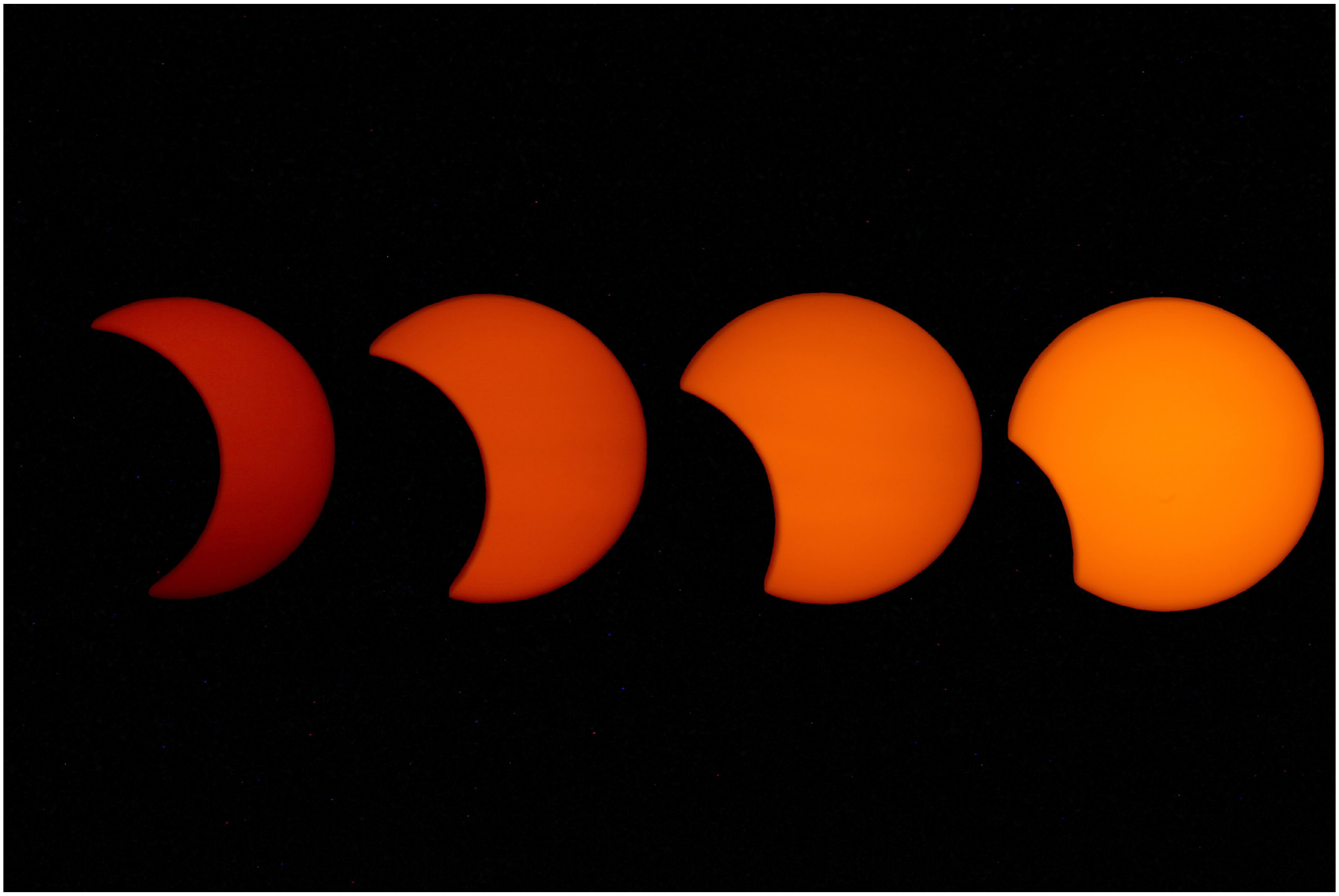
The Best of ~~Monochrome~~ Colour

Special colour edition.



This great series of images was taken by Raymond Kwong from his balcony in Toronto. He used a Canon EOS 500D, with a Sigma 70–300 ƒ/4–5.6 Macro Super lens (shot at 300 mm), a Kenko Teleplus HD 2× DGX teleconverter and a Thousand Oaks solar filter. The series of photos was shot at ISO 100, 0.1s, 600 mm at ƒ/11.

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Bleary-eyed astronomers across most of the country woke up early to catch what they could of the June 10 annular eclipse. Accomplished astrophotographer Kerry-Ann Lecky Hepburn managed to snap a shot of Toronto's iconic CN Tower during the partial phase. She used a Canon 6D, at f/32, 1/500 second at ISO 500 with a 400-mm lens.

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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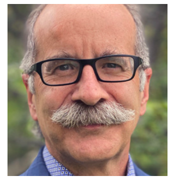
President's Corner



by Robyn Foret, Calgary Centre
(arforet@shaw.ca)

"The Stars Belong to Everyone" was the theme of the 2021 General Assembly. A most famous phrase by our beloved Helen Sawyer Hogg. But what does it mean for the RASC in 2021 and beyond?

At its roots, it is simple in nature and easy to understand, but in the context of the 21st Century, it becomes a deep and thoughtful exercise.

Looking back to early 2020, our normality was shocked by a military action against a civilian airliner, taking the lives of innocent victims, many from the Canadian scientific community and almost all of those from what we might consider under-represented and marginalized elements of society.

Then our normalcy was shattered by the COVID-19 pandemic. Modern science developed responsive vaccines in record time, likely saving millions of lives, while some segments of society propagated conspiracy theories about the source, the response, the threat and on and on and on. Anti-maskers, anti-vaxxers, and others of their ilk continue to make headlines. The war between science and belief rages on.

And then George Floyd happened. His murder and the brutality that led to it was sadly not something we hadn't heard of before, but in this time and place, and in this self-professed level of "civilization," it was too much. Black Lives Matter became the underlying conceptual message of the oppressed, the marginalized, and the under-represented.

And most recently, the discovery of what are believed to be the remains of 215 Indigenous children at a residential school in British Columbia raises the ire of the country and sets us on a quest to right the wrongs of the past, to continue to search for Truth and Reconciliation.

What on earth do these things have to do with astronomy and in particular, the RASC? Good question. The RASC created the Inclusivity and Diversity Committee to ensure that everybody—no matter who they are or how they identify—feels welcome, and to better educate the Board and the members. Some of their work and the topics they address are uncomfortable for some, and we've had our share of vitriolic comments and we've even lost some of our members because of this, but we've also seen some impressive results. Our outreach—which, due to COVID, has been virtual—is reaching a broader and more diverse public audience. The virtual world is a great equalizer and Zoom audiences are never marginalized nor too shy to ask basic questions. There are only people who want to learn more about the Universe and our place in it.

And that brings me back to the opening question. What does it mean, 'The stars belong to everyone?' It means that we have a challenge in front of us as we come out of this pandemic-induced virtual world and back into the world of the real. How do we replicate the welcoming and anonymous environment of the virtual world in our parks and observatories?

Empathy is critical towards achieving this. And to be empathetic we must first understand the concept of unearned privilege and what that means for each of us. Only then can we hope to empathize with marginalized, under-represented, non-dominant gender and gender-diverse clients.

It means that as we teach and educate and enlighten and mentor, that we recognize that the stars do belong to everyone. It means that we are not just an astronomy club, it means that we are a society that helps people understand astronomy and the Universe and most importantly, their place in it.

For more information and insight, connect with our Inclusivity and Diversity Committee at www.rasc.ca/committees/inclusivity. ✶

News Notes / En manchette

Compiled by Jay Anderson

Cloudy blanket keeps Mars snuggly

One of the great puzzles of modern space science is neatly summed up by the view from NASA's Perseverance, which landed on Mars on February 18: today it's a desert planet, and yet the rover is sitting right next to an ancient river delta.

The apparent contradiction has puzzled scientists for decades, especially because at the same time that Mars had flowing rivers, it was getting less than a third as much sunshine as we enjoy today on Earth. A new study led by University of Chicago planetary scientist Edwin Kite, an assistant professor of geophysical sciences and an expert on climates of other worlds, uses a computer model to put forth a promising explanation: Mars could have had a thin layer of icy, high-altitude clouds that caused a greenhouse effect.

"There's been an embarrassing disconnect between our evidence, and our ability to explain it in terms of physics and chemistry," said Kite. "This hypothesis goes a long way toward closing that gap."

Of the multiple explanations scientists had previously put forward, none have ever quite worked. For example, some suggested that a collision from a huge asteroid could have released enough kinetic energy to warm the planet. But ongoing calculations showed this effect would only last for a year or two—and the tracks of ancient rivers and lakes show that the warming likely persisted for at least hundreds of years.

Kite and his colleagues wanted to revisit an alternate explanation: high-altitude clouds, like cirrus on Earth. Even a small amount of high cloud in the atmosphere can significantly raise a planet's temperature, a greenhouse effect similar to carbon dioxide in the atmosphere. Greenhouse-type warming is most efficient when the difference in temperature between the

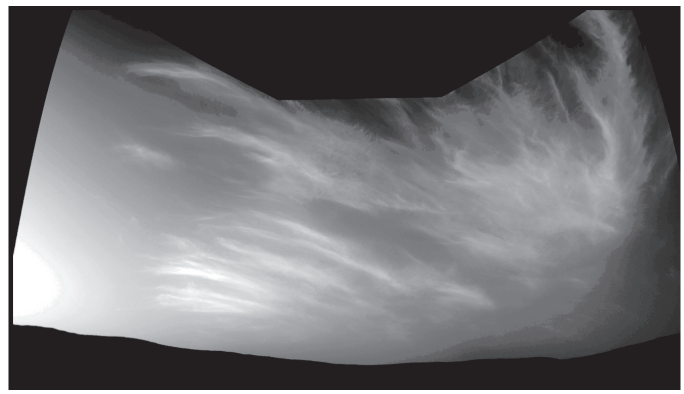


Figure 1 — NASA's Curiosity Mars rover imaged these drifting clouds on 2019 May 17 using its black-and-white navigation cameras (Navcams). These are likely water-ice clouds about 31 kilometres above the surface. They are also "noctilucent" clouds, meaning they are so high that they are still illuminated by the Sun, even when it's night at Mars's surface. Image: NASA/JPL-Caltech.

surface and cloud level is large—a feature that favours high, cold clouds over lower, warm clouds.

The idea had first been proposed in 2013, but it had largely been set aside because, Kite said, "It was argued that it would only work if the clouds had implausible properties."

For example, the models suggested that water would have to linger for a long time in the atmosphere—much longer than it typically does on Earth—so the whole prospect seemed unlikely.

Using a 3-D model of the entire planet's atmosphere, the research team went to work. The missing piece, they found, was the amount of ice on the ground. If ice covered large portions of Mars, it would create surface humidity that favours low-altitude clouds, which aren't thought to warm planets very much and can even cool them, because such clouds reflect sunlight away from the planet.

But if there are only patches of ice, such as at the poles and at the tops of mountains, the low-level air becomes much drier.

Those conditions favour a high layer of clouds—clouds that tend to warm planets more easily. The biggest catch is that such clouds must persist for century-long periods in order to reproduce Martian topographic features.

"In the model, these clouds behave in a very un-Earth-like way," said Kite. "Building models on Earth-based intuition just won't work, because this is not at all similar to Earth's water cycle, which moves water quickly between the atmosphere and the surface."

Here on Earth, where water covers almost three-quarters of the surface, water moves quickly and unevenly between ocean and atmosphere and land—moving in swirls and eddies that mean some places are mostly dry (the Sahara) and others are drenched (the Amazon). In contrast, even at the peak of its warming, Mars had much less water on its surface. When water vapour winds up in the atmosphere, in Kite's model, it lingers. Because lower regions of the planet are arid, atmospheric moisture must rise to approximately 25 km before it cools enough to condense. The high-altitude clouds trap outgoing long-wave radiation, re-radiating the energy to warm the lower layers—in effect, a cloud blanket over the lower latitudes.

"Our model suggests that once water moved into the early Martian atmosphere, it would stay there for quite a long time—closer to a year—and that creates the conditions for long-lived high-altitude clouds," said Kite.

NASA's Perseverance rover should be able to test this idea in multiple ways, such as by analyzing pebbles to reconstruct past atmospheric pressure on Mars. Understanding the full story of how Mars gained and lost its warmth and atmosphere can help inform the search for other habitable worlds, the scientists said.

"Mars is important because it's the only planet we know of that had the ability to support life—and then lost it," Kite said. "Earth's long-term climate stability is remarkable. We want to understand all the ways in which a planet's long-term climate stability can break down—and all of the ways (not just Earth's way) that it can be maintained. This quest defines the new field of comparative planetary habitability."

Compiled in part with material provided by the University of Chicago.

Composite image of Milky Way core hints at magnetic energy source.

New X-ray and radio images composited by University of Massachusetts Amherst astronomer Daniel Wang reveal, with unprecedented clarity, large- and small-scale details of violent phenomena in the centre of our galaxy. The images, published recently in *Monthly Notices of the Royal Astronomical Society*, reveal two plume-like structures emerging from the Milky Way's centre, numerous X-ray "threads," and dozens of discrete sources associated with a variety of small-scale energetic events. One particular thread, G0.17-0.41, hints at a previously unknown interstellar mechanism that may govern the energy flow and potentially the evolution of the Milky Way.

"The galaxy is like an ecosystem," says Wang, a professor in UMass Amherst's astronomy department. "We know the centres of galaxies are where the action is and play an enormous role in their evolution." And yet, whatever has happened in the centre of our own galaxy is hard to study, despite its relative proximity to Earth, because, as Wang explains, it is obscured by a dense fog of gas and dust. Fortunately, the dust and gas are largely transparent to X-rays and radio waves and so Wang was able to study the galaxy core using NASA's *Chandra X-Ray Observatory*.

Wang's findings give the clearest picture yet of a pair of X-ray-emitting plumes that are emerging from the region near the massive black hole lying at the centre of our galaxy. Even more intriguing is the discovery of an X-ray thread called G0.17-0.41, located near the southern plume. "This thread reveals a new phenomenon," says Wang. "This is evidence of an ongoing magnetic field reconnection event." The thread, writes Wang, probably represents "only the tip of the reconnection iceberg."

In the image composite produced by Wang (Figure 2), two arcing plumes stand out, spreading outward to the north and south from the galactic centre. The faint southern plume (more prominent in radio wavelengths) surrounds a broad orange X-ray plume; the arc in the north is easier to recognize, though fainter, and coloured in shades of orange and mauve.

Numerous white or gray threads stand out at the base of the northern plume and one, G0.17-0.41 (between the yellow lines), is particularly prominent and is visible in both X-ray and radio wavelengths. The thread is about 20 light-years in length. Wang suggests that the filament is a twisted rope of magnetic flux in which magnetic reconnection is taking place.

A magnetic field reconnection event is what happens when two opposing magnetic fields are forced together and combine with one another, releasing an enormous amount of energy. "It's a violent process," says Wang, and is known to be responsible for such well-known phenomena as solar flares, which produce space weather powerful enough to disrupt power grids and communication systems here on Earth. They also produce the spectacular Northern Lights. Scientists now think that magnetic reconnection also occurs in interstellar space and tends to take place at the outer boundaries of the expanding plumes driven out of our galaxy's centre.

"What is the total amount of energy outflow at the centre of the galaxy? How is it produced and transported? And how

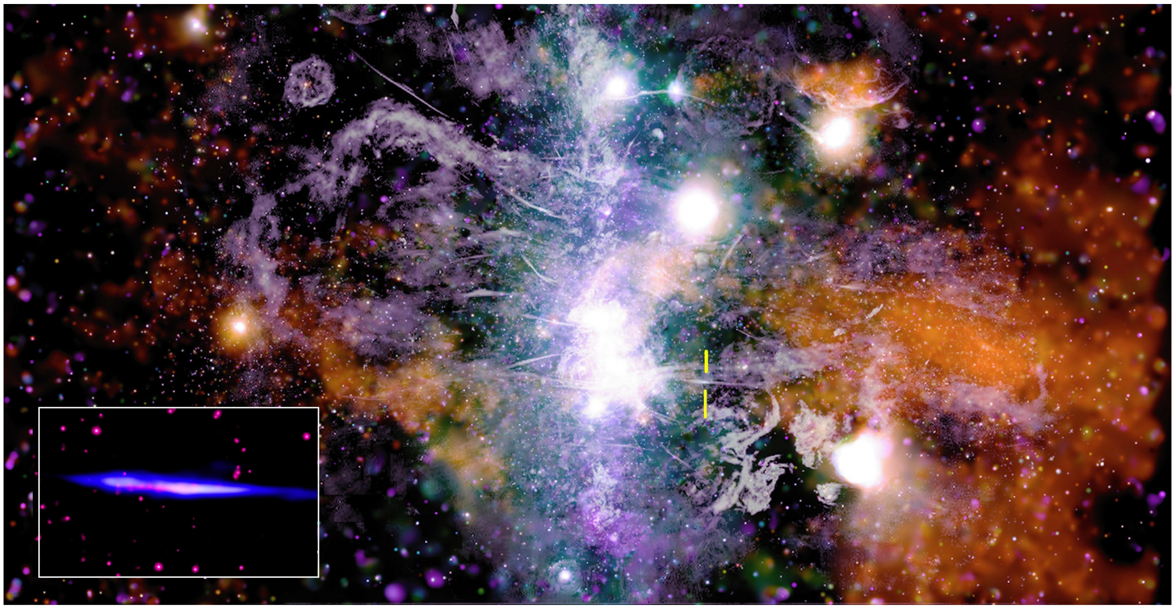


Figure 2 — This panorama shows the central region of the Milky Way Galaxy. It builds on previous surveys from NASA's Chandra X-ray Observatory *and other telescopes, and expands Chandra's high-energy view farther above and below the plane of the galaxy than previous imaging campaigns. X-rays from* Chandra *are orange, green, and purple, showing different X-ray energies, and the radio data from* MeerKAT *are gray. The inset shows a radio/X-ray image of X-ray thread, G0.17-0.41, which is marked by the two yellow lines in the larger image. Image credit: NASA/CXC/UMass/Q.D. Wang/NRF/SARAO/MeerKAT.*

does it regulate the galactic ecosystem?" These, says Wang, are the fundamental questions whose answers will help to unlock the history of our galaxy. Though much work remains to be done, Wang's new map points the way.

Compiled in part with material provided by the University of Massachusetts Amherst.

Heavy metal content in comets

A new study by a Belgian team using data from the European Southern Observatory's Very Large Telescope (ESO's VLT) has shown that neutral atoms of iron and nickel are visible in the atmospheres of comets throughout our Solar System, even those far from the Sun. A separate study by a Polish team, who also used ESO data, reported that nickel vapour is also present in the icy interstellar comet 2I/Borisov. This is the first time heavy metals, usually associated with hot environments, have been found in the cold atmospheres of distant comets.

"It was a big surprise to detect iron and nickel atoms in the atmosphere of all the comets we have observed in the last two decades, about 20 of them, and even in ones far from the Sun in the cold space environment," says Jean Manfroid from the University of Liège, Belgium, who led the new study on Solar System comets.

Astronomers know that heavy metals exist in comets' dusty and rocky interiors. But, because solid metals don't usually sublimate (become gaseous) at low temperatures, they did not expect to find them in the atmospheres of comets that travel far from the Sun. Nickel and iron vapours have now even been detected in comets observed at more than three times the Earth-Sun distance.

To detect the presence of the metals, the researchers first modelled the emission spectrum of iron and nickel when exposed to interplanetary solar radiation and then searched the spectra of a sample of past Solar System comets to find the predicted lines. The lines were easily identified among the host of other cometary spectral features, once primed with the results of the model predictions. Because the signatures of iron and nickel were found in all comet spectra studied, even those at large distances, it suggested a volatile source for the metal ions. The metallic signatures were visible only in the coma close to the nucleus of the comet.

The Belgian team found iron and nickel in comets' atmospheres in approximately equal amounts. Material in our Solar System (for example that found in the Sun and in meteorites) usually contains about ten times more iron than nickel. This new result therefore has implications for astronomers' understanding of the early Solar System, though the team is still decoding what these are.

"Comets formed around 4.6 billion years ago, in the very young Solar System, and haven't changed since that time. In that sense, they're like fossils for astronomers," says study co-author Emmanuel Jehin, also from the University of Liège.

While the Belgian team has been studying these "fossil" objects with ESO's VLT for nearly 20 years, they had not spotted the presence of nickel and iron in their atmospheres until now. "This discovery went under the radar for many years," Jehin says.

The Belgian team had spotted weak, unidentified spectral lines in their UVES data and on closer inspection noticed

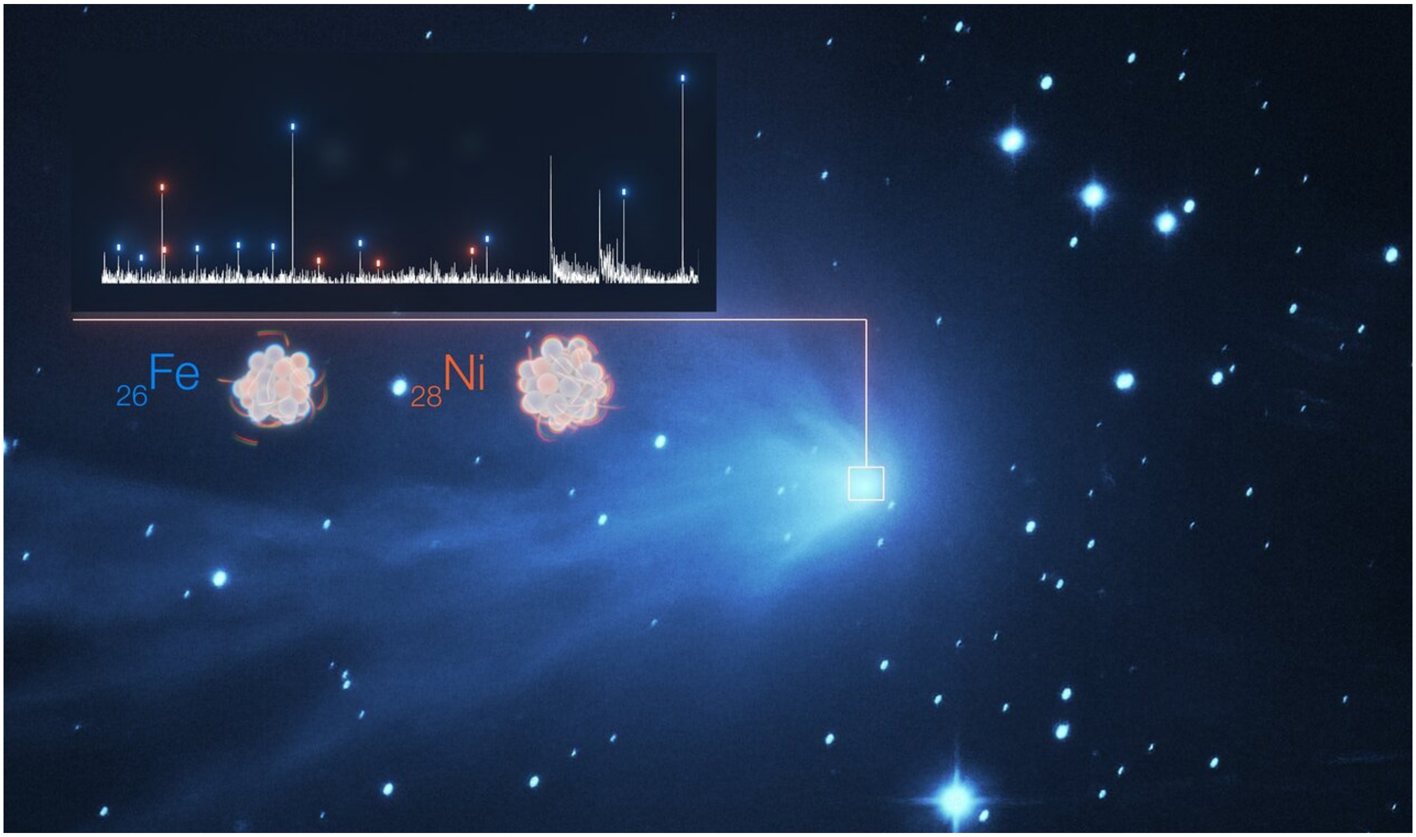


Figure 3 — The detection of the heavy metals iron (Fe) and nickel (Ni) in the fuzzy atmosphere of a comet are illustrated in this image, which features the spectrum of light of C/2016 R2 (PANSTARRS) on the top left superimposed on a real image of the comet taken with the SPECULOOS telescope at ESO's Paranal Observatory. Each white peak in the spectrum represents a different element, with those for iron and nickel indicated by blue and orange dashes, respectively. Image: ESO/L. Calçada, SPECULOOS Team/E. Jehin, Manfroid et al.

that they were signalling the presence of neutral atoms of iron and nickel. A reason why the heavy elements were difficult to identify is that they exist in very small amounts: the team estimates that there is only 1 g of iron ejected every second compared to 100 kg of water, and about the same amount of nickel.

"Usually there is 10 times more iron than nickel, and in those comet atmospheres we found about the same quantity for both elements. We came to the conclusion they might come from a special kind of material on the surface of the comet nucleus, sublimating at a rather low temperature and releasing iron and nickel in about the same proportions," explains Damien Hutsemékers, also a member of the Belgian team from the University of Liège.

The Belgian team hope their study will pave the way for future research. "Now people will search for those lines in their archival data from other telescopes," Jehin says. "We think this will also trigger new work on the subject."

A second study shows that heavy metals are also present in the atmosphere of the interstellar comet 2I/Borisov. A team in Poland observed this object, the first alien comet known to visit our Solar System, using the X-shooter spectrograph on ESO's VLT when the comet flew by about a year and a half ago. They found that 2I/Borisov's cold atmosphere also contains gaseous nickel.

"At first we had a hard time believing that atomic nickel could really be present in 2I/Borisov that far from the Sun. It took numerous tests and checks before we could finally convince ourselves," says study author Piotr Guzik from the Jagiellonian University in Poland. The finding is surprising because, before the two studies were published, gases with heavy metal atoms had only been observed in hot environments, such as in the atmospheres of ultra-hot exoplanets or evaporating comets that passed too close to the Sun. 2I/Borisov was observed when it was some 300 million kilometres away from the Sun, or about twice the Earth-Sun distance.

The Polish and Belgian studies show that 2I/Borisov and Solar System comets have even more in common than previously thought. "Now imagine that our Solar System's comets have their true analogues in other planetary systems—how cool is that?" Drahus concludes.

Compiled in part with material provided by the European Southern Observatory.

Stellar nursery at the Milky Way centre

Using the Atacama Large Millimetre/submillimetre Array (ALMA), astronomers have found a number of baby stars hiding around the centre of the Milky Way. Previous studies had suggested that the environment there is too harsh to form stars because of the strong tidal forces, strong magnetic fields, high-energy particles, and frequent supernova explosions. These new findings indicate that star formation is more resilient than researchers thought and that there is ubiquitous star-formation activity hidden deep in dense molecular gas that may allow for the possibility of a future burst of star formation around the Galactic Centre.

"It is like hearing babies' cries in a place we expected to be barren," says Xing Lu, an astronomer at the National Astronomical Observatory of Japan. "It is very difficult for babies to be born and grow up healthily in an environment that is too noisy and unstable. However, our observations prove that even in the strongly disturbed areas around the Galactic Centre, baby stars still form."

Stars are formed in cosmic clouds assembled by gravity. If something interferes with the gravity-driven processes, star formation will be suppressed. There are many potential sources of interference in the Central Molecular Zone (CMZ) of the Milky Way, located within a radius of 1,000 light-years from the Galactic Centre. Examples include strong turbulence that stirs up the clouds and prevents them from contracting or strong magnetic fields that support the gas against self-gravitational collapse. In fact, previous observations indicated that star formation in the core is much less efficient; with the exception of one active star-forming region called Sagittarius B2.

The team has discovered more than 800 dense cores of gas and dust particles in the region, but the presence of these cores does not necessarily point to the formation of new stars. To solve that question, the team used ALMA to search for energetic gas outflows associated with the cores, which are like the birth cries of young stars. Thanks to ALMA's high sensitivity and high spatial resolution, the team detected 43 small and faint outflows in the clouds, unambiguous evidence of ongoing star formation. Many of the young stars were hiding in the regions that were thought to be unsuitable for stellar growth.

The small number of detected outflows is another mystery. Considering the fact that more than 800 "stellar eggs" have been found, the small number of "stellar babies" might indicate that the star formation activity in the CMZ is in the very early phase. "Although a large number of outflows might be still hidden in the regions, our results may suggest we are seeing the beginning of the next wave of active star formation," says Lu.

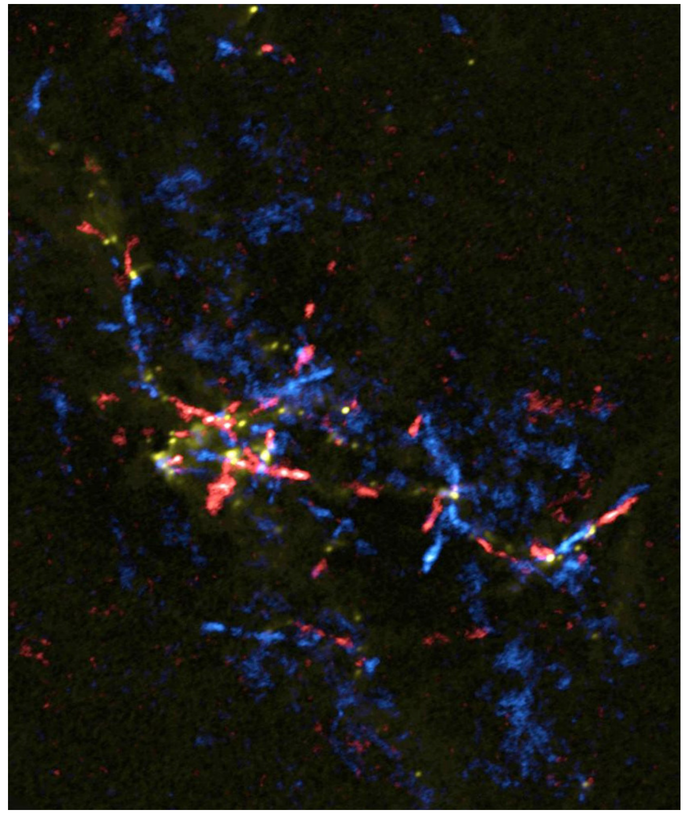


Figure 4 — ALMA pseudo-colour composite image of the gas outflows from baby stars in the Galactic Centre region. Gas moving toward us is shown in blue and gas moving away is shown in red. Credit: ALMA (ESO/NAOJ/NRAO), Lu et al.

"Although previous observations have suggested that overall star-formation rates are suppressed to about 10 percent in the giant molecular clouds in the Galactic Centre, this observation shows that the star-formation processes hidden in dense molecular gas clouds are not very different from those of the solar neighborhood," explains Shu-ichiro Inutsuka, a professor at Nagoya University and a co-author of the research paper. "The ratio of the number of star-forming cores to star-less cores seems to be only a few times smaller than that in the solar neighborhood. This can be regarded as the ratio of their respective lifetimes. We think that the average duration of the star-less core stage in the Galactic Centre might be somewhat longer than in the solar neighborhood. More research is needed to explain why it is so."

The research team is now analyzing ALMA's higher-resolution observation data for the CMZ and aims to study the properties of the accretion disks around the baby stars that drive the gas outflows. By comparing with other star-forming regions, they hope to better understand star formation in the CMZ, from clouds to protostars, and from chemistry to magnetic fields.

Compiled with material provided by the ESO.

A *Pas de Deux* with Aurora and Steve

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Judy Anderson, Winnipeg Centre (judy.anderson@umanitoba.com)

Abstract

A fortuitous auroral storm and a clear dark sky in a rural prairie setting allowed the authors to observe a Strong Thermal Emission Velocity Enhancement (aka STEVE) on a warm March night. It was a night of marvelous sights and new discovery.

The Dance

We had a date with Aurora but she didn't come alone. Steve showed up. Wasn't much we could do about that, and I don't think Aurora was too happy, because Steve stole the show.

It started out well enough: Aurora came early as a bright green glow along the north horizon as soon as the sky darkened. Her green outfit pulsed rhythmically, occasionally shooting purplish and green spikes like the sparkle from a bracelet, about halfway toward the zenith, a fairly typical display for a Manitoba view of the aurora borealis. Aurora was really pretty, sometimes even spectacular, especially when she broke up into those twisting curtains against the north horizon—a treat that didn't linger nearly long enough, alas. The lady was a regular prima donna that night, clad all in green with just a touch of ruby and sapphire jewellery.

We had expected that a subdued Aurora would attend the sky party that night, so a Kp-index that spiked up to 5 for a few hours around midnight was a pleasant surprise. With plans of observing in a dark sky interrupted, we turned most of our cameras to the north, leaving two others to follow some clusters in the south. Space weather forecasting may suffer from the same ills as regular weather forecasting, but there were no regrets that night for an under-forecast solar storm.

Steve didn't so much as arrive, as kind of drift into the scene, unobtrusively crashing the party. A quarter after 11, we noticed a thin gray-purplish band sprouting upward, almost comet-like, from the east horizon (Figure 1). Barely visible to direct view, it took averted vision to confirm his presence. "Hey, there's Steve!" Sheila noted, but after half an hour, Steve faded into the background and we lost sight of him. We went back to deep-sky photography and watched our Aurora dance, or

Figure 1 — STEVE's first appearance (at 11:37 p.m. CST) was as a fan-shaped "comet" stretching from the east horizon to the zenith. Though colourless to the eye, this exposure shows that the arc has a green tint on the north (left) side and a red tint on the south, a reversal of later images.

just lay down on the snow and talked, gazing upward to enjoy the year's first warmish night of naked-eye astronomy—a sign of the coming spring and shorter nights. Off in the north, Aurora's dress flashed in the colours that we love so well when she dances, and she was full of beautiful energy at the midnight hour.

Steve, being Steve, didn't hide away for long. A quarter-hour after the clock struck 12, he decided that being a wallflower while Aurora pirouetted was not in his best interest. In the space of a few minutes, Steve put on *his* party clothes (much more spiffy!), brightened up, and stretched out again to reach right across the sky to the west horizon (Figure 2). Now he was "happening!" From Arcturus, over the head of Leo, under the Gemini twins, and then down past Betelgeuse to the horizon, Steve's path across the celestial dance floor was now obvious and dominated the overhead sky, drifting slowly to the south. All our cameras were rapidly turned about to face Steve, just as Aurora's dance began to flag a little as she yielded centre stage. We restocked our energies, too, so we'd be ready for an extended performance. After a short trip inside under dark-red illumination, we were intrigued by the appearance of the sky

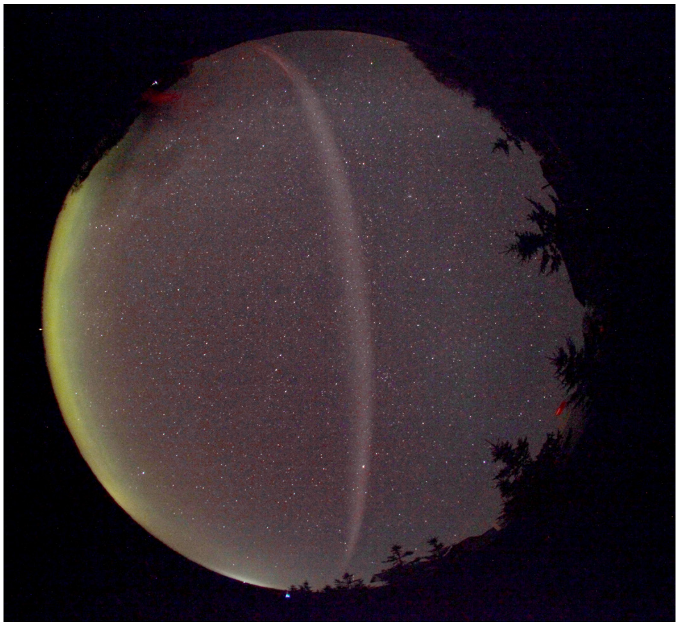

Figure 2 — A fisheye view of STEVE during the early stages of its second appearance, taken at 12:20 a.m. CST. The ribbon lies nearly overhead and is almost colourless, showing a vague purplish tint. Note the reddish colour of the sky, more apparent on the north (left) side of STEVE.

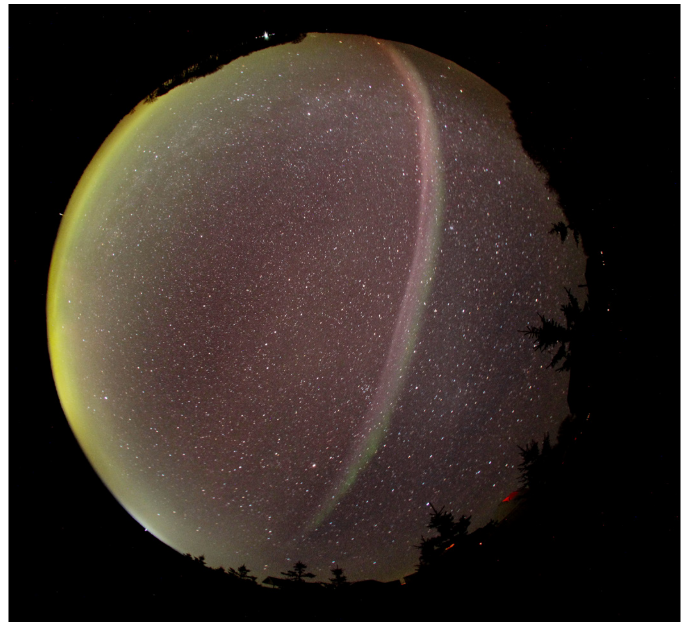

Figure 3 — A fisheye view of STEVE at 12:37 a.m. CST. STEVE has slipped to the south side (right) of the sky and now displays a bi-coloured ribbon along most of its length. Note the faint dark band separating the red and green colours along part of the ribbon. This image is rotated 20° clockwise from Figure 2.

as we returned; it seemed darker to the south of Steve than to the north.

Steve was no shrinking violet, now. After a time, he began to widen, perhaps doubling in width; as he did so, he opened his drab gray-purple jacket to reveal another more impressive layer underneath. It had real colours, and those colours separated the band into red and green sides—red on the north and green on the south—a bicoloured ribbon bedecking the constellations in a horizon-to-horizon bunting (Figures 3, 5). For a while, there was a darker dusky gap between the red-side and green-side streamers, as if the ribbon was made of two independent parts. For the first hour, Steve had placed himself at the zenith, but now gradually slid a little further to the south side of the sky so that we were no longer directly below him. He even swiveled his hips, as at one point, a small wave seemed to flow through the ribbon from east to west, pushing him southward.

Twenty minutes after his return to the dance, Steve started to show some hints of striations or twists toward the west horizon (Figure 5). Within a four-minute period, this part of his display turned into a line of large colourful streaks, making an angled westward descent (Figure 4) to the horizon, showing off (perhaps doffing his hat) to the Pleiades. The stripes were tilted toward us, with now-bright green on the bottom and bright red at the top—an unexpected and dramatic display of colour. There was no gap between the red and the green, but instead a smooth transition from one to the other. We were on the lookout for the formation of a green picket-fence (it's one of Steve's mannerisms) but these "fence posts" surprised us with their really obvious colours rather than being the more mundane green spikes that Steve had sported in pictures others had taken during past appearances.

The colours we saw mimicked the shades of a watermelon-tourmaline gemstone, and so we later decided that Steve had sprouted a half-dozen "watermelon flags" or maybe, "tourmaline banners" to distinguish them from the green picket fences (Figure 6). Perhaps it was Aurora's influence, because even though she was still dancing quietly by herself, she had sidled

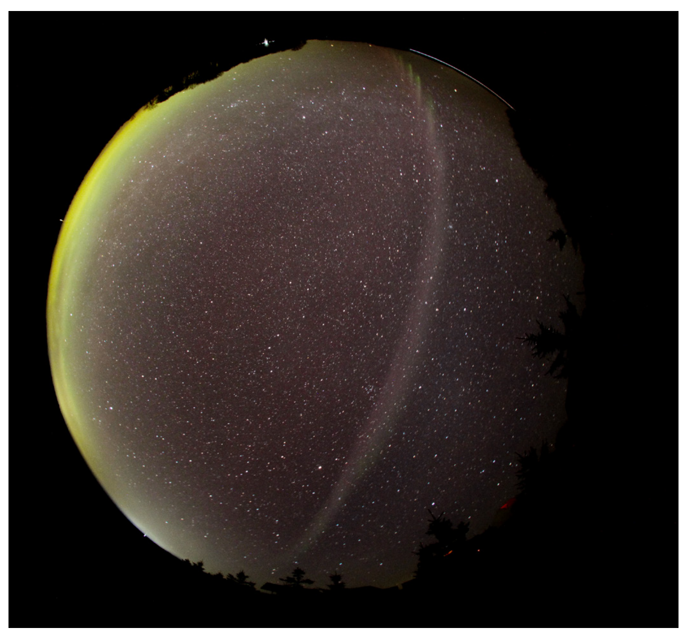

Figure 4 — STEVE at 12:47 a.m. CST showing the red and green banners that have formed near the western horizon. STEVE still has a red side-green side colouring but the green has largely faded away in the middle part of the banner.

up to Steve on the west horizon, the first time they had been close all night. There must have been some attraction, as the whole western sky between them glowed a deep red that was just visible to the eye—their dance together was mesmerizing! And what was the role of the banners, whose appearance coincided with the gradual decline of Steve's purple-tinged display and its eventual fading from view?

The tourmaline banners remained stationary in the sky over the next 18 minutes, fluctuating in shape and intensity. The dance floor seemed like a turbulent place—the highest flags became ragged and poorly defined as if some large stick was stirring the ionosphere. The farther banners, lower toward the horizon, kept their shape, marching Steve off the dance floor into Saskatchewan and Alberta and becoming less and less visible as 1 a.m. approached.

Through all of the costume changes during the dance, we'd tried to capture different parts of the sky, shifting the tripod-mounted cameras from east to west, from portrait to landscape or landscape to portrait, or changing to fisheye lenses on full-frame cameras. The sky was crazy busy and we were caught unprepared for such a magical dance so high in the sky, and our excitement didn't help!

Even though his be-ribboned suit was fading away, Steve wasn't quite ready to give up and head west. His original overhead band was now replaced by a vague mauve ribbon that gradually disappeared in concert with the coloured flags in the west (Figure 7). Soon, Steve was only visible in long-exposure photographs, and barely, at that. And then, toward the east, a really obvious picket fence appeared, about half-way up the sky (Figure 8). These streaks were all green—it was the picket fence we'd seen in other photos of Steve and had been anticipating all along! Steve was laying it all out for Aurora and us: a dozen or more vertical green stripes, glowed softly, marching toward the zenith—an emerald necklace of long crystals to match Aurora's still-bright northern dance costume. Steve was now dancing on a celestial keyboard and it glowed with his footsteps!

The new green pickets didn't last long—only about ten minutes—before fading away one by one, but they were a fitting denouement for Steve's marvelous solo appearance. Aurora, with the stage to herself again, continued her solo, shining as a green, north-horizon glow with occasional slow twirls like soft waves of chiffon, until the morning twilight gradually overwhelmed her ballet. Though game to stay until morning, her passion for the dance slowly waned as night's curtain opened on the dawn.

On reflection, it first seemed to us that Steve's sky-spanning purplish-gray banner had formed on a flat plane somewhere above us, but when it evolved into a red-side, green-side ribbon, we began to realize that there was much more to his character. The colours were either side-by-side above us at one layer, or were formed at two levels, with red above and green below. When first spotted, we were almost directly under Steve, so it seemed logical that the red top and green bottom were always there and had blended into gray with a little bit of a left-over purple tinge. As he drifted slowly toward the south and away from the zenith, we began to see him from a slightly different perspective—more from the side than from underneath—and the two-colour relationship became clear. Were the red and green levels there at the start, blended, or did an initial single reddish-gray layer later turn into separate red and green layers?

Figure 5 — A close-up view of the western terminus of STEVE at 12:30 a.m. CST. This enhanced image shows a hint of the "twisting" at the end of the ribbon that several minutes later resulted in the formation of the coloured, comet-like banners.

At one point, we noticed that the two ribbons of colour were separated by a darker band, reinforcing the impression that they were formed at discrete altitudes rather than being part of a continuous vertical structure that transitioned from green to red. Much of the mystery was resolved with the appearance of the coloured banners toward the west horizon. Since our view of Steve's watermelon flags was from the side, the vertical

Figure 6 — An early view (12:41 a.m. CST) of the western terminus "watermelon" banners. Note the breakup of the ribbon at the top left and the impending formation of new banners toward the west horizon. The progression of colours from east to west reveals that banner development is accompanied by strengthening of green wavelengths, as red tones are fairly constant along the length of the ribbon. There are small sub-structures within the strong green banners on the left that resemble the picket fence formation shown in Figure 8. Note also, the nearly complete disappearance of the ribbon between the banners at the centre of the image; only a faint reddish tinge remains.

Figure 7 — In this image, acquired at 12:57 a.m., STEVE's ribbon has almost disappeared in the eastern side (left) of the image while a few remaining banners march off toward Saskatchewan on the horizon. As in Figure 6, there is no clear separation between the green and red parts of the banners but instead a gradual transition from one colour to the other.

relationship between the colours became obvious: green was on the bottom and red was on the top, though they blended gradually from one colour to the other, without evidence of a gap between them.

Time-lapse movies, though assembled from irregularly spaced images, revealed magical things about Steve's evolution. In a fisheye view, the gray ribbon of early Steve was stationary at the zenith for the first dozen minutes or more before slipping southward, perhaps propelled by a small amplitude, long-wave impulse that seemed to travel westward along the band. A dozen minutes later, the first banners formed when Steve's bi-coloured ribbon "twisted up" on the western side. The ribbon formed what looked, at first, like a bit of a spiral pattern before separating into the coloured flags, a process that took less than four minutes. We have watched those short movie loops time and time again, and each matinee reveals more and more details of the ionospheric choreography.

One further and unusual part of our dance party with Steve and Aurora, was a largely unnoticed participant present in the rest of the sky, south of Steve's arc. A small telescope on a tracking mount had been left unattended taking time-lapse photographs of various Messier objects, while our attention was directed on Aurora twirling to the north, and Steve's overhead response in their beautiful *pas de deux*. When that series of 30-second images was examined, we found that the southern sky was flooded with red light, similar but fainter than the red sky colours we could see in the north. Was somebody else at the dance—a SAR arc perhaps (Mendillo 2012)? Probably not—it doesn't fit the description of a SAR arc—but something else was in the dance hall.

From Steve to STEVE

STEVE is short for a Strong Thermal Emission Velocity Enhancement, an acronym awarded to fit a nickname given earlier in humour. The classical apparition of STEVE consists of a purplish ribbon of light that stretches from east to west across the sky, and is often accompanied by a sidekick in the form of a series of vertical, green auroral bands likened to a picket fence that marches across the sky toward the west. STEVE always seems to come just after an auroral storm, and the aurora was, indeed, very bright on March 13–14. STEVE likes the pre-midnight hours, and though Steve stayed a little later than that on our night, it might have been the change to daylight time that kept him up. Though our Steve did have green pickets, they were on their own instead of alongside the purple ribbon; the watermelon-coloured flags toward the western horizon seem to be unusual, though not unknown. It seems that the Steve who came to our party compared quite closely with the traditional appearance of STEVE, although with a few impressive embellishments of his costume.

Scientific interest in STEVE is relatively recent, although the phenomenon has been observed for some time. An internet search of images using "proton arc" or "stable auroral red" will reveal many mis-identified STEVE photos stretching back beyond 2010. The story of STEVE's discovery (or recognition) is now well-known among auroral photographers. In 2016, a group of western Canadian photographers known as Alberta Aurora Chasers, shared their images of an unusual aurora form with Elizabeth MacDonald, a NASA space-weather scientist, and Eric Donovan, an auroral expert at the Department of Physics and Astronomy at the University of Calgary. The Aurora Chasers thought they'd captured a "proton arc," but MacDonald and Donovan realized that the images showed something much too bright to suit that identity. From that fortuitous exchange, the evolution of Steve to STEVE began; today, the spectacle is well known, although the nature of that display is still being untangled.

The ionosphere and adjacent magnetosphere form a complex region of the Earth's upper atmosphere. Ever-changing, always-interacting electric and magnetic fields, positive and negative ion flows, and strong thermal and energy boundaries are bombarded by an assortment of solar and terrestrial electrons and positive ions. This stew of activity generates several partly-to-mostly understood "glows." The aurora, of course, and skyglow are in this mix, plus a sub-auroral ion drift, the green picket fence, proton aurorae, SAPSOs (SubAuroral Polarization Stream Oscillations) and SAR arcs (Stable Auroral Red). Other strange apparitions that we find in our own past images are as-yet unnamed—green or reddish auroral "blobs" will have do for the time being.

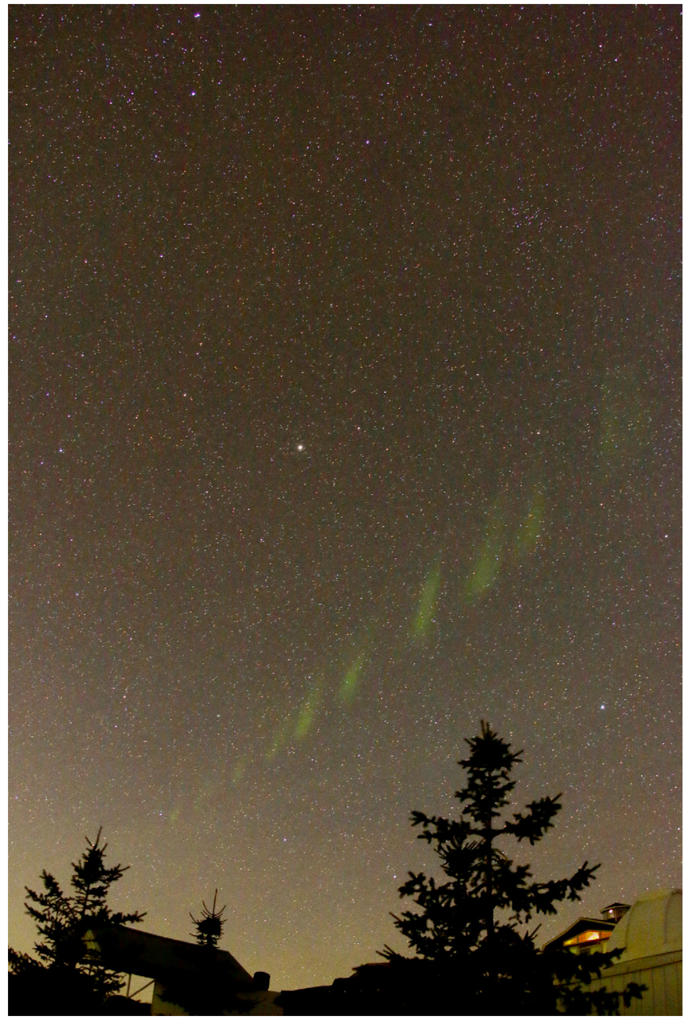

Figure 8 — A look back at the eastern side of the sky at 12:59 a.m. showing the green picket fence formation that is a characteristic part of the STEVE display. These features were faint, though discernable to the eye. The picket fence persisted for about 10 minutes.

Early on, the STEVE phenomenon was suspected of being an example of a sub-auroral ion drift (SAID). SAIDs form on the polar side of a low-density plasma trough in the ionosphere during geomagnetically active times. That trough forms regularly every night, when recombination of electrons and ions reduces the density of the ionospheric plasma in the absence of UV radiation from the Sun. During a SAID, the trough is unusually deep. The low plasma density allows the available energy to be parcelled out among fewer candidates, causing the average electron temperature within the trough to increase, sometimes dramatically. This in turn, promotes a high-speed flow (several km/s) of electrons and ions along the channel.

It is now widely accepted that STEVE proper—the purplish band—is an extreme version of a SAID. Archer (2019a) compiled statistics for 122 SAID events and compared them to eight appearances of STEVE. SAID ion velocities in the study ranged from 500 m/s to 5 km/s (median ~1.3 km/s) but more than half were below 1 km/s. STEVE velocities (only four were measured) ranged from 3.2 to 6 km/s. Similarly, the peak electron temperature of seven of the eight STEVE events fell in the top 3 percent of the SAID range. Most dramatically, the plasma density of all but one of the STEVE events fell outside the range of SAID measurements; in two cases, STEVEs had plasma density more than three orders of magnitude lower than SAIDs. In effect, STEVE has all of the characteristics of a supercharged SAID.

A study by Gallardo-Lacourt (2018) indicated that STEVE displays are most common in September and April and absent in the cold season months from October to January, though more observations are needed to affirm the seasonal nature of the appearances. STEVE seems to have a certain amount of annual variability, being less frequent from 2012 to 2014 than in earlier and later years, but past statistics are likely to be revised in view of STEVE's recent popularization and a larger number of public reports. The same study showed that STEVEs have a typical duration of about 1 hour, a width of around 20 km, and an average movement southward of 50 km during its appearance.

The green picket-fence structure that typically appears with STEVE, seems to be a colour of a different colour. The same satellite passes and ground-based observations that revealed the nature of STEVE also showed that the picket fence formation is caused by electron precipitation—that is, by the same mechanism that causes the "normal" aurora borealis: electrons raining down into the ionosphere. However, the auroral fence pattern appears well outside the usual auroral zone, and while the mechanism is familiar, the location and shape have yet to be explained. Alas, the attractiveness of a new ionospheric structure to study—STEVE—has made the picket fence seem ordinary and studies of that formation are languishing.

While ionospheric measurements have revealed some of the energetic mechanisms of STEVE, most casual observers are probably more interested in explanations of the physical appearance of STEVE. Ours and other's photographs show an intriguing mixture of gray, red, and green colours, vertical and horizontal structures, movements west and south, and the expansion and contraction of the STEVE ribbon. What's up?

Archer (2019b) used citizen photographs from two locations and triangulation to determine the altitudes of STEVE's purple arc and the picket fence. In the event they studied (2017 September 16), the lower boundary of STEVE lay between 141 and 151 km altitude; the upper boundary was between 226 and 249 km. The green picket-fence structure had a lower edge between 92 and 97 km and an upper from 141–153 km. STEVE and the picket fence were within 35 km of each other horizontally, suggesting that they formed on the same magnetic field line (which need not be vertical). If that idea is assumed to be correct, it is possible to make a more precise measurement of STEVE, which gives it a vertical depth of between 130 and 270 km, with fainter parts extending to 300 km. RGB colour profiles across STEVE and the picket fence show that red and blue colours (i.e. purple) dominate above about 260 km, while green dominates from 100 to 200 km. Between these levels, colours are equally distributed.

One of the intriguing questions about STEVE is what causes the colours? Gillies (2019) collected the spectrum of both the STEVE ribbon and the picket fence using the TREx (*Transition Region Explorer*) spacecraft as it overflew a ribbon in April 2018. STEVE displayed a continuous spectrum brighter than, but almost identical to, the background skyglow from ~400 to 730 nm, including emission lines at 427.8 nm (blue), 557.7 nm (green), and 630.0 and 636.4 nm (both red). STEVE's only embellishment that night was an elevated emission at the two red lines, about 60-percent higher than the adjacent skyglow. Since both skyglow and aurora have strong green OI (un-ionized atomic oxygen) emission at 557.7 nm, the absence of any additional energy at that wavelength in the ribbon excludes STEVE from being an auroral feature. Overall, the brightness of STEVE was approximately twice the background skyglow; the combination of this enhanced skyglow and the excess of red OI emission gives STEVE its purplish or mauve colour. In effect, STEVE is just a brighter-than-normal nighttime skyglow with a little extra red. But don't tell Steve that!

The spectrum reported for the picket fence in the same study showed a very strong emission from OI at 557.7 nm and no continuum background, reinforcing its identification as an auroral line caused by high-energy electrons colliding with atmospheric atoms.

The explanation for the STEVE spectrum, particularly the continuum enhancement, is still under investigation. Nightglow is known to have a weak emission across a broad range of wavelengths and is attributed to numerous photochemical reactions involving excited states of nitric oxide, nitrogen, atomic oxygen, ozone, and others. These excited ions and molecules are produced on the Earth's dayside or transported from there. Harding (2020) proposed a chemical reaction between nitric oxide (NO) and atomic oxygen that would produce nitrogen dioxide (NO_2) and a broadband emission of light, but this now seems unlikely since that reaction works best at altitudes well below STEVE. A reaction between nickel (from meteorites) and oxygen has also been suggested but since dismissed on the grounds of it being too faint, as have other reactions between electrons and neutral atoms (Gillies 2019). The enhanced red emissions at 630.0 and 636.4 nm could be produced when the high-temperature electrons within STEVEs (Sazykin 2002) excite the lowest electronic state of atomic oxygen $O(^1D)$, which then returns to the ground state. Green emission is produced when atomic oxygen is excited to the ^1S level and then relaxes to the lower ^1D level.

One aspect of our night with Steve that also piqued our curiosity was the shape and movement of both the luminous ribbon and the picket fence. Steve began as a fairly unobtrusive, spreading, gray-purplish comet-shaped streak in the eastern sky that lasted for only 10 minutes before fading away. That first faint streak had its separate reddish south and green north, although we didn't notice colours at the time; they later showed up in the photographs (Figure 1). Thirty minutes later, Steve was back. At first mostly gray (Figure 2), he then evolved into a prominent, coloured band as he grew across the sky from east to west without any large amount of longitudinal structure (Figure 3). This second time, the red tones were on the north and the green on the south, the reverse of Steve's first appearance. Over the next half hour, the colours faded overhead, returning to an almost-gray shade, but lingered in the east and west. The green emission in the east evolved into a picket fence that tracked toward the zenith; that in the west broke up into the watermelon-coloured banners, an attention-grabbing process that took only a few minutes.

Time-lapse video shows that the evolution of the banners along STEVE's western side began about 45 degrees high when some kind of impulse entered the field of view of the camera and moved down along the band toward the horizon. As the impulse advanced, the lower green edge of the ribbon immediately downstream increased dramatically in brightness while simultaneously forming the discrete red and green streaks that we've likened to a flag or banner. The green bottom of each flag had some embedded substructure in the form of a cluster of slightly brighter small streaks.

After the impulse's passage, each newly formed banner decayed away, first in the green and then the red. One intrepid banner first faded and then temporarily brightened again, persisting for a few minutes longer, all alone on the ribbon as the wave moved westward. Behind the impulse, portions of STEVE's largely colourless ribbon reappeared, but much fainter, and then became invisible to the eye. At the end of the time lapse, which lasted barely 20 minutes, there was almost nothing left of STEVE.

What caused this transition from a sedate bi-coloured band into a wave-train of quasi-vertical banners? And why was the display of banners, those beautiful watermelon flags, confined to the western side of the STEVE display? Is the same wave-like impulse that caused (or appeared simultaneously with) the transition in STEVE, also responsible for the green picket-fence appearance that is now understood to be auroral bands? Why did the impulse brighten the lower green edge while leaving the higher red layer largely untouched?

SAIDs and STEVE are known to form in association with the plasmapause, the boundary that separates the cold inner part of the Earth's magnetosphere that rotates with the planet (the plasmasphere) from the warmer outer magnetosphere. The plasmapause lies outside the ionosphere, but during solar storms, charged particles and the electric field of the solar wind can penetrate into the ionosphere along magnetic field lines. One of the mechanisms proposed to account for the plasma flow of a STEVE involves the coincidence of strong magnetic and electric fields promoted by a solar storm along and outside the plasmapause, with Alfvén waves (waves in the magnetic field) responsible for accelerating electrons (Chu 2019) to high velocity and temperature.

Movement of structures within STEVE and the picket fence were investigated by Gillies (2020), who tracked features in an August 2019 display. The fine structures in STEVE were found to have a westward motion of 5–10 km/s. The pickets in the picket-fence formation moved at 400–600 m/s, an order of magnitude slower than STEVE. According to Gillies, this discrepancy suggests that STEVE and the pickets are not co-located, but are adjacent to each other, separated by a distance of less than 20 km. Such closely aligned but distinct ionospheric signatures require a large gradient of velocity, temperature, and geomagnetic conditions; conditions that appear to be present in a SAID of substantial magnitude. At the moment, however, most explanation requires further research.

STEVE's magic

The appearance of a STEVE on the night of March 13–14 was a marvelous surprise. Equally surprising and rewarding was how much we could discover from our photography, visual observations, and discussions, before we went to the literature. We were able to embed ourselves in the structures and physics of the ionosphere, and, after some study, come to understand a fair bit of what we saw. Many of the revelations in the formal publications about STEVE and the picket fence over the past three years—relative height, colours, location, behaviour—could be and were deduced subjectively from our visible observations, photographs, and time-lapse animations.

There are images in our memory that we wish had been captured in a camera, or captured in a better format or with longer (or shorter) exposure or at higher ISO. But, even now, knowing better what to expect next time, nothing could really capture the excitement that we felt watching Steve dance with Aurora, as he twirled, pulsed, and waved tourmaline banners while dancing across the sky! A ballet we won't forget!

There is a larger lesson here, as well. How many of us spend time, money, and energy collecting and processing astrophotographs and then ignore their content? Images are beautiful, yes, but there's so much to learn from their close study, to enhance the initial observations made while we revel in their magical reproduction. Sharing detailed recollections, pointing out observations as they happen, discussing images with fellow observers, and perhaps immersion into the internet library of all things—scholar.google.com, academic journals, and Wikipedia—should become integral parts of our efforts to really see what we've recorded. In the meantime, we'll await another STEVE—because it was so intriguing, and because we want to see what we can discover (and dance) anew. ✷

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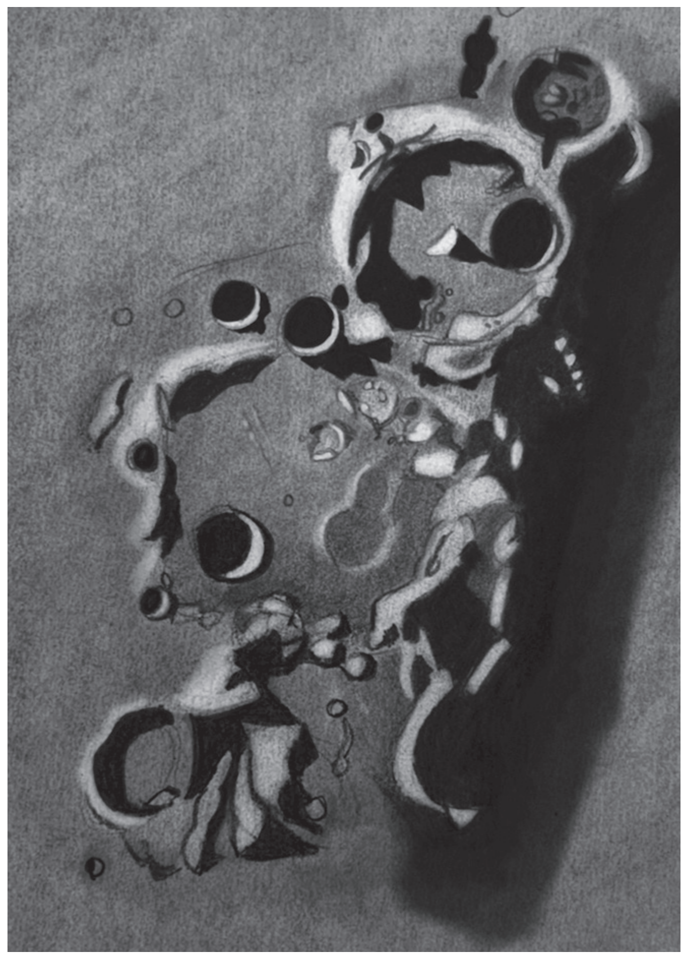
Great Images

By Michael Gatto



Nova Scotia had a remarkable 5 clear nights in a row in March, and many lunar observers were taking advantage of the clear weather. Michael Gatto enjoyed a night of good seeing on March 20 to do this sketch of Hipparchus, *centre, (notable is the nice feature that looks like 2 older craters that have been flooded or eroded to make it look like 2 smooth "dents.")* Halley, *the small crater along the top right edge,* Albategnius, *top, which has a nice crater inside it and an obvious central peak. Sketched at the eyepiece of a 8″ f/7.5 reflector, scanned and coloured in Photoshop.*

Detection Threshold of Noctilucent Clouds and its Effect on Season Sighting Totals

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Abstract

Synoptic observations of noctilucent clouds (NLC) in 1967–1977 during a North American observing campaign are studied in order to determine observers' ability to detect NLC. The average detection threshold of brightness varies, sometimes greatly, from observer to observer and group to group. The average initial brightness of a sighting is brighter than the average final brightness as an observer follows a display to its faint conclusion. Ability to detect faint NLC indeed plays a role in the number of NLC-active nights tallied during a season. When a group is showed a series of NLC photos of varying brightness, there is good agreement with regard to what constitutes a bright, moderate, or faint display, with observer experience not being a factor.

Noctilucent clouds (NLC), the beautiful ice clouds that form in Earth's mesosphere in the boreal and austral summers and that can be seen in twilight in May–August and November–February in the respective seasons, are a marvel to watch (Figure 1). At the point they are bright enough in the local twilight sky to recognize, they enchant the observer with their eerie blue-white glow, their fine filamentary structure, and mesmerizing, albeit barely perceptible motion. The phenomenon has only been known since June 1885, when they appeared to many individuals (amateurs and scientists) in Europe and Russia. This rather sudden onset has caused scientists to speculate that they are a result of changes occurring in Earth's atmosphere. Thomas et al. (1989) concluded that the appearance of NLC is the result of gradually increasing levels of methane originating from Earth's surface. The methane diffuses to the stratosphere where it is broken down by sunlight into water vapour, among other compounds. The water vapour continues to diffuse upward through the stratosphere and into the mesosphere, where NLC form at the topmost level, around 80–85 km. Part of the theory states that around the 1880s, NLC brightness reached

Figure 1 — Photo of NLC display by the automated NLC camera at Athabasca University Geophysical Observatory, 2016 July 24–25, 0940 UT. This photo was Picture 6 in the Brightness Survey. Of the 12 participants, 6 judged a brightness of 3, 5 - a 2, and 1 - a 1.

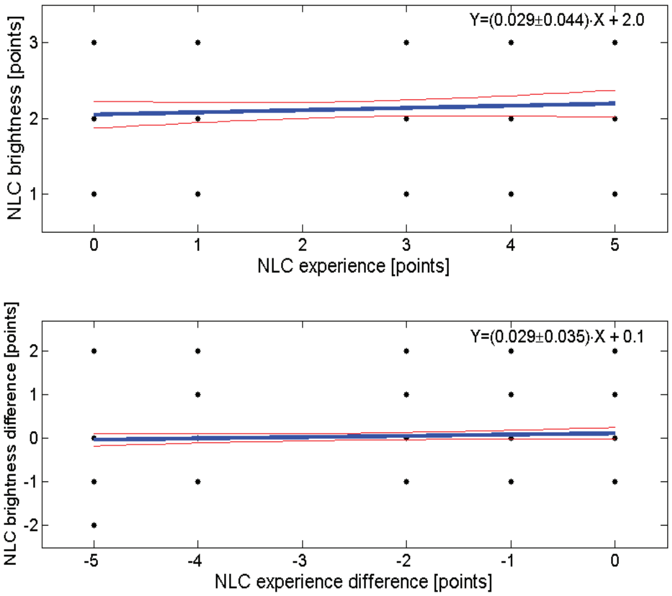

FIGURE 2 — Graph showing the agreement of brightness estimates among a group of 12 participants. Top panel - agreement of brightness values; Bottom panel - agreement based on observer experience.

a threshold allowing them to be seen by the naked eye. The onset of visibility may have been enhanced by the August 1883 Krakatoa catastrophic volcanic eruption, which injected huge amounts of fine dust and water vapour into the atmosphere.

The noticing of a display of NLC is of course dependent on the brightness of the clouds at the time, and as is the case with other natural phenomena, the detection of the NLC will depend on the individual observer's ability to pick out, in this case, a faint display from the background twilight. It could be contended that the onset of NLC globally in 1885 was in part thanks to those European viewers who were observant enough to discover displays of NLC and recognize them as a distinct, new phenomenon, and then to report them to various authorities, usually educational institutions.

In the ensuing decades, NLC have become a more-reported phenomenon. In the 21st century, the prevalence of media to extoll their beauty and mystery has yielded a dramatic increase in reports, especially in the form of photographs by various forms of digital cameras that can now record natural phenomena with ease and ever-greater sensitivity. But this increased exposure has frankly done little to help us conclude that there may have been an actual increase in NLC activity in the last 130 years. Actually, organized synoptic observations since the 1960s have yielded studies. For example, Pertsev et al. (2014) and Dalin et al. (2020) have concluded that there has been an increase in the frequency of nights with NLC during the season, but the increase has been slight and statistically insignificant.

The brightest NLC displays are so conspicuous, even members of the general public with little interest in atmospheric phenomena recognize the displays as something extraordinary. Fainter displays are often missed because they are simply too feeble in brightness, or because they look like ordinary cirrus clouds that may be perceived as being lit by the last vestiges of twilight. Even in the latitude zone of highest NLC incidence, 55–60 N in the Northern Hemisphere, seasonal sighting totals vary greatly. Why? For observers in this zone, the total is usually 10 to 15 displays (Noctilucent Clouds around the World Facebook Group [www.facebook.com/groups/120898778545736], personal communication). An observer such as Edmonton's Mike Noble, who travels nightly to reach clear skies and uses digital photography to aid NLC detection, can increase the NLC number well into the 40s (Zalcik and Noble, 2019). The current record for a fixed research camera is Vilnius, Lithuania, with 35 active nights (Pertsev et al., 2014). Conclusions about the strength of NLC activity during a particular NLC season must take into consideration the varying ability of people and cameras watching the sky to detect the clouds, with whatever ease and acuity.

Organized campaigns for NLC monitoring have usually included NLC brightness as one of the key characteristics to be recorded. Personnel at weather stations participating in such programs are at the outset briefed as to what NLC look like and are instructed to estimate the brightness of the NLC according to an established scale. If a bright patch of NLC appears from behind tropospheric clouds, the initial brightness value recorded by the observer will be a 3 (bright, on a 1–3 scale, whereby 2 is moderately bright and 1 is faint). But the vast majority of displays seem to start out faintly. If a display starts during the twilight period, the clouds usually appear very close to the horizon, at which time they start out as faint, even though they can quickly increase in brightness. Similarly, the rarer displays that are already well up in the sky in evening twilight are faint until the contrast improves as the sky gets darker.

To verify that most NLC displays indeed start out as faint, we looked at photographic data by Mike Noble from the years 2019 and 2020. Mike's avid observing regimen involves setting up digital cameras in twilight, in readiness for the first faint hints (using Mike's own terminology!) of NLC. The first images of the displays recorded had their NLC brightnesses estimated on the 1-3 scale. Of a total of 44 displays surveyed, 40 had an initial brightness of 1, 4 of 2, and 0 of 3, with the average initial brightness being 1.1. The fact that the overwhelming majority of initial NLC in Noble's data were faint, fully 91%, shows that displays indeed show up inconspicuously.

We will now look at historical NLC observation data to see if naked-eye NLC observations echo the above photographic ones in that the initial NLC seen are feeble in brightness. The data set being studied is the observation program conducted by Canadian and American (all in Alaska) weather stations and airports from 1967–1977. This 11-year campaign was the continuation of a program under the direction of Fogle

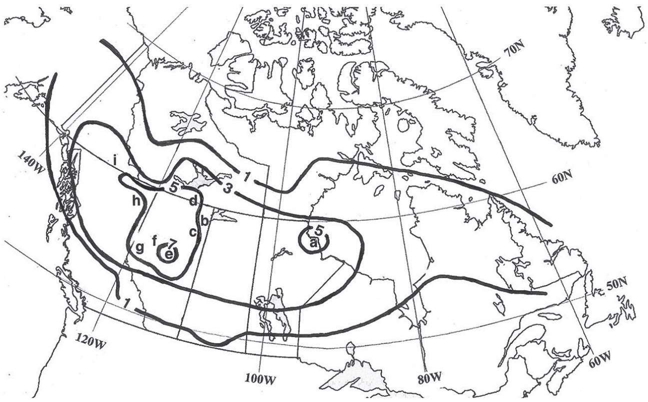

Figure3 — Map showing locations of nine weather stations in the detection threshold study. a – Churchill, b – Ft. Chipewyan, c – Ft. McMurray, d – Ft. Smith, e – Slave Lake, f – Peace River, g – Grande Prairie, h – Ft. Nelson, and i – Watson Lake

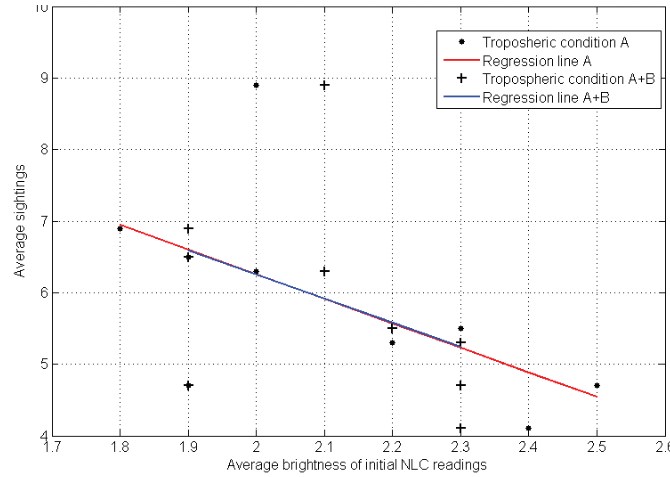

Figure 4 — Graph showing relationship between average initial brightness and average seasonal sightings for the nine sites in the study. Lines are shown for both tropospheric conditions A and B.

(1966) of the University of Alaska. In total, over 40 stations kept watch for NLC, with staff entering observation data onto dedicated forms when NLC were seen. Details on annual totals of network-wide sightings during the program, variation of average NLC brightness with respect to latitude, and comparisons of activity and brightness at specific sites, were presented by Zalcik et al. (2016).

The scale for brightness estimation used by Fogle, and for that matter put forward by global NLC observing programs (Grishin, 1957; WMO, 1970) is a 5-point scale with the following values:

1 – faint

2 – not very bright, but easy to recognize

3 – clearly visible

4 – very bright

5 – extremely bright, illuminating objects facing them.

The scale adopted by the North American surveillance network NLC CAN AM is the more simple and easier to remember 3-point scale mentioned previously. The "4" and "5" brightness values of the global program were seldom entered on the observing forms, with the "3" designation used far more often to indicate bright NLC. In essence, then, the "3" value of the North American program was roughly the equivalent of the combined "3", "4", and "5" values of the global program.

What degree of agreement is actually established within a group of observers with regard to the brightness of a display of NLC? To find out, one of us (MZ) conducted a survey of attendees at the 2017 June 23 "Astro-café" talk, one of a series of talks organized by the RASC Edmonton Centre. For the survey, a set of 25 images of NLC was shown to the attendees, who were asked to rate the brightness of the NLC in each image. The results of the survey are shown in Table 1; the NLC photo in Figure 1 is one of the test photos. The attendees had varying experience in observing NLC. Results (Figure 2) suggest that there is good agreement in the group with regard to the full spectrum of brightness. Interestingly, agreement in test answers was also good for observers with lots of NLC observing experience compared with those with minimal experience.

Of the aforementioned 40 sites contributing synoptic NLC data in the 1967–1977 program, we chose 9 Canadian sites in the prime NLC viewing zone of 55–60 N. These sites consequently tallied more seasonal sightings, and hence more brightness values to contribute to this study. A map showing the locations of these sites is shown in Figure 3.

Table 2 shows the average brightness values of initial and final nightly sky checks of NLC from the above sites. Table 3 shows a season's sightings at one particular site, Churchill, during the 1968 season, with the aggregate brightnesses based on a reading every 15 minutes recorded during each of the active nights. The global observing program estimated tropospheric opacity on a 4-letter scale:

A – sky completely clear

B – sky with some scattered tropospheric clouds present

C – most of the sky covered with tropospheric cloud with only small holes between clouds

D – sky overcast with tropospheric clouds.

Table 2 incorporates NLC sightings with corresponding tropospheric cloud values of "A" and "B" only. The problem that may arise if including "C" observations was previously mentioned, that being, bright NLC could briefly appear between broken tropospheric clouds, giving the impression that this "initial" sighting was actually of bright NLC, not necessarily a true indication of the progression of NLC brightness over the course of a night's display. Not surprisingly, NLC sightings with a corresponding "A" value are the most valuable as there is no chance of tropospheric cloud interference.

From Table 2 it is readily apparent that the average initial brightness of these sightings is *not* faint, with the majority of sites in both the "A" and "B" scenarios having an average initial brightness of 2.0 or more. Thus, a significant number of displays were already of moderate brightness when detected; still others were not noticed until the display was bright. A possible factor in the elevated initial brightness readings is the periodicity of sky checks by the weather and airport personnel doing the observing. Typically, sky checks were performed on the quarter hour. Hence, a display exhibiting a rapid increase in brightness could conceivably jump from a brightness of 1 to a 2 or even a 3 in a 15-minute time span. For all sites, the brightness of the final NLC reading was significantly fainter than the initial reading, indicating that once the NLC were unequivocally detected, the observers were able to follow the display to the point where it became faint.

Picture	A0	B1	C1	D3	E1	F4	G4	H1	J4	K5	L1	M5
1	2	2	2	3	3	2	2	3	2	2	3	2
2	1	1	1	1	1	1	1	1	1	1	2	1
3	2	1	2	2	2	2	2	2	2	2	1	2
4	2	1	3	3	3	3	2	3	1	2	1	2
5	1	1	2	2	1	2	3	2	2	2	1	1
6	1	2	3	2	2	3	3	3	2	3	3	2
7	2	3	3	3	3	3	3	3	3	3	3	3
8	1	1	1	1	1	1	2	1	1	1	1	1
9	3	3	3	3	3	3	3	3	3	3	3	3
10	3	3	3	2	3	3	3	3	3	3	3	3
11	1	2	1	2	1	2	2	2	2	2	2	2
12	1	1	1	1	1	1	1	1	1	1	1	1
13	3	3	3	3	3	3	3	3	3	3	3	3
14	2	2	2	2	2	2	3	3	2	2	2	2
15	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	2	2	1	2	2	2	2	1	2	2
17	3	3	3	3	3	3	3	3	3	3	3	3
18	1	2	1	1	1	2	1	1	2	1	2	1
19	1	2	2	2	3	3	2	3	3	2	3	3
20	1	2	1	1	1	1	2	1	1	3	1	2
21	2	3	3	2	3	3	3	3	3	3	3	3
22	2	3	2	2	2	2	3	3	3	3	3	3
23	3	3	3	3	3	3	3	3	3	3	1	3
24	3	3	3	3	3	2	3	3	3	2	3	3
25	2	2	2	2	1	1	2	2	2	2	1	2

Table 1 — Results of the NLC Brightness Survey Observer (experience factor 0 [none] to 5 [much])

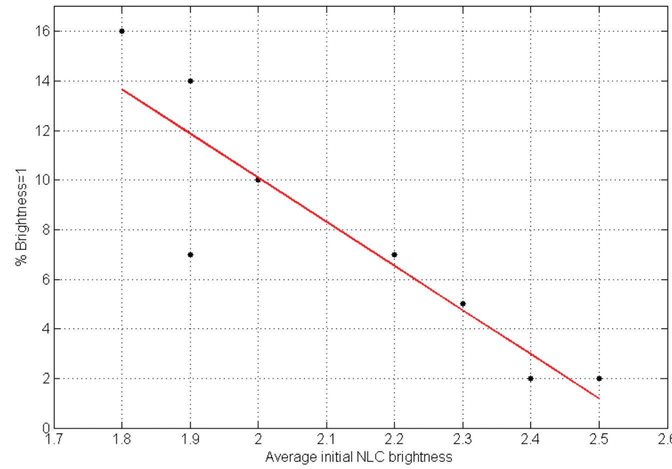

Figure 5 — Graph showing the effect on average brightness by percentage of active nights during which the NLC brightness remained at a level of 1 through the entire display.

There is no clear advantage of having completely clear skies, condition "A", during the initial observation versus skies with some tropospheric cloud, condition "B". Some sites had a fainter average initial observation under "A" conditions; others under "B" conditions. A comparison of the individual sites' average initial brightness values indicates that some sites, for example Ft. Nelson, Churchill, and Peace River, were <2, whereas others, such as Ft. Chipewyan and Watson Lake, were significantly higher, 2.4–2.5. With these higher values it could be expected that initial sightings with faint NLC were in the minority. Is the reason for the marked difference between some sites simply personal factors such as experience and visual acuity? A more comprehensive list of such factors is outlined by Zalcik et al. (2014). The Churchill site had an average of 6.9 active nights per season despite having poorer weather conditions than sites further inland (Yorke and Kendall, 1972). Notice, however, that Churchill also had the lowest average initial brightness, 1.8, suggesting that many of the initial sightings had a brightness value of 1. Perhaps unfavourable weather at this site was more than offset by the staff's ability to detect NLC while they were still faint.

Figure 4 attempts to show a relationship between average initial brightness and average number of sightings for the nine sites. The curves show that an average initial brightness of 1.8 yields about twice as many sightings as a brightness of 2.5. Recall the aforementioned data from Mike Noble; his average initial brightness of 1.1 has contributed to his lofty sighting totals, into the 40s during some seasons. Zalcik et al. (2016) pointed out that an increase in NLC sightings at the Baker Lake, NU Flight Service Station (64°N, 96°W) in 2003–2009 may have been due to a high proportion of faint displays detected.

In Figure 5, we show the relationship between average initial brightness and the percentage of total nights for each site when the brightness for the entire display remained at 1. From the curve, one can see that at an average initial brightness of

Site	No. Sightings	Yrs	Avg		A	a	b	B	c	d	a+c	b+d
Churchill	62	9	6.9		25	1.8	1.5	25	2.0	1.6	1.9	1.5
Ft. Chipewyan	52	11	4.7		21	2.5	1.6	16	2.0	1.6	2.3	1.6
Ft. McMurray	61	11	5.5		21	2.3	1.3	18	2.1	1.3	2.2	1.3
Ft. Smith	58	11	5.3		27	2.2	1.9	15	2.5	2.1	2.3	2.0
Slave Lake	71	8	8.9		24	2.0	1.3	22	2.1	1.4	2.1	1.3
Peace River	72	11	6.5		27	1.9	1.4	20	1.7	1.5	1.9	1.4
Grande Prairie	63	10	6.3		33	2.0	1.3	10	1.7	1.5	1.9	1.4
Ft. Nelson	42	9	4.7		22	1.9	1.4	9	1.8	1.3	1.9	1.4
Watson Lake	41	10	4.1		11	2.4	1.5	9	2.2	1.5	2.3	1.5

Table 2 — Weather station NLC data from the 1960s–1970s.

A – number of nights having sightings with clear tropospheric conditions   a – average initial brightness   b – average final brightness

B – number of nights having sightings with scattered tropospheric clouds   c – average initial brightness   d – average final brightness

2.0 or fainter, four of the five sites have >10% of their sightings staying at a brightness of 1; at an average initial brightness of 2.4–2.5, this percentage drops to only 2%.

The Flight Service Station at the airport at La Ronge, Saskatchewan (55°N, 105°W), has been the best site at yielding synoptic observations in the NLC CAN AM surveillance network, which has been monitoring NLC in North America since 1988. Fully 24 seasons of data, from the 1990 to the 2013 NLC seasons, were compiled (Zalcik et al., 2014), and the average number of NLC-active nights at La Ronge in this time period was 9.7. Note that this average is nearly one full active night per season higher than Slave Lake ("e" in Figure 3), also situated at 55°N. Whether the difference is because of better ability by the La Ronge staff to detect NLC, or because of an actual increase in NLC frequency in the La Ronge epoch compared with the earlier Slave Lake one, is unclear.

Zalcik et al. (2016) introduced the concept of the "average detection threshold" of a group of observers. Such a threshold is the average brightness at which a display of NLC is unequivocally recognized. The threshold is dependent on the actual brightness of the NLC present, but also on a number of personal factors among observers, such as experience, acuity, dark adaption, and fatigue, as well as site factors, such as flatness of horizon and degree of ambient lighting. The averages derived in column "a+c" in Table 2 essentially constitute the average detection thresholds of observers at the sites listed in the table. The range of averages in these values from site to site harkens to the above factors at play when determining the presence of an NLC display.

To aid the ability to increase one's seasonal sighting total by detecting faint displays, a couple of different strategies can be employed. One would be the use of such optical aids as binoculars, which have proven to be invaluable in picking out the fainter NLC displays. Employing digital photography to bring out the faintest displays would work just as well.

However, as faint NLC detection, as shown here, can vary greatly from observer to observer, the pursuit of finding weak NLC displays can actually be a detriment in determining the true frequency of NLC and, by extension, determining decadal trends in NLC frequency. It may be preferable to use only bright NLC displays when making such comparisons, this strategy already being suggested by Zalcik et al. (2016).

Conclusions

For an individual observer or group of observers of NLC, the average detection threshold of NLC varies, sometimes markedly, from one observer to another or one group to another.

The average initial brightness of NLC for an observer or group of observers is brighter than the average final brightness, presumably because of the ability to follow a display of NLC to a fainter brightness once the display is recognized.

The difference in average detection threshold from one observer or group of observers to another determines the difference in NLC seasonal active-night totals. The individual or group who is better able to pick out faint NLC displays, which seem to constitute a high proportion of total displays, will with no surprise end up with more NLC-active nights during that season.

When a group of observers evaluates a quantity of NLC images to estimate brightness of each display, there is good agreement among the individuals as to what constitutes a bright, moderately bright, or faint display.

There is good agreement among experienced and non-experienced observers with regard to judging what constitutes a bright, moderately bright, and faint NLC display. ✷

Date	Times	Brightness Values	Weather
Jun 15–16	0600–0815	4,4,4,4,4,4,3,3,3,1	A
25–26	0500–0645	2,2,3,3,3,3,3,3	B
27–28	0500–0645	2,2,2,2,2,2,2,1	D
30–Jul 1	0545–0715	1,2,2,2,3,3,3	A
Jul 6–7	0500–0715	1,2,2,2,3,3,3,2,2,1	A
20–21	0600–0730	1,1,2,2,1,1,1	C
Aug 1–2	0800–0900	4,4,2,2,1	C

Table 3 — Brightness values of NLC recorded at the Churchill weather station during the 1968 season. Only data from the nights with weather values of "A" and "B" were used in the analysis as only under these conditions is tropospheric cloud not a detrimental factor. Hence, in 1968 only four of the seven nights were usable. Brightness values of "4" for Jun 15–16 were converted to "3" to conform to the 3-point brightness scale used in this study.

Acknowledgements

Thanks to all the observers who have contributed observations to NLC CAN AM since 1988. Thanks in particular to all the weather and airport personnel at Churchill, Ft. Chipewyan, Ft. McMurray, Ft. Smith, Slave Lake, Peace River, Grande Prairie, Ft. Nelson, and Watson Lake. Thanks to Mike Noble for providing the impressive data collection to aid this study. Thanks to the participants of the NLC brightness study: Clive Figueiredo, Gina Figueiredo, Ken Gehring, Danny Jones, Alister Ling, Bruce McCurdy, Mike Noble, Peter, Larry Wood, Janey Yu, Lourdes Zalcik, and Mark Zalcik. The Astro-café concept originated with the RASC Victoria Centre; these events carried over to the Edmonton Centre under the presidency of Luca Vanzella. Thanks to the Namao Agricultural Society—their community hall proved a cozy venue for the 2017 event. Martin Connors and Ian Schofield continue to operate the automated NLC camera at Athabasca University Geophysical Observatory, part of the network of cameras across the Northern Hemisphere monitoring NLC each season since 2006 (Dalin et al., 2008).

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Pen & Pixel

Journal editor-in-chief Nicole Mortillaro managed to fight her instinct and got up before sunrise to capture our star rising over Lake Ontario in Toronto's Beaches neighbourhood with onlookers and seagulls. She took the image with a Canon 60D, 250-mm, ISO 100, at 1/5000.

SkyNews *editor Allendria Brunjes got her snapshot of the partial eclipse on June 10 using a Nikon D5200 with a Nikkor 55–200-mm lens. "Fishers, joggers, and celestial-events chasers watched the eclipse sunrise over the Georgian Bay waterfront in Collingwood, Ontario," she said. The image was taken at ƒ/7.1, 1/4000 sec, focal length 200 mm and ISO 100.*

Shelly Jackson and her husband, Stefan Jackson, took their image of the eclipse from Sarnia, Ontario, using a Canon T3 Rebel. Processed single frames with PixInsight. (right)

Former RASC Executive Director Randy Attwood imaged the partial eclipse across Lake Ontario from Coronation Park in Oakville, Ontario, using a Canon 60D at ISO 800 at 1/800 of a second on a Questar 3.5″. (below)

AAVSO

Your Monthly Guide to Variable Stars

by Jim Fox, AAVSO

Editor's Note: This is a new column we will be publishing together with the American Association of Variable Star Observers that will highlight variable stars for each month.

August – R Aquilae

Many, if not most, of the stars we see change brightness over various periods of time for various reasons. Sometimes a star can dim, brighten, and dim again in less than a second! Other stars can take years to complete a cycle of brightness variation.

These stars are called "variable stars." One variable that you can see this month is R Aquilae. Located just off the trailing edge of the western wing of Aquila the eagle, it is about 5 degrees due south of Zeta Aquilae that marks the wing tip. R Aquilae is a red giant star. It has about the same mass as our Sun, but it has expanded as it aged. If it were located at the place of our Sun, Earth would be orbiting just inside its outer atmosphere!

At its brightest, R Aquilae is visible to the naked eye as a dim, red star at magnitude 5. When it dims to magnitude 12, it would be just visible in binoculars. Its period from one dimming to the next is about 270 days. Oddly, this period has been decreasing at an average rate of 0.4 days per year since first determined in 1915. The reason for this decrease is not understood at this time (see chart overleaf).

For more than 100 years, the American Association of Variable Star Observers (AAVSO) has encouraged the observation and study of variable stars, maintaining databases of all submitted observations. Observing techniques include both visual and photometric (CCD/CMOS, DSLR and photoelectric) and now even spectroscopic. For more information on AAVSO and how you can contribute to astronomical science through variable stars, visit their website at www.aavso.org.

The October 2021 *Journal* deadline for submissions is 2021 August 1.

See the published schedule at

rasc.ca/sites/default/files/jrascschedule2021.pdf

September – Delta Cephei

One variable that you can see at night is Delta Cephei, normally the fourth brightest star in the constellation Cepheus, The King. Delta Cephei is the prototype of a whole class of variable stars known as "Cepheids."

Astronomer John Goodricke first noted the variability of Delta Cephei in 1784. In 1912, Henrietta Swan Leavitt studied Cepheid variables at Harvard College Observatory. These stars vary in brightness with a regular period and Leavitt discovered that the period of variation of individual Cepheids is related to the intrinsic brightness of the star. Knowing that light dims according to an inverse square law with distance from the source, measuring the apparent brightness and period of variation of a Cepheid lets us determine the star's distance. In 1914, Harlow Shapley showed that Cepheids pulsate, alternately expanding and contracting in size. The star dims as it expands and brightens as it contracts.

By measuring the periods of a dozen Cepheid variables in the Andromeda Nebula, M31, in 1933, Edwin Hubble determined that it was 2 million light-years distant and that the so-called "nebula" was another galaxy outside our own Milky Way! Cepheid variables have become one of several "standard candles" allowing us to determine vast distances in the Universe.

Delta Cephei is much closer, being only 865 light-years from us within the Milky Way. It varies from magnitude 3.5 to magnitude 4.4 once every 5.4 days. You can watch it go through its cyclic dimming by comparing it to the nearby stars Zeta Cephei (magnitude 3.4) and Epsilon Cephei (magnitude 4.2).

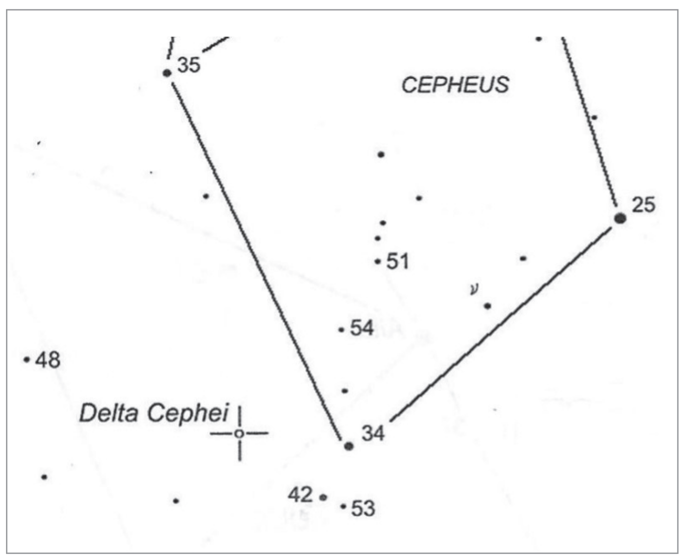

Figure 1 — This finder chart for Delta Cephei will help you estimate its brightness. The image is not inverted so it is suitable for binoculars. Delta Cephei is the highlighted circle and magnitudes are in tenths with the decimal point omitted so as not to be confused with a star – so, 42 = 4.2. Chart is courtesy of AAVSO.

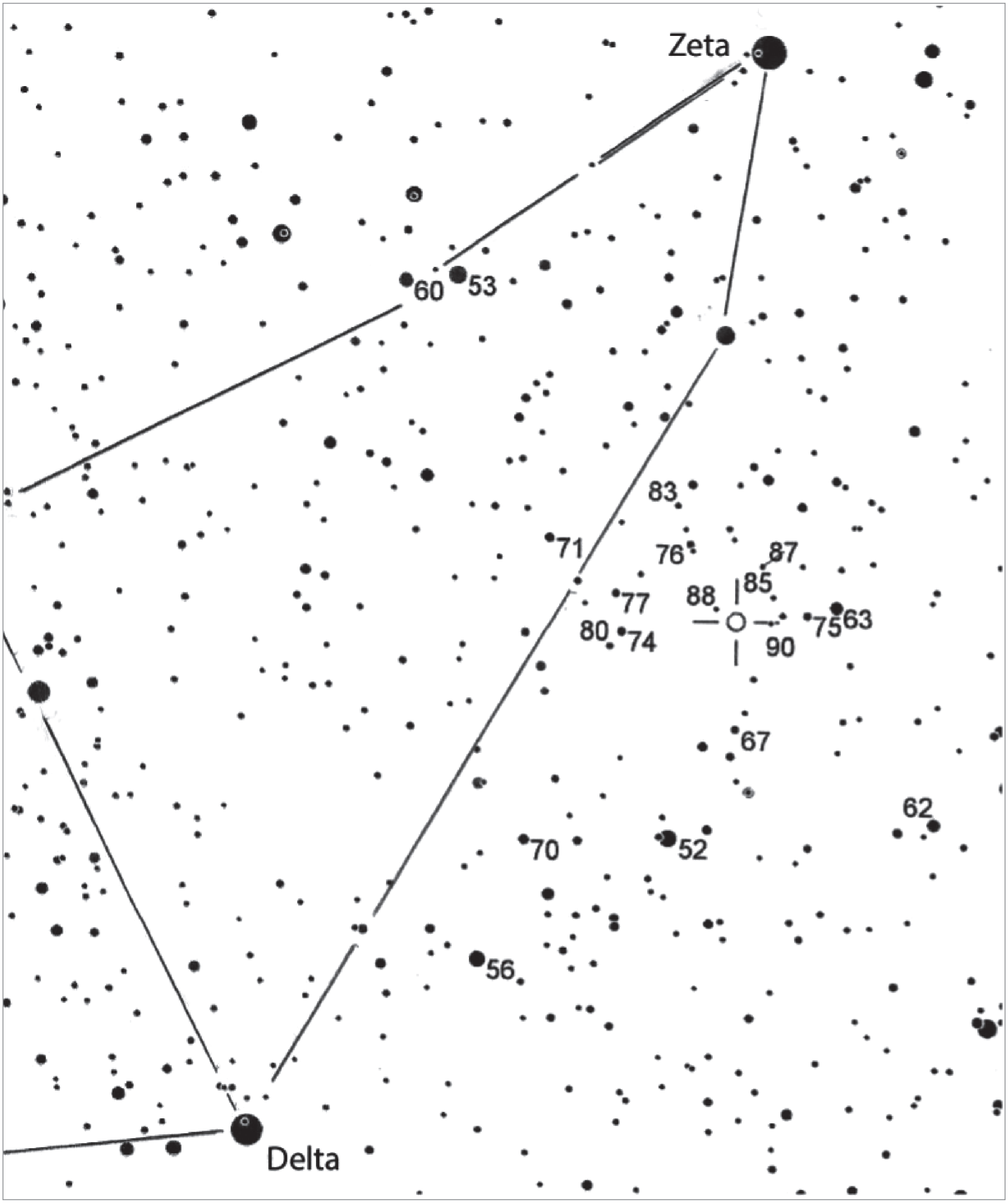

Figure 2 — This finder chart for R Aquilae will help you estimate its brightness. The image is not inverted so it is suitable for binoculars. R Aquilae is the highlighted circle and magnitudes are in tenths with the decimal point omitted so as not to be confused with a star – so, 52 = 5.2. Chart is courtesy of AAVSO.

Skyward

Faint Fuzzies and Gravity

by David Levy

Recently, a comet named Palomar (known as C/2020 T2 Palomar) was gliding near one of the most beautiful clusters of stars in the entire sky, Messier 3. It was parading about at nearly magnitude 11, which means that for my oldish eyes, it would be too faint to see. In fact, just before that, I had spotted a second comet named ATLAS. That comet, at ninth magnitude, was so diffuse that I barely spotted it. So, there was no way I was going to try for this Palomar.

However, it *was* named Palomar, after one of my favorite observatories. The mighty 200-inch telescope was opened in 1948, just a couple of weeks before I was born, and the big telescope has been sighting stars for more than 70 years. In 1994, I was allowed to sit in the prime focus cage, that beautiful place where light from what the telescope is seeing comes to a perfect focus. So, sighting a comet with that hallowed name would be special. The comet was discovered by Dmitry A. Duev from images taken using Palomar's Oschin Schmidt telescope last October. As the comet was brightening slowly, I learned that on Friday evening, May 14, the comet was planning to glide past Messier 3, one of the brightest globular star clusters in the sky.

That was just too much to resist. Clusters of stars are scattered all over the sky, and our own galaxy has more than 100 of them. Globular clusters consist of hundreds of thousands of stars. Messier 3 was discovered by Charles Messier, the famous Parisian discoverer of comets. It consists of roughly half a million stars and is more than 32,000 light-years away. At about 11.4 billion years old, it is also one of the oldest things in the Universe.

With the onset of darkness that Friday evening, I set up my telescope in my backyard observatory and pointed it toward Messier 3. The exquisite star cluster made its appearance. Then I nudged the telescope just a little bit to a nearby field of stars. Suddenly I spotted a faint fuzzy spot precisely where Comet Palomar was supposed to be. As I looked around, a meteor scratched the sky to the north. It was a bright and unusual member of the May Ophiuchid meteor shower, a bonus on this unforgettable night.

Comet Palomar is the 219th comet I have seen during my lifetime. Most of these comets have also been faint, barely visible spots of haze. But some have been wondrous. My first comet, Ikeya-Seki, was the great comet of 1965. Whether a comet is a faint fuzzy or a magnificent comet with a long tail, they are always welcome visitors to the Earth's region of the

Figure 1 — The dome for the 18-inch telescope, which Gene and Carolyn Shoemaker and the author used to discover all of the Shoemaker-Levy comets, including the one that collided with Jupiter in 1994.

Solar System, each one signing, as comet-finder Leslie Peltier loved to write, "its sweeping flourish in the guest book of the Sun."

"Nature had spoken to him"

(with Roy L. Bishop)

Gravity is one of the most fundamental things in physics. Everything and everyone has gravity. The more massive something is, the more gravity it has. When you jump into the air, Earth's gravity brings you back down. What you cannot see while you are in the air is that your gravity brings Earth towards you just a wee little bit, offsetting the extra push away from you that your feet gave Earth when you jumped.

Isaac Newton presented the first mathematical description of gravity in 1687. I admit that I know nothing about gravity, except that it is all around me. I do recall the myth that Newton was sitting under a tree when an apple fell on his head. Supposedly, he then formulated his law of gravity. Did the apple actually fall on his head? I doubt it. But at his childhood home in the village of Woolsthorpe, England, he probably did witness an apple fall from a tree.

During the last half of the 19th century, physicists realized that Newton's theory of gravity did not accurately describe the orbit of Mercury, the planet closest to the Sun. Mercury's elongated orbit precesses slightly faster than Newton's theory predicts. Several unsuccessful attempts were made to account for this discrepancy.

Figure 2 — Sir Isaac Newton's childhood home, taken by Roy Bishop. He had just visited it and was driving through a rain shower when he noticed the sky clearing. He rushed back in time to capture the house framed by a double rainbow. Credit: Roy Bishop

Newton's theory, which assumes that gravity is a force, held sway for more than two centuries, until superseded by Albert Einstein's general theory of relativity in 1915. A decade earlier, Einstein realized that mass and energy are two aspects of one thing, and that space and time are interrelated, a blended spacetime. With general relativity, Einstein treated gravity not as a force, but as the geometry of spacetime. The geometry of spacetime is curved by the mass-energy of matter, and the curvature instructs matter how to move.

Now comes the hard part. When Roy Bishop, emeritus professor of physics at Acadia University, pointed out to me that gravitation is geometry, and not a force at all, I didn't believe him at first. But Dr. Bishop is the most brilliant person I have ever had the privilege of knowing. Recently he described gravity this way, and he is right:

Einstein spent several years in an eventual successful attempt to include gravity in a modified description of spacetime. Early in his progress toward that goal, Einstein had what he called the happiest thought of his life—that if a person were to fall off the roof of a house, while falling she would not feel a force of gravity. Before she falls, she feels the force of the roof supporting her. When her fall comes to its abrupt halt, she feels the ground pushing against her. If she cannot feel a force of gravity while she is falling, why pretend that she felt a force of gravity when the roof supported her before she fell, or that she feels a force of gravity when she is lying on the ground?

When thinking about the falling lady, Einstein had the fantastic insight that perhaps gravity never was a force. By late in 1915, he had that insight in elegant mathematical form such that the resulting theory, general relativity, can be used to make precise predictions concerning gravitation.

Einstein was elated when, on 1915 November 18, he found that his general theory of relativity predicted the measured precession of Mercury's orbit. According to his friend and biographer Abraham Pais: "This discovery was, I believe, by far the strongest emotional experience in Einstein's scientific life, perhaps in all his life."

Pais then continues with five words that crystallize that profound experience: "Nature had spoken to him." After several years of work, on that day Einstein knew that he was the only person on Earth who understood gravity.

Today, there are thousands of people who understand gravity. Roy is one of them. Most of us, including me, are not one of them. But reading it described so well is one of the pleasures we can feel as we try to appreciate the wonderful cosmos in which we live. Not only does general relativity correctly predict the precession of Mercury's orbit, but it is essential to the programs used in the GPS navigation systems we rely on almost every day, and it describes the gravitational waves (ripples in the geometry of spacetime) generated by two coalescing black holes, directly detected by the Laser Interferometer Gravitational-Wave Observatory (LIGO) 100 years after Einstein's general theory of relativity. ✶

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 the 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.*

Astronomical Art & Artifact

Exploring the History of Colonialism and Astronomy in Canada II: The Cases of the Slave-Owning Astronomer and the Black Astronomer Knighted by Queen Victoria

by R.A. Rosenfeld, FRASC
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Abstract

This contribution continues the exploration of the history of colonialism and astronomy in Canada begun in an earlier paper (Rosenfeld 2021). Several cases are offered here, one examining the relationship to slavery of a major figure in "Canadian" practical astronomy of the Enlightenment, J.F.W. DesBarres (1721–1824), the second presenting the astronomical interests of a Black Canadian knighted by Queen Victoria, Sir James Douglas (1803–1877). These cases are not what we might imagine them to be, and they illustrate why simplistic, unambiguous judgements are often inadequate to describe the complexity of actual situations.

On Reading Challenging Material

Some attributes of past astronomical practice, such as the decorative features of 17th-century star charts, or allegorical frontispieces to 18th-century expedition reports, may appear at first sight to be mere decoration, offering little to unsettle the casual glance of the modern viewer unfamiliar with their idiom (yet even "decoration" is rarely unweighted, and empty of meaning; Figure 1). Other aspects of the past may be difficult and unsettling from the start, such as the role of astronomy in colonialism. Elements of the material may be challenging, the questions raised uncomfortable, and closure in regard to the issues confronted seems always to lie just beyond reach. The instances drawn from the history of colonialism and astronomy presented here, following on from the earlier treatment (Rosenfeld 2021), *are* difficult; an 18th-century astronomer working on the east coast who was a slave owner, and a black Canadian astronomer knighted by Queen Victoria who had a distinct preference for colonial power over democratic representation. So far, the question of the involvement of Black

Figure 1 — Jean Chappe d'Auteroche, Voyage en Sibérie fait par ordre du roi en 1761... *(Paris: Debure père, 1768), frontispiece. Reproduced courtesy of the Specula astronomica minima. This image is decoration, but it is decoration with a message. This scene is reminiscent of something from a baroque opera! 18th-century power is arrayed before us in the cultural trappings of Greco-Roman culture. The centre of attention is the ruler by divine right, the source of the cultural program's direction and patronage. Scientific instruments—telescope, globe, dividers, protractor, and map—are in the hands of putti, the western "European" figures, all deities of one sort or another—Louis XV, Mars, Urania, personifications of the graphic, sculptural, and literary arts—are dominant either through size, placement, or both. "Native" figures are smaller, of lesser prominence, and are placed in the background, with their attention riveted on the main actors. It would be tempting to take the diminutive "dark" figure placed in relative shadow, the single one facing away from the light, the science, and the representatives of high-status culture & power, as the black "other," perhaps symbolizing the colonized, outside the realm of science, except as a subject of scientific inquiry. It is, in fact, a monochrome image of a Kalmyk Buddhist religious figure in red-brass. It is functioning here as a colonial trophy, tamed and of negligible cultural power in the presence of "enlightened" culture. It has shrunk to an object of collection, and study.*

astronomers has been missing from the published histories of colonial astronomy in Canada. They belong in the narrative of astronomy in Canada, for without their stories any account of the making of that science is incomplete—and unscientific. How we deal with the uncomfortable questions they raise is important for our ongoing conversation about the present state, and future evolution of the astronomical community in Canada. These are narratives about the past that reach into the present. They resist being confined to the page where they are read; they are still alive, and we all have a stake in their outcome. And it is reasonable to expect that there are more stories than the two explored here.

In facing our astronomical past there are some limitations, responsibilities and obligations, reasonable expectations, and matters of balance that must be acknowledged.

In working through our astronomical past we have to recognize the incompleteness of our information. There is much we cannot know with certainty, because a sufficient evidential basis has simply not survived. This is particularly the case for personal archives, and the motives for actions they might reveal. Whatever the state of the evidence, we have a moral responsibility to respect the people whose pasts we hold in our hands, however imperfectly.

How can we recover the stories of the people missing from the standard narrative of our astronomy? They may have been assistants to astronomers prominent in our narrative, but, being of a lower class, they barely appear by name. Some may have possessed astronomical knowledge in the context of their communities, but, the communities having been deemed marginal, or not even acknowledged, they remain absent from our standard narratives. While there is some hope of recovering those people, there are others who may have been drawn to astronomical pursuits, and possessed real ability, but the difficult circumstances of their lives may have materially prevented them from ever pursuing that calling, particularly if the cultures that nourished them were disrupted. A slave with an affinity for numbers—and there must have been some—who could have excelled as a computer reducing observations, compiling tables, or determining orbits, would not in the normal course of things have been free to follow such an inclination, to say nothing of having access to even the bare minimum of resources for exploring astronomy. We must, however, never paint them as people lacking agency, whatever the harshness of their circumstances. And we must retain hope that such people may be recoverable from our colonial archives. Unexpectedly informative documents do surface now and again.

The past is not the present, and we should guard against making it in our own image. Among past astronomers we should not expect to find either angels or devils, heroes or zeros, worthy only of praise or condemnation, fit for placement on pedestals or fit to be toppled from them. People are not by and large absolutely consistent in their views, strictly comprehensible through their actions, or fully portrayed through unnuanced representations. Jérôme Lalande (1732–1807), a committed atheist, risked his life to save priests from the guillotine, and Charles Darwin (1809–1882), a committed abolitionist, by the time he came to write *The Descent of Man* seemed to espouse views that we more readily associate with modern-day Republicans in the deep south of the United States (Dumont 2007, 190; Beasley 2010, 97–111—Darwin is perhaps just saved by his ambiguity of expression). Philipp Fauth (1867–1941), perhaps the greatest of the amateur visual selenographers, author of an outstanding visual guide to the Moon (*Unser Mond* 1936), whose hand-drawn observationally based lunar maps remain unexcelled in that genre, was a deeply unpleasant person. Additionally, he played a large part in effectively propagating the bogus-science *Welteislehre* theory beloved of the Nazis, and he had the distinction of the title of "professor" conferred on him in 1939 by the Führer's government (Dupont 1941, 435; Ashbrook 1984, 265–271; Whitaker 1999, 165–168; Sheehan & Dobbins 2001, 263–293). Yet his lunar guide and atlas retain their value for visual observers. And in the professional realm good, even great science can be done by those whose characters we find totally reprehensible. Pascual Jordan (1902–1980) was in the front rank of mathematical physicists working on quantum mechanics, with many lasting scientific contributions to his credit. He was also an active member of the Nazi Party (Hentschel 2007, 47–48). Did Jordan's social and political views and actions affect the quality of his science? No. Do they affect one's view of the quality of the man? Yes. These are aspects of the same person. We may not like it, but bad people can do good science. Our preferences won't change this.

Can the past be reconciled to the present, and what exactly does that mean?

The Slave-Owning Astronomer

Joseph Frederick Wallet (J.F.W.) DesBarres (1721–1824; Figure 2) was a significant figure in the long 18th-century history of what was not yet Canada. He had a fascinating and complex personality, was prodigiously skilled and dogged, and arguably produced the single greatest monument of practical Enlightenment astronomy with a significant "Canadian" connection, *The Atlantic Neptune* (published 1774–1782).[1] DesBarres's genius for cartographic design embodied in the *Neptune*'s charts still has the capacity to amaze, and delight.

DesBarres received the foundations of his training as a mathematical practitioner from Jean (1667–1748) and Daniel Bernoulli (1700–1782), having matriculated at the University of Basle in 1750 (Evans 1965, 1; Hornsby 2011, 23).[2] He later attended the Royal Military Academy at Woolwich, leading to a long career as a British military officer excelling in the surveying branch of engineering. There are several very good studies of aspects of his administrative and scientific careers, including Evans (1968) chiefly on the former, Hornsby (2011) on his cartographic achievements, and Bishop (1977; 2012) on his astronomy, with a particular focus on DesBarres's observatory, one of the earliest and best equipped in the colonies at that time.

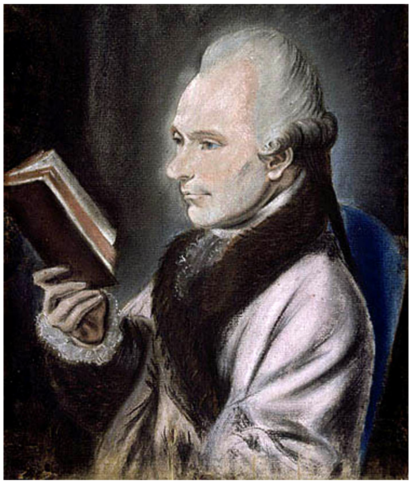

Figure 2 — Portrait of J.F.W. DesBarres (1721–1824), by James Peachey (?–1797), ca. 1785. Ottawa, Library and Archives Canada (www.bac-lac.gc.ca/eng/CollectionSearch/Pages/record.aspx?app=fonandcol&IdNumber=3636269&new=-8585785012679775165).

According to records from 1767–1783, the equipment of DesBarres's observatory comprised at its height a "Large Brass Astronomical Quadrant of the Compleatest Sort," "a Large Reflecting Telescope w[i]th. Some Equatorial Parts" by the Dollond firm, a "3 1/2 ft. Achromatic Telescope with Triple Object Glass," a Hadley's "quadrant" (this last was probably an octant), a "Mahogony Sextant with Ivory Arch & Adjusting Screw to the Nonius with Tellescope & 3 dark Glasses in Wainscott Box...", a "p[ai]r 17[-inch] Globes," "a Plain Table very large with Brass frame Rising Plates to Receive the Paper a Vertical Arch and Telescope on a Large Parrallel Ruler & Half with Parallel Plates," a "…Clock," compasses and tools for their maintenance, and some meteorological instruments, not to mention a truly impressive supply of drawing and writing tools for recording observations, and turning them into charts.[3] In 1767 he procured for his astronomical library "Cassinis Elements of Astronomy...De La Cailles Ephemerides...Maupertuis Degree du Meridian...Ulloa Voyage De la Merique...," followed in 1769 by "...a Nautical Almanac... Mayers Astron[omica]l Tables..." (Bishop 1977, 434).[4] He even had an "Instrument Maker from the 1st May 1766 to the 31 Dec[embe]r 1773" in his employ.[5] This was serious gear for the serious pursuit of science.

And for about eight years (1764–1772) DesBarres and his men did precisely that, spending the inshore sailing season (roughly May to October) on surveying expeditions of the coastline of Nova Scotia and Sable Island with a staff of junior naval officers and some Acadian assistants, and the winter at Castle Frederick reducing the observations to cartographic form (Bishop 1977, 428). The *Atlantic Neptune* also incorporated the survey work of others, such as Samuel Holland, the Surveyor General for North America, another very skilled and well-equipped mathematical practitioner. Based in London from late 1783, it took DesBarres and those working under him the better part of a decade to complete the engraving and publishing of the *Neptune* (in its various iterations). And, in fulfilling the goals of practical astronomy, DesBarres and his coworkers ended up producing spectacular examples of cartographic design. Readers are encouraged to experience the art for themselves, either in the reproductions in Hornsby (2011), or online (www.loc.gov/item/75332506/).

The Navy personnel and Acadian assistants weren't the only people "on staff" at Castle Frederick, however. The DesBarres *familia* also included several slaves, and here is where the story becomes interesting, and perhaps not quite what we expect it to be.

Slavery was a social factor in Falmouth in the late 18th and early 19th centuries. And the available documentation from which to reconstruct the lives of the unfree is more often than not wholly inadequate to the task, as follows from their social status.[6] The fullest secondary discussion of the unfree in the DesBarres household is David W. States's thesis done at Saint Mary's in 2002.

States (39–40) cites the rather unreliable W.C. Milner (1930), for information about one family slave: "Col. DesBarres left three daughters...They had a slave, "Old Andy", who after the emancipation of slaves continued to live with the DesBarres ladies until their death. He was a character and a lot of traditions were repeated about him" (130)—a fine example of an unreflectively offensive early 20th-century style of expression. Milner cites no sources, but it is clear from other matter he quotes that he enjoyed some access to the family's papers, and therefore to the descendants of DesBarres's daughters.

More valuable is a citation of a contemporary document about Cato Smith:

> Another DesBarres slave's brief obituary appeared in the *Novascotian* newspaper in 1838 [April 12, p. 114, col. 4]:
>
> Death at Castle Frederick, on 8th Feb. Cato Smith, aged 81 years. He was with Governor DesBarres when he surveyed the coast of B.N.A. [=British North America] and remained with the family ever since—by whom he will be long remembered for his good qualities, and his death much regretted (States 2002, 40).

That both men, Andy and Cato Smith, elected to stay with the DesBarres after emancipation (Slavery Abolition Act 1833 [3 & 4 Will. IV c. 73]), could be a sign that they had been treated decently when unfree, and through mutual agreement with the DesBarres had remained members of the household, or it could indicate that emancipation had come too late for them to acquire either the material or the intellectual means to break with the pattern of dependence to which they had been subject. The sources are not full enough to resolve this question.

Other aspects of the 1838 notice, however, allow us to speculate in a positive way about the relationship of Cato Smith with the DesBarres family. Even the placement of a brief obituary in a newspaper cost effort, and possibly some money in the 1830s. It would not be worth the expenditure of either to commemorate someone who was considered just a piece of property. The presumption is that it is a sincere public expression of bereavement by the DesBarres for someone they valued as a person, and someone who had a place in the community the newspaper served.

Even more potentially significant is the statement that Cato Smith "…was with Governor DesBarres when he surveyed the coast of B.N.A." Unlike his colleague Samuel Holland, DesBarres did not receive any adequate advances for expenses in connection with his survey work from his employer, the Admiralty. He had to provision his crew and equip much of the survey out of his own resources, and he did not have a reputation for extravagance. He would only have taken staff who would be of use on a survey. Because he was unfree, Smith would not have drawn a wage, but he'd still have cost DesBarres for his upkeep. The only reasonable inference to be drawn is that Cato Smith aided the work of the survey—he was part of the crew. Even if his duties were mostly haulage, or setting up and taking down camp, or cooking, he was still performing tasks vital to the work of the survey, for without that labour the science could not have been done or done as efficiently. In modern terms, he was a co-worker on DesBarres's scientific expeditions. He may, however, have done much more. If he possessed the aptitude, DesBarres could have trained him as a technical assistant to aid directly in the scientific part of the survey work. He may even have had natural gifts as a mathematician, like Benjamin Banneker (Bedini 1999). It would have been a shrewd use of resources on DesBarres's part, for once trained, Smith could not of his own accord seek employment elsewhere, being unfree.

We don't know how many slaves DesBarres had, or how he acquired them. There may have been many working on the DesBarres properties, who had been directly purchased, or there may only have been a few, who were not acquired directly, but came with various of the lands DesBarres had amassed. Given the evidence as poor as it is, I incline to the latter view.

And it should be said that the matter of slavery was contested in late 18th-century Nova Scotia, compete with pamphlet wars. DesBarres always had the option of not being a slave owner, even if he had not directly purchased the unfree members of his household. He could have given Cato Smith his freedom from the start of their relationship and paid him a wage for his work.

It is necessary to again state that this is all speculation, given the meagre sources. One can only hope better documentation on Cato Smith and his relationship with DesBarres emerges. Until it does, Smith remains a candidate for the distinction of being the first unfree black person who had a hand in the making of professional astronomy in "Canada." And that is an intriguing possibility.

Figure 3 — Sir James Douglas (1803–1877), Governor of British Columbia, by Stephen Allen Spencer (ca.1829–1911), ca. 1876. British Columbia Archives Catalogue Number: HP002657 As. Number: 193501-001, Wikimedia Commons (commons.wikimedia.org/wiki/File:Sir_James_Douglas-1876.jpg).

The Black Astronomer Knighted by Queen Victoria

Sir James Douglas (1803–1877; Figure 3) is a figure best known to those on the West Coast as the second Governor of Vancouver Island (1851–1864) and the first Governor of British Columbia (1858–1864; Ormsby 1972; Adams 2011; Perry 2015). And who can resist mentioning that he was the sometime political opponent of the exotically named and bracingly unstable liberal reformer and second premier of the province, Amor De Cosmos (1825–1897, originally one William Alexander Smith, from Windsor near DesBarres's Castle Frederick estate). What is less well known is that Douglas would now be considered an amateur astronomer, who also did a bit of "professional" work in practical astronomy. And he would now be considered black, and his spouse, Amelia Lady Douglas, was Metis, with a strong commitment to her Cree ancestry.

Douglas was probably born in Demerara, now part of Guyana, to John Douglas, a member of a prominent Glaswegian trading family, and Martha Ann Telfer, a free black woman. Both Douglas's mother and grandmother, Rebecca Ritchie, could own property outright in their own names due to their status as free black women in island society; legally they were better off in that regard than many European women at the time (Perry 2015, 62–63). Among their assets were a considerable number of slaves (!; Perry 2015, 60), which they occasionally traded, and at the time of emancipation Douglas's grandmother did very well financially from the British Government's compensation plan for former slave owners (Perry 2015, 62). Douglas's mother was also a brothel owner (Adams 2011, 51). An ocean away, and probably at a time when he exercised some authority (or could foresee himself doing so), Douglas wrote a set of manageable moral goals seemingly directed to himself, among which occurs: "Remember...Abolition of slavery within our limits..." (Douglas MS 1112, 24). He seems to have been true to his word.

Douglas's father arranged for him to receive a good basic education in Scotland (although he did not attend university), and in 1819 when he was 15 (some sources give 16), he re-crossed the Atlantic to become an apprentice clerk to the North West Company (NWC) of fur traders based in Montréal (Adams 2011, 10). At around the time of the merger of the NWC and the Hudson's Bay Company (HBC) in 1821, Douglas was a clerk of the second class, and a year later he had impressed his employers sufficiently to be left in charge of trading posts and sent out to establish others; by 1830 he was second in command at Fort Vancouver. In 1834 (or 1835 depending on the source), he rose to the rank of Chief Trader, and in 1839 (or 1840) to that of Chief Factor (Adams 2011, 37; 55–56).

Douglas proved remarkably competent and able in the work of the fur trade—as one modern commentator has noted "...often contemporaries described Douglas as hyper-competent..." (Perry 2015, 202). He seems to have had a lifelong eye for detail, and much energy to pursue it.

George Simpson (ca. 1792–1860, after 1840 "Sir"), Governor of the HBC, referred to Douglas in a character sketch as a "Scotch West Indian," others in the 1830s and 1840s could refer to him as "a native of the West Indies," or "a *mulatto* son of *the* renowned M^r^ Douglass of Glas[g]^ow^," or as a young and intelligent "Scotchman" (Perry 2015, 122; Adams 2011, 121). Douglas, while never denying his origins lay partially in a Black West Indian heritage, preferred to identify himself as Scottish. There was clearly a certain fluency and flexibility to "racial" assignment in the period, and class doubtless played a role here; the higher one's status, the more flexibility one enjoyed in selecting or editing one's origins. Naturally, it was impossible to really control others' perceptions of one's origins. And social flexibility in "race" assignment appears to have decreased as Victoria's reign lengthened, a trend of which Douglas was aware (Perry 2015, 222–223).

Douglas the "Scotsman," hyphenated or not, can be seen as an heir of aspects of the Scottish Enlightenment. Throughout his life he was continually engaged in efforts at betterment through self-education, as his surviving note and clipping books attest (these were personal compilations, at the extenuated end of the "commonplace" book tradition).[7] It is in his notebooks that we come closest to Douglas the amateur astronomer. Before turning to his manuscript materials the scene can be set by glancing at other kinds of evidence.

Books were important to Douglas: "Reading was one of Douglas's lifelong pursuits...His eclectic tastes were reflected in the titles of 34 books he ordered in 1854 and 1857, which included...The Practical Astronomer..." (Adams 2011, 115). This book was undoubtedly one of the early editions of Thomas Dick's (1774–1857) popular *The Practical Astronomer* (1845; 1850; 1854; or 1857; Figure 4). One use he made of the learning he acquired is evocatively recalled in an anecdote:

> As Douglas aged and rose up the ranks, he shared the specific knowledge and general culture he gained from books. Helmcken remembered him sitting at the head of a table of more than twenty men and saying grace. After the meal he toasted "the Queen" and the junior officers left the table. The senior men then smoked and Douglas led them in a closely regulated conversation. "I was informed that no frivolous conversation was ever allowed at table," recalled Douglas's son-in-law, "but that Mr. Douglas as a rule came primed with some intellectual or scientific subject, and thus he educated his clerks" (Perry 2015, 127–128).

It is a fair assumption that astronomy was among the "intellectual or scientific subject" matter of Douglas's after dinner fur-trade seminars.

After his retirement from office, and the bestowal of the rank of Knight Commander of the Order of the Bath (KCB) in 1863 (this was for his governmental and HBC service, and not for his astronomy), Sir James Douglas undertook a Grand Tour of Europe 1864–1865. While in England he attended meetings of the British Association for the Advancement of Science (BAAS), remarking that "No one can be more sensible than I am of the benefits to be derived from the extension of Science" (Perry 2015, 206).

What then, do the notebooks reveal? In one, we find an article on the Leonid meteor shower of 1837 (Douglas was rarely in the habit of noting the source of the articles he excerpted), a loose-leaf insert of scientific definitions in Douglas's own hand, and also in Douglas's hand another loose-leaf insert of "Magnetic Variations [at] Fort Vancouver" (Douglas MS–0678 Box 2 File 1, 38; 64–65; 70–71). A companion notebook contains an article giving brief biographical notes on mathematical practitioners (astronomers), an article on meteorites, and two manuscript pages of "Meteorological Observations" (an observatory science in the 19th century) in Douglas's hand (Douglas MS–0678 Box 2 File 2, 33; 38–39; 60–61). The third notebook has two pages titled "Astronomy" in Douglas's hand, the first with a drawing of the Solar System, and below it a drawing of the Earth's yearly course around the Sun in illustration of the seasons (both are finely and beautifully drawn), and the second with a table giving numerical data on the planets then known, out to the *Georgium sidus* (=Uranus), and including the first four asteroids Piazzi(=Ceres), Pallas, Juno, and Vesta (Douglas MS–0678 Box 2 File 3, 29–30). Douglas's planetary table predates 1845–1846, when the fifth asteroid Astraea was discovered, and the planet Neptune.

Finally, although we would now call Douglas an amateur astronomer, he did do some professional work in practical astronomy. In Richard Ruggles's valuable work on the maps done under the auspices of the HBC, Douglas is included in the category of "Persons Who Prepared Hudson's Bay Company Maps or Charts, 1670–1870" (Ruggles 1991,

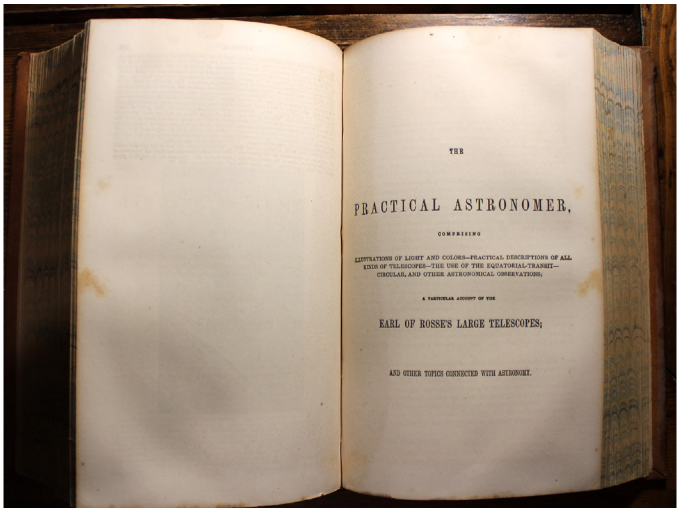

Figure 4 — Title page of Thomas Dick's The Practical Astronomer*, this edition from* The Complete Works of Thomas Dick, LL.D...*, vol. 2 (Cincinnati: Applegate & Co., 1853). Reproduced courtesy of the Specula astronomica minima.*

264–265). Surviving in the HBC Archives is "A Ground Plan of Portion of Vancouver Island Selected for New Establishment taken by James Douglas Esqr. 1842 James Douglas and Adolphus Lee Lewes [HBCA] G2/25" (Ruggles 1991, 213, and pl. 50). Unfortunately, we don't know the division of labour between Douglas and Lee in the making of the map but given Douglas's considerable graphic skills evidenced in his notebook of astronomical diagrams, and his interest in the discipline, it is quite conceivable that he performed more than a supervisory role in the production of the map. It should also be mentioned that, as Chief Trader, Chief Factor, and Governor, Douglas was also a patron of practical astronomers, such as Joseph Despard Pemberton, "the best-trained surveyor and cartographer employed by the company over the years of its operations in the north and west of the continent" (Ruggles 1991, 105).

Coming to Terms with the Past

In the earlier paper on astronomy and colonialism in Canada, I wrote that it was only a matter of time before one or more of the major figures in our standard narrative of "Canadian" colonial astronomy will turn out to have been a slave owner (Rosenfeld 2021, 93, & 95 note 3). Little did I suspect that I would find such a figure in the redoubtable J.F.W. DesBarres within a week of seeing those lines in print. Nor did I expect to find a black Canadian astronomer who was a younger contemporary of DesBarres, and who would occupy such a prominent position in the "establishment" of "Canada" as Sir James Douglas. Nor dared I harbour even the slightest hope that a black person of unfree status would emerge as a possible participant in Enlightenment practical astronomy, yet Cato Smith has emerged as a candidate. I have not exhausted the available material; it is not unreasonable to expect that others will complete the social accounts of Col. DesBarres, Cato Smith, and Sir James Douglas doing astronomy, and will discover others from diverse communities to produce a more inclusive narrative of the history of astronomy in Canada, figures of whom we presently know nothing. In some significant senses, the history of astronomy in Canada has yet to be written.

I am interested in DesBarres. I like the fact that he was trained by the Bernoullis, that he had such advanced astronomical equipment in Nova Scotia in the 1760s and 1770s and considered it necessary that he should have the equipment there, and I respect the physical and mental resources he and his coworkers mustered to do astronomy under trying conditions I can only imagine. I stand in awe of the graphic virtuosity of the cartography that resulted from his work, and I find myself inclined to favour someone of whom it was said that "He danced a jig on top of a table to celebrate his hundreth birthday" (Evans 1965, 273). Yet DesBarres was a slave owner, and none of what I continue to respect about him can minimize that or justify ignoring it. However much slavery was a recognized practice in the late Georgian period, there were those who considered it unjust and unjustifiable. At present, too little is known about the quality of DesBarres's slave owning to characterize it. I hope that he did indeed train Cato Smith in practical astronomy, and even manumitted him, and others, but all we now know with certainty is that DesBarres owned slaves. And that undeniable and uncomfortable fact will have to be part of what I say or write about him in the future.

I am delighted that someone we would now consider black, Sir James Douglas, rose to such prominence in the power structures on the West Coast in the 19th century, and that in our terms he was an amateur (and sometimes professional practical) astronomer. He was also a decidedly undemocratic figure in his practice of government. And part of the material wealth he inherited was derived from the profits of the slave trade, even if he was very much against the practice of that trade. Historical figures are as complex as contemporary ones. In telling his story, as in telling DesBarres's, it should not be sanitized.

Can the past be reconciled to the present, and what exactly does that mean? ✶

Acknowledgements

This research has made use of NASA's Astrophysics Data System.

Endnotes

1 The publishing history of the work is complex; according to Hornsby (2011, 176) it may have been as long as three years after the first charts were engraved that DesBarres conceived of the maps as a unified project under the name of *The Atlantic Neptune*.

2 Due to pandemic conditions the author does not have access to the published version (1969) of Evans's thesis, but only to the version he defended at Yale in 1965.

3 Ottawa, Library and Archives Canada, DesBarres Papers, Series 5 (M.G. 23, F1–5, Vol. 6) Accounts, 1767–1794, 1252–1253; DesBarres Papers, Series 5 (M.G. 23, F1–5, Vols. 1–2), Naval Surveys and Atlantic Neptune, 1762–1814, 116–117; DesBarres Papers, Series 5 (M.G. 23, F1–5, Vol. 6) Accounts, 1767–1794, 1189–1190; DesBarres Papers, Series 5 (M.G. 23, F1–5, Vols. 1–2), Naval Surveys and Atlantic Neptune, 1762–1814, 355–356; DesBarres Papers, Series 5 (M.G. 23, F1–5, Vols. 3), Charles Morris and Correspondence Received, 1771–1784, 610–613; Bishop 1977, 433–434. The evidence for the clock has only recently come to light (DesBarres Papers, Series 5 [M.G. 23, F1-5, Vols. 3], Charles Morris and Correspondence Received, 1771–1784, 611), and finally allows Hornsby's question (2011, 114) about its existence to be answered in the affirmative. Unfortunately, the document does not specify the clockmaker. It is striking that the clock appears to have been the only substantial piece of astronomical equipment DesBarres didn't return to the Admiralty for reimbursement in 1783.

4 These books are probably to be identified as Cassini 1740, De Lacaille 1763, Maupertuis 1738, Juan & de Ulloa 1752, Maskelyne 1769, & Mayer 1770(?); DesBarres Papers, Series 5 (M.G. 23, F1-5, Vol. 6) Accounts, 1767-1794, 1252-1253; Bishop 1977, 434.

5 DesBarres Papers, Series 5 (M.G. 23, F1-5, Vols. 1-2), Naval Surveys and Atlantic Neptune, 1762–1814, 350. Where the instrument maker was based, and what he did has yet to be established; nor do we even have his name—yet the Admiralty was content to reimburse DesBarres for the "maintenance" of the instrument maker for seven years(!). If his work was maintaining and repairing DesBarres's scientific instruments from the London trade, and producing the simpler ancillary equipment for surveying that wore out in the course of use (perhaps tripods, cases, sounding leads and lines, and such like), then he would most sensibly have been part of DesBarres's establishment at Castle Frederick.

6 I wish it were otherwise, as I wish slavery were not a social practice there.

7 In their state of organization they resembled the *adversaria*, or "waste book" type of 17th-century notebook—a commonplace book with a low level of organization; Yeo 2014, 16–17.

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CFHT Chronicles

Times They Are A-Changing

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

It's been quite the year and we are seeing changes in Hawaii. As a state, the vaccination roll-out started strong. All CFHT staff who want to be vaccinated have the opportunity. I anticipate our offices reopening by the time you all read this column in August.

I will write more reflections of our past year later, but one benefit of Zoom has been meeting with so many RASC Centres across Canada—*mahalo* for inviting me.

Before diving in, I want to acknowledge the passing of a friend, collaborator and *pwo* (master) navigator, Kālepa Baybayan, who passed away in early April. As navigator in residence at ʻImiloa Astronomy Center, I and many others worked with Kālepa over the years. He taught navigational principles to our Maunakea Scholars students through MANU ʻImiloa and was working with me on a cultural astronomy class we are launching this summer. Kālepa's obituary appeared in *The New York Times*; he's been honoured with beautiful words by so many since his passing. Below is the statement shared on the Maunakea Observatories website in his honour:

"The Maunakea Observatories are deeply saddened by the news of Kālepa Baybayan's death and offer our deepest sympathy to his *ʻohana*. *Pwo* navigator, incomparable educator, mentor and friend, Kālepa inspired us to learn with open hearts and to continue to grow always.

Kālepa possessed incredible strength, a fortitude hardened by decades of leadership and continued exploration. He used that strength to uplift those he cared for, to perpetuate precious knowledge entrusted to him, to weather countless storms and to hold an open space for continued learning, growth and innovation. He sailed countless miles on board Hōkūleʻa, trained countless hours as a navigator, and was a relentlessly passionate teacher taking on the *kuleana* to pass on thousands of years of knowledge to those willing to learn.

Kālepa stood at an uncommon intersection where different ways of understanding can meet and flourish. For anyone with the humility and curiosity to come to him at that intersection, no matter what knowledge system they started from, they had the opportunity to learn and grow. These lessons we learned from Kālepa will continue to shape our approach to inquiry and education of all kinds, but more importantly, the way we must stand to support each other as neighbours, friends, and family here in our island community."

Recruiting a New Director

In mid-April, CFHT's Executive Director Dr. Doug Simons announced his departure from CFHT to lead the University of Hawaiʻi's Institute for Astronomy (IfA) starting 2021 September 1.

"The heart of CFHT is its staff and it's been my privilege to lead them for the past nine years," says Simons. "Their dedication, ingenuity and determination make CFHT a world-class facility, and I have simply tried to provide them with the resources and a framework to help them succeed."

Simons started his tenure as CFHT's Executive Director in May 2012. Over the past decade under Simons' leadership, CFHT launched all of the projects shared in this column—the Maunakea Spectroscopic Explorer project office, the installation of dome vents improving image quality (future column idea!), completed new and challenging large programs and took the delivery of two new

Figure 1 — pwo navigator Kālepa Baybayan talking with students on Lanai.

Figure 2 — Doug Simons, CFHT executive director

Figure 3 — Maunakea Scholars Frame hand crafted by Doug

instruments, SPIRou and SITELLE. Simons oversaw major failures of the dome shutter and hydraulics systems as well as navigated CFHT through the Thirty Meter Telescope protests and COVID-19 pandemic, both of which shuttered CFHT for a time.

"Doug's time at CFHT was marked by unprecedented challenges and successes, but under his leadership, CFHT continued to enable outstanding research, consistently ranking among the most scientifically productive observatories in the world," said Dr. Howard Yee, University of Toronto astronomer and chair of the CFHT Board of Directors. "I look forward to continued collaboration with Doug as he transitions to the Institute for Astronomy, one of CFHT's partner institutions."

During Simons' tenure, CFHT expanded its community engagement efforts, adding the Maunakea Scholars program, the first statewide astronomy outreach initiative, providing observing time on the Maunakea Observatories to Hawaii public high-school students. Simons will continue to work with Maunakea Scholars in his new role as IfA director. IfA supported Maunakea Scholars from day one, providing graduate student mentors for each of the schools. He handcrafts frames for each student receiving telescope time through Maunakea Scholars.

Simons was one of the originators of the EnVision Maunakea program, an effort to create a compelling account of the community's vision for Maunakea. Working with 'Imiloa Astronomy Center, the University of Hawai'i at Hilo's Ka Haka 'Ula O Ke'elikōlani College of Hawaiian Language and community partners, he helped establish the A Hua He Inoa program melding astronomical discoveries with traditional Hawaiian naming practices. While Pōwehi and 'Oumuamua are now well known in the global community, Hawaiian immersion school teachers and students named three other objects: Pōniuā'ena, the most massive quasar in the Universe, which formed only 700 million years after the Big Bang; Kamo'oalewa, an asteroid; and Ka'epaoka'āwela, a companion of Jupiter that orbits near the planet, but in the opposite direction.

As IfA Director, Simons plans to further strengthen the relationship between IfA and the community. Building on his work with Maunakea Scholars, he will place an emphasis on underrepresented students participating in the University of Hawai'i's extensive astronomy program.

"When I applied to graduate school decades ago, IfA was the only institution that accepted me. At the time, I had no idea moving to Hawai'i would change my life and help me discover my life's work, Hawai'i astronomy," says Simons. "Finishing my career where it began, where I received a fabulous education, brings me full circle and I look forward to helping ensure a continued bright future for IfA."

As of this writing, the CFHT director position is posted on our website. Announcement of an interim director is likely before you read this column, so stay tuned for updates in my next column.

Spectacular "Honeycomb Heart" Revealed in Iconic Stellar Explosion

A unique "heart shape," with wisps of gas filaments showing an intricate honeycomb-like arrangement, has been discovered at the centre of the iconic supernova remnant, the Crab Nebula. Using SITELLE at the CFHT, astronomers mapped the void in unprecedented detail, creating a realistic three-dimensional reconstruction. The new work is published in *Monthly Notices of the Royal Astronomical Society.*

The Crab Nebula, also known as Messier 1, exploded as a dramatic supernova in 1054 CE, and was observed over the subsequent months and years by ancient astronomers

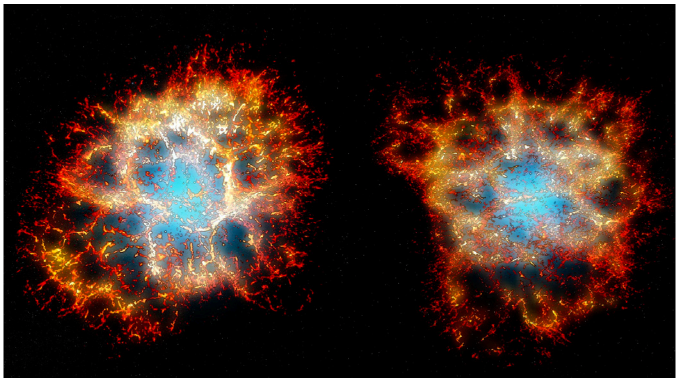

Figure 4 — 3-D reconstruction of the Crab Nebula remnant as seen from Earth (left), and from another point of view showing its heart-shaped morphology (right). Credit: Thomas Martin, Danny Milisavljevic, and Laurent Drissen

across the world. The resulting nebula—the remnant of this enormous explosion—has been studied by amateur and professional astronomers for centuries. However, despite this rich history of investigation, many questions remain about what type of star was originally there and how the original explosion took place.

Thomas Martin, the researcher at Université Laval who led the study, hopes to answer these questions using a new 3-D reconstruction of the nebula.

"Astronomers will now be able to move around and inside the Crab Nebula and study its filaments one by one," he said.

The team used the powerful SITELLE spectrograph at CFHT on Maunakea to compare the 3-D shape of the Crab to two other supernova remnants. Remarkably, they found that all three remnants had ejecta arranged in large-scale rings, suggesting a history of turbulent mixing and radioactive plumes expanding from a collapsed iron core.

Astronomers use computer simulations of supernova explosions to estimate what patterns the ejected materials make as they expand into a supernova remnant. Each possible explosion is associated with a specific pattern or fingerprint. The honeycomb pattern observed by the team resembles the fingerprint caused by the collapse of a heavier iron core. Co-author Dan Milisavljevic, an assistant professor at Purdue University and supernova expert, concludes that the fascinating morphology of the Crab seems to go against the most popular explanation of the original explosion.

"The Crab is often understood as being the result of an electron-capture supernova triggered by the collapse of an oxygen-neon-magnesium core, but the observed honeycomb structure may not be consistent with this scenario," Milisavljevic said. "Future work mapping the Crab's chemical distribution of elements is needed to address this inconsistency."

The new reconstruction was made possible by the groundbreaking technology used by SITELLE, which incorporates a Michelson interferometer design allowing scientists to obtain over 300,000 high-resolution spectra of every single point of the nebula.

"SITELLE was designed with objects like the Crab Nebula in mind; its wide field of view and adaptability make it ideal to study nearby galaxies and even clusters of galaxies at large distances," said co-author Laurent Drissen, co-author on the paper and professor at Université Laval.

Supernova explosions are among the most energetic and influential phenomena in the Universe. Consequently, Milisavljevic adds: "It is vital that we understand the fundamental processes in supernovae which make life possible. SITELLE will play a new and exciting role in this understanding."

The team created a 3-D reconstruction of the Crab Nebula made of 406,472 data points represented as tiny cubes, which can be viewed on our website at: www.cfht.hawaii.edu/en/news/HeartofTheCrab

Each data point shows the positions in space where nebular emission has been detected. The measured velocity of each point has been translated into spatial positions under the assumption of an unaccelerated outward motion of the nebular material. This movie presents the exact data astronomers will be working with. The only artistic inclusion is the blue glowing sphere at the centre, which simulates the continuum emitted by the pulsar wind nebula. The Milky Way background (credit: NASA / Goddard Space Flight Center Scientific Visualization Studio) has been adequately positioned to simulate the typical perspective of someone moving around the nebula. The soundtrack is a sonification of the data set, using interferograms directly as sound waves. Multiple samples played at different rates have been mixed, with the playing speed simulating the Doppler effect and the volume of the samples related to the distance to the nebula.

SITELLE is the result of a joint collaboration between Université Laval, ABB Inc.-Québec, Université de Montréal, and the CFHT, under the scientific leadership of co-author Laurent Drissen. ✶

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

Watch the Planets Wheel Overhead

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

I recently downloaded Skywheel and was pleasantly surprised, finding it to be more than simple eye candy. The uncluttered design belies the true nature of the app: It proves a robust tool with rich data on our home Solar System. It is a wonderful example of less is more.

Revolving Sky

Skywheel shows the planets overhead and what's below the horizon (see Figure 1). The Sun is rendered as a large ochre disk. The pale Moon is sized similarly and shows the appropriate phase. Jupiter sports a spot and Saturn has ears. Even Pluto is plotted with a tiny currant circle.

The whimsical daytime sky reminds me of a three-dimensional decoupage. You might catch yourself staring at it as the display slowly, inexorably turns.

When the Sun falls below the western horizon, the sky colours flip, with indigo overhead (Figure 2) and sky blue below.

I thought that was all there was to it. I was mistaken.

Rich Details

When you tap on a Solar System object, a little Info Bar slides into view with the body name and a Details button. Alternatively, you may tap the mode button at the bottom-right.

The information page appears (Figure 3) where you can learn a great deal about your selected object, including distance, angular size, magnitude, direction, altitude and azimuth values in degrees and minutes, along with an easy compass bearing.

Depending on your preference settings, you might also note the equatorial position and ecliptic measures.

The top of this panel tells you about the Sun and Moon; the bottom outlines your location. The Date and Time section notes all the usual suspects plus Local Sidereal Time, Julian date, and ΔT—the Equation of Time!

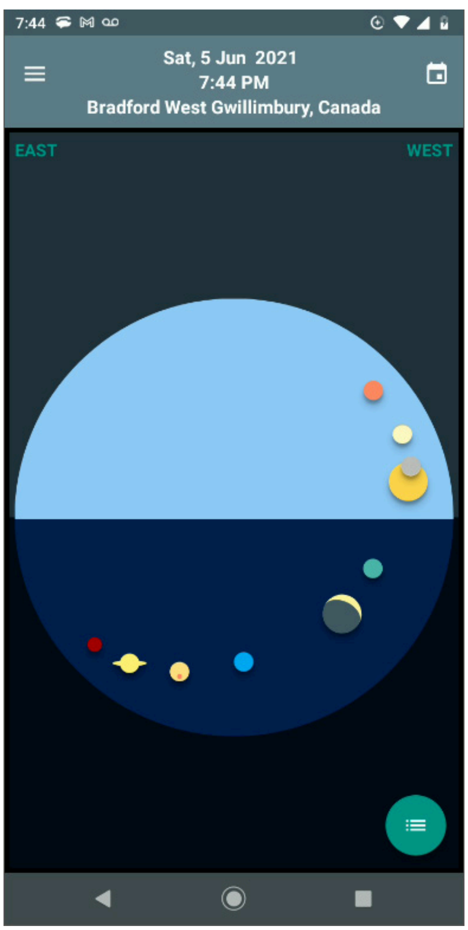

Figure 1 — The main screen of Skywheel showing a bright blue sky just before sunset.

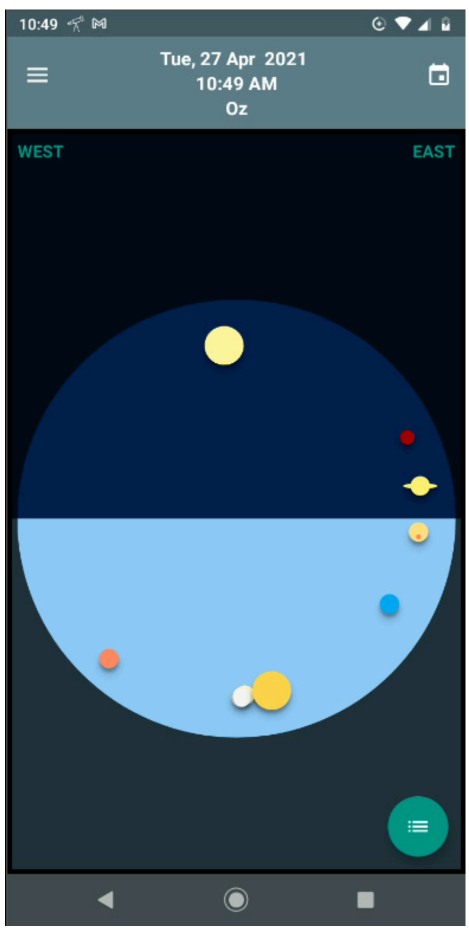

Figure 2 — The main screen for an Australian location, sun overhead, and a full Moon.

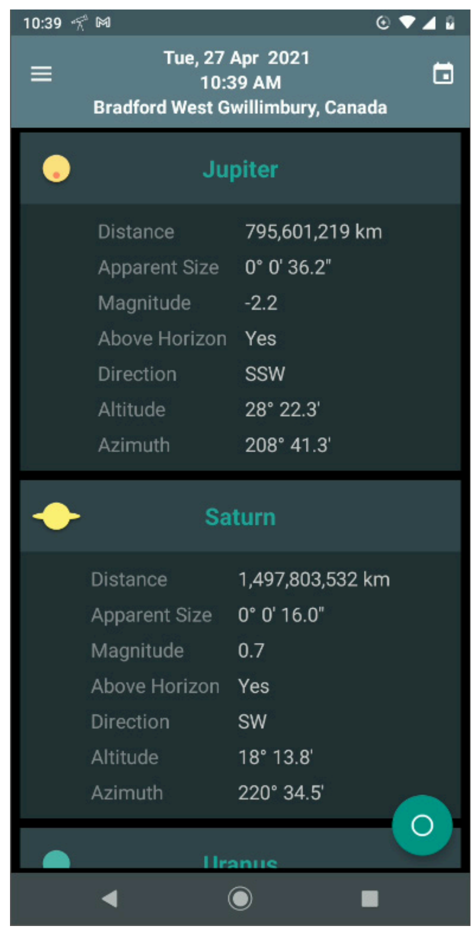

Figure 3 — Detailed information on planets Jupiter and Saturn.

Incredible Calendar

A calendar button shows at the top-right of most screens. Tapping it switches to the Events page (Figure 4), which lists the dates and times for a useful array of phenomena.

Moon rise and set times are noted with the phases. It is satisfying to see the author use proper terms, perigee and apogee.

Planet rise and set times appear along with culmination times! Maximum elongations for Mercury and Venus display. Further into the future, opposition and conjunction dates show making for a very thorough listing.

Sun rise and set times show. Perihelion and aphelion! It is great to see civil, nautical, and astronomical twilight times. Equinoxes and solstices, even eclipses, are listed!

The list goes out to December 2022! This surprising Skywheel feature allows the app to be used for immediate and long-range planning.

Eclipse Circumstances

Lunar and solar eclipse events come with still more information, accessed via the little circled "i" button.

An impressive screen (Figure 5) shows timings, magnitudes, and the gamma! The author knows his stuff.

Stunning Settings

You're in for another surprise when you explore the Settings.

There are options for units, time format, date format, and map orientation. The app even compensates for atmospheric refraction! I found it easy to change the location or put it back to home turf, easy to jump to a specific date and time, or to make it follow the system clock.

There are options for everything! And the Help screen is well written, too.

A Serene Widget

Skywheel also comes with a widget (Figure 6) making for a mesmerising view on your Home screen. This makes it easy to monitor the clockworks of the celestial sphere.

A Joy To Use

Skywheel was a treat to find. A light, breezy, enjoyable app, it was quick and easy to install. And just what I needed in these

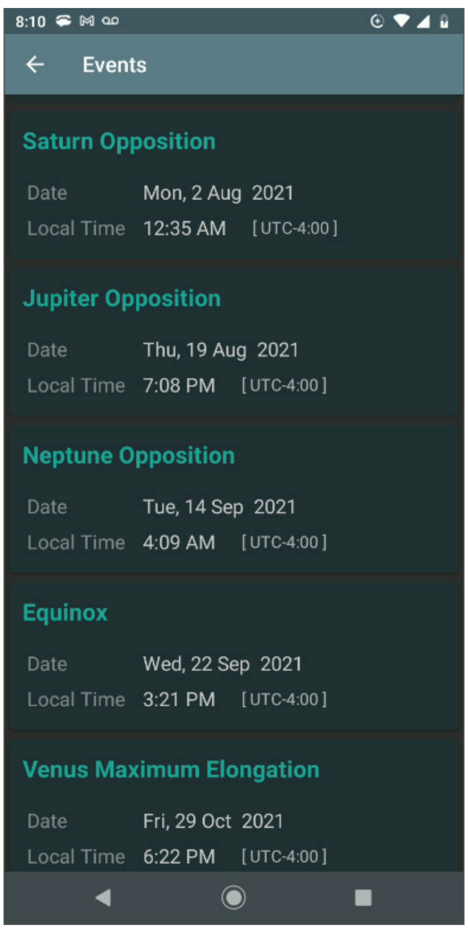

Figure 4 — The calendar screen in Skywheel lists many types of events including oppositions.

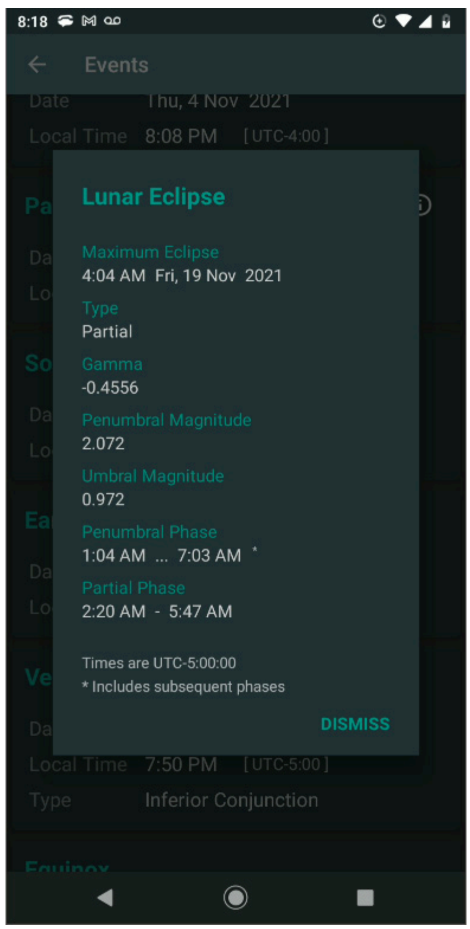

Figure 5 — The Skywheel pop-up screen for a lunar eclipse shows many event details.

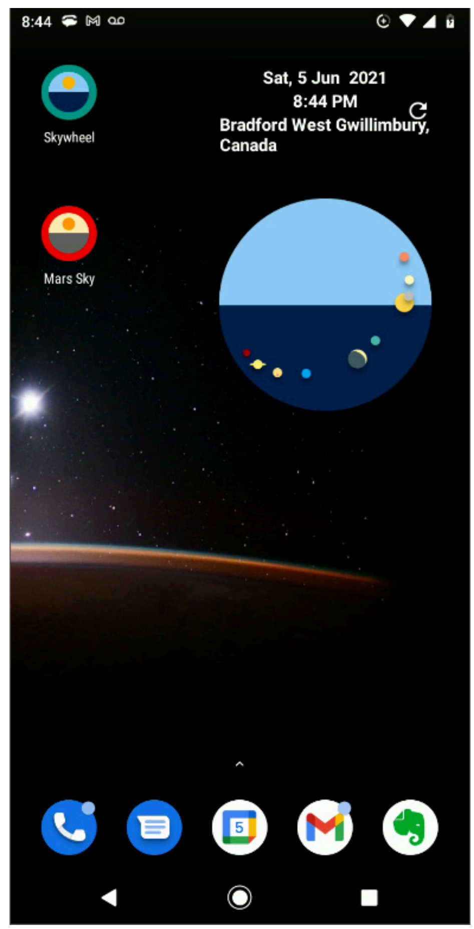

Figure 6 — The Skywheel widget lets one monitor the planets from the Android home screen.

dark days. Skywheel is like Toy Theatre with the Sun, Moon, and planets as the players, on the tiny circular half-lit stage.

Getting to know the author Brett Hanna was a pleasure and he asked if I had any suggestions. He seemed genuinely receptive. The beautiful little program, version 1.7.0 from March 2021, works flawlessly. I'm not the only one marvelling at Skywheel: It has a rating of 4.7 in the Google Play store.

From the widget or main screen, you can immediately know where the planets are. Diving deeper, you can quickly learn facts and figures for the main solar system objects. It's a decent planning tool, too.

Another World

If you like Skywheel, I bet you'll like Mars Sky...

Bits And Bytes

Stellarium 0.21.1 was recently released and corrected the positioning of the Great Red Spot on Jupiter. ✶

Blake's interest in astronomy waxed and waned for a number of years but joining the RASC in 2007 changed all that. He helps with volunteer coordination in the RASC Toronto Centre and is the interim chair of the national Observing Committee. In daylight, Blake works in the IT industry.

Dish on the Cosmos

FYSTing on a New Opportunity

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

Recently, a team that I am on received excellent news: We would be able to participate in the construction and operation of an experimental observatory, the Fred Young Submillimeter Telescope (FYST). The FYST (pronounced "feest") project is building a novel observatory on Cerro Chajnantor mountain in the Atacama Desert of Chile. The telescope is named after a generous Cornell University alumnus donor, whose financial contributions allowed astronomers to develop the telescope design and technologies to maturity. With a clear design and demonstration of some of the risky camera technology, the experimental telescope recently was awarded funding from the Canadian, U.S., and German governments. After years of work, the telescope team has received the standard reward for a job well done: an even harder job.

The FYST telescope will be built on a mountain with an altitude of 5,600 metres, taking advantage of the high altitude to get above a large fraction of the Earth's atmosphere. FYST will be operating in the "submillimetre" regime, measuring electromagnetic radiation with a wavelength between 0.2 mm and 1 mm. Scientifically, this is a challenging regime for observations because the Earth's atmosphere absorbs radiation of these wavelengths, leading to the greenhouse effect that keeps the surface of our planet warmer than would be predicted from the simple physics of sunlight. By observing from a high, dry site, the telescope will be above most of the water vapour in the atmosphere, leading to a more transparent view of space. There is vast scientific opportunity in meeting the challenges of the submillimetre observations. FYST will be able to study the first generation of star-forming galaxies in the Universe, the elusive cosmic magnetic field, and the interface between young stars and gas with an unmatched new perspective from the long-wavelength astronomy.

The major challenge in building this telescope is the high site in Chile. In addition to being remote, the other big challenge for the construction site is the altitude that leads to the unique opportunities. While being above most of the water vapour, the telescope is also above most of the oxygen. This altitude means that construction workers at the site need to wear supplemental oxygen supplies and operate with extreme caution. It also means that FYST will be operated without an astronomer on site: the telescope will need a sophisticated

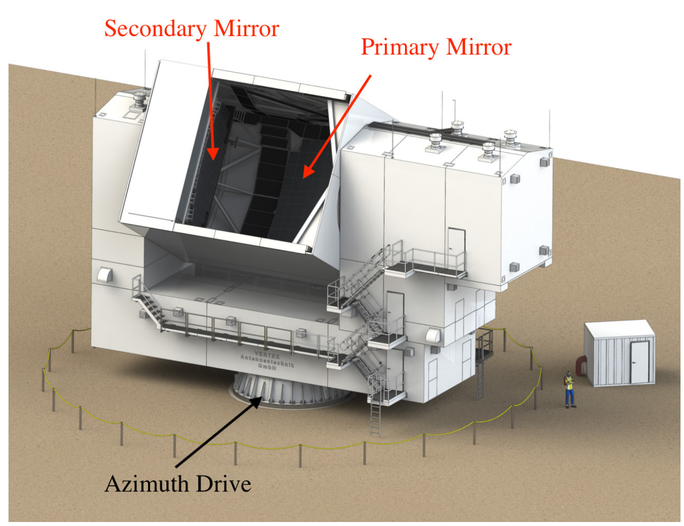

Figure 1 — Design Rendering of the FYST telescope showing the unusual design that is developed for a wide-angle field of view. The mirrors used in FYST are in a large cabin that can spin in altitude and the entire facility will rotate around a single bearing in azimuth. Image Credit: FYST observatory, Vertex Antennentechnik GmbH.

remote-control system to execute the observations and a well-managed data plan to make sure all of a night's observations are captured and transmitted back for analysis.

The FYST telescope may sound a lot like another telescope that is frequently featured in this column: the Atacama Large Millimetre/submillimetre Array (ALMA). The two telescopes are in nearly the same location: FYST will be located on a mountain above the plateau where ALMA operates. While the 600-metre elevation difference between the two observatories does make FYST better at peering through the atmosphere, the optical design of FYST also makes it unique. While ALMA is an exceptional observatory for making detailed observations of small parts of the sky, the optics of FYST are designed for a wide-area field of view. This leads to an atypical design for an observatory (Figure 1), where the entire building containing the observatory pivots around on a single bearing that tracks in azimuth. The primary and secondary "mirrors" are suspended in a large cabin that can rotate around a horizontal axis that allows the telescope to track in elevation. Finally, the primary and secondary mirrors are nearly the same size (6 metres in diameter) and are mounted in a "cross-Dragone" configuration that focuses an extremely wide field of view onto the telescope cameras.

FYST will use one of two main detectors that take advantage of the particle/wave dual nature of light. The "Prime-Cam" detector detects individual submillimetre-wave photons using a technology called kinetic inductance detectors (KIDs). A KID measures the flow of electrical current through a superconductor. While a superconductor should normally allow electrons to flow completely unimpeded, KIDs can detect single photons hitting the detector where they slightly but measurably disturb the electric flow. KIDs are similar to the CCD/CMOS detectors used for making images of the sky in the optical. Like optical imagers, KIDs measure photons with a wide range of energies so they are sensitive but cannot measure the wavelength of the radiation received precisely. The other detector on FYST takes a different approach: the CHAI receiver measures light as a wave rather than individual particles. Using the wave nature of light, this receiver can precisely measure the wavelength of the received radiation, which allows this receiver to study individual spectral emission lines. The two detectors are complementary, allowing them to study different phenomena.

One of the driving science cases for FYST is to study the first generation of star-forming galaxies. Thanks to the finite speed of light, we can observe galaxies as they were early in the Universe by studying the most distant targets. In particular, FYST aims to study targets 10-12 billion light-years away, which traces how galaxies built the first generation of stars during the first 1–3 billion years of the Universe. These observations require telescopes like FYST because star formation takes place in cold, dark clouds of gas where the dust in the clouds absorbs the optical starlight and re-radiates the light in the infrared part of the spectrum. Because of the huge distances to these galaxies, this infrared light must travel across an expanding Universe to reach us. In this travel, the expanding Universe further stretches the wavelength of the light so that it can be best observed in the submillimetre part of the spectrum where FYST will operate. With a large-diameter telescope, we can find individual star-forming galaxies across large parts of the sky.

The goal of finding these distant galaxies is to measure how the Universe forms stars across its history. Using other observations, we have good measurements of the cosmic star-formation rate from about 1/3 the current age of the Universe up to today. The results are noteworthy: Galaxies in the past were forming stars at about 10-times the rate we observe today. However, we do not expect that trend to continue as we peer back to even earlier times. We expect that the earliest phases were less vigorous, but we don't really know how the star formation is distributed. Is most of the early star formation found in a few, rare galaxies? Or are all galaxies forming stars, just at a relatively low rate. FYST will directly map the dust-enshrouded star-forming systems and directly answer these questions.

Tracing cosmic star formation is one of the many questions that can be answered with FYST, taking advantage of the large field-of-view. The telescope will finish construction over the next year and start collecting data. The path from first light to science is long and there will be hard work in understanding the telescope, correctly calibrating the new instruments, and finally spending the time to execute the observations. I am excited to be working as part of the FYST team, building the software that will process the instrument signals into science-ready data. There are a lot of challenges, but the new facility promises an exciting, unseen view of the long-wavelength Universe. ✶

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John Percy's Universe

Everything Spins

by John R. Percy FRASC
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Astronomers like to rhapsodize about the "astronomical" masses, sizes, densities, luminosities, ages, and distances of objects in the Universe. But what about spin? Everything spins. And it makes a difference.

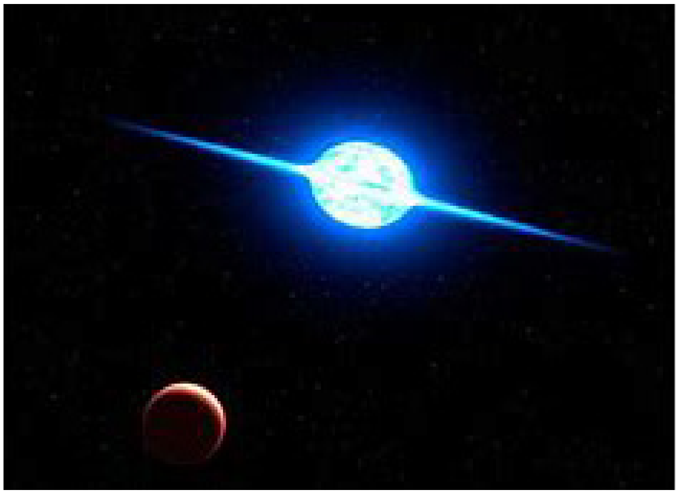
Remarkably, our bodies and our societal activities have evolved to follow the rhythm of the Earth's daily spin or rotation. Actually, the Earth rotates in 0.99727 day, because the day is set by the noon-day Sun, which appears to move slowly eastward in the sky during the year as a result of Earth's revolution. The rotation is gradually slowing, due to the braking action of the tides. That's why an extra second is inserted into the year every now and then. Fossils tell us that, three billion years ago, there were only 15 hours in a day.

Earth's equator is whizzing around at almost 1,700 km/hr as a result of its rotation. Early scholars assumed—incorrectly, of course—that if Earth was really rotating, we would all be flung off into space. That was one reason for initially rejecting the heliocentric model of the Solar System. The rotation does cause the equator to bulge outward; it is about 43 km wider at the equator than pole-to-pole.

You can easily observe the rotation of the Moon by noting that it keeps the same face to the Earth during the month. But wait! Doesn't that mean that the Moon doesn't rotate? It does from an outside perspective, where you would see that the Moon rotates in the same period of time that it revolves. This lends itself to interesting classroom demonstrations. The Moon's synchronized rotation is also a result of tides—those of the Earth on the Moon, over the course of billions of years of its history. For an excellent discussion of tides, see Roy Bishop's article in the RASC *Observers Handbook 2021*.

With simple equipment, you can also observe and measure the rotation of the Sun, by watching sunspots as they are carried across the Sun's disk by its rotation. But do it safely! And remember to allow for the fact that, as the Sun rotates, our viewpoint is changing as a result of the Earth's annual revolution around the Sun. With great perseverance, you could also observe that the rotation period of the Sun varies with the latitude of the spot, by observing spots at higher and lower latitude. The average latitude of spots decreases during the 11-year sunspot cycle.

The rotation period of the Sun varies from about 25 days at the equator to about 35 days at the poles. This is possible because the Sun is a fluid, not a solid body like the Earth.



Artist's conception of VFTS 102, the most rapidly rotating star known, with an equatorial rotational velocity of at least 2,000,000 km/hr, or over 500 km/s. It is seen from a hypothetical planet. Note the ejected disk of gas. This massive star is located in the Tarantula Nebula in the Large Magellanic Cloud. Source: ESA/Hubble.

We call this *differential rotation.* Canada's MOST satellite famously observed differential rotation on another Sun-like star, kappa-1 Cet. The Sun's rotation, together with the convection in its outer layers, generates its magnetic field, and its many forms of "activity"—very important!

The other planets rotate. Mercury's rotation period is 58.646 days, exactly 2/3 of its orbital period, semi-synchronized due to solar tidal effects. Venus hardly rotates at all. Mars's rotation period is very similar to Earth's. Jupiter's and Saturn's are less than half a day which, together with their large size, means that their equators are whipping around more than twenty times as fast as Earth's. This dramatically affects their weather and causes their equators to bulge outward by up to ten percent.

Asteroids rotate. Ceres's rotation period is about nine hours. Small asteroids have similar periods and, because they are highly irregular in shape and shine by reflected light, their brightness changes noticeably as they rotate. An interesting project would be to measure the rotation period of an asteroid from its "light curve" of brightness *versus* time.

Comet nuclei rotate; the rotation periods of the nuclei of Comets Halley, Hale-Bopp, and NEOWISE are 2.2 days, 0.5 day, and 0.3 day, respectively. This rotation affects the way that gases are vented from their icy nuclei.

We often think of the Solar System itself as rotating, but we really mean that the planets are all revolving in the same sense. These motions are the result of the rotation of the cloud from which the Solar System formed, 4.5 billion years ago. As the cloud contracted under gravity, *angular momentum* was conserved[1] and the cloud rotated more rapidly and spun down into a disk, in which the Sun and planets formed.

The sense of the orbital motions, and most of the rotation is therefore the same—counterclockwise when viewed from the north.

Other stars rotate. Low-mass stars like the Sun begin life rotating rapidly, but then gradually slow down as their angular momentum is lost through their magnetic fields and winds (Percy 2020). The Sun is a middle-aged star, rotating much more slowly than it once did, and therefore being much less "active."

High-mass stars also begin their lives rotating rapidly on average but, in their short lifetimes, have not had time or means to slow down. They have equatorial rotational velocities of up to 300 km/s or more. That would get you from Toronto to Ottawa in just over a second. The rotation produces an equatorial bulge which, in the case of Regulus, is about 30 percent. It also helps some of the stars to eject an "excretion disk" of gas that produces rare emission lines in the star's spectrum—the so-called Be stars[2]. They were one of my research interests for many years.

There's a rare and interesting group of A-type stars that have global magnetic fields of thousands of Gauss (the Earth's and Sun's global magnetic fields are about one Gauss). These fields cause different chemical elements to segregate on different parts of the star's visible disks so that, as the star rotates, both the brightness and the spectrum vary. The study of the changing brightness of "peculiar A stars," together with that of low-mass spotted stars (like the Sun) is a powerful way to measure stellar rotation. These, and spotted Sun-like stars, are classified as "rotating variable stars."

When stars run out of energy and die, they contract or collapse. As they do so, the "figure skater effect" takes hold and the spin increases, just like the figure skater's does as they pull their arms close to their bodies at the end of their routine. This is another example of "conservation of angular momentum."

At the end of the Sun's life, its core will contract and it will become a white dwarf. Such star remnants' rotation periods can be hours or days, as determined from the broadening of the absorption lines in their spectra, or from *asteroseismology* (Percy 2021).

Rare, massive stars collapse. Their cores may become neutron stars, with densities of millions of tonnes per cubic cm, and their outer layers may explode as supernovae. A freshly formed neutron star has a rotation period of a fraction of a second. The one in the Crab Nebula supernova remnant has a rotation period of 0.03 sec, a thousand years after its birth. Their rotation slows as they radiate away their rotational energy through their ultra-strong magnetic field; they are observed as a pulsating radio source, or *pulsar.* By the time their rotation period slows to a second or so, they are no longer observable as pulsars. However, their rotation could be "spun up" by mass transfer from a close companion (if they have one) and they would become a *millisecond pulsar,* spinning at close to the speed of light.

The rarest, most massive stars collapse to produce a black hole. A black hole has only three properties: mass, spin, and electrical charge; the latter should be negligible. But the star that produced the black hole had angular momentum, and that angular momentum must have been conserved as the black hole was formed. Now that astronomers can observe the merger of binary black holes through the gravitational waves emitted, they are starting to get information on black-hole spin.

We often say that galaxies rotate—especially spiral galaxies like our own, the Milky Way. But we really mean that the stars are revolving around the galaxy's centre. As with stars, that collective motion is caused by the rotation of the gas cloud from which the galaxy formed billions of years ago. Likewise, some star clusters "rotate" for the same reason.

Does the Universe rotate? Not according to the latest studies of the cosmic microwave background radiation—the left-over radiation from the Big Bang—in which our Universe is immersed.

I am often asked why stars rotate at all. Why don't they just stand still? Certainly, they would need some source of their original angular momentum. That's the angular momentum of the cloud from which the star formed. As the cloud contracted to form the star, its very small spin resulted in a much larger spin in the star. But why did the cloud have any angular momentum in the first place? That's because it was a small part of a much larger cloud, like the Orion Nebula. And clouds are turbulent as a result of their random motions and interactions. Just go out and watch a cloud in the sky! ✶

Notes

1 Angular momentum is a quantity that depends on the object's rotation period and mass distribution. If the mass distribution becomes more concentrated, and therefore smaller, the spin must increase.

2 The B is from the spectral temperature sequence OBAFGKM from hot to cool; the e denotes emission lines in the spectrum.

References

Percy, J.R. (2020). Young stellar objects and their variability, *JRASC, 114*, 227.

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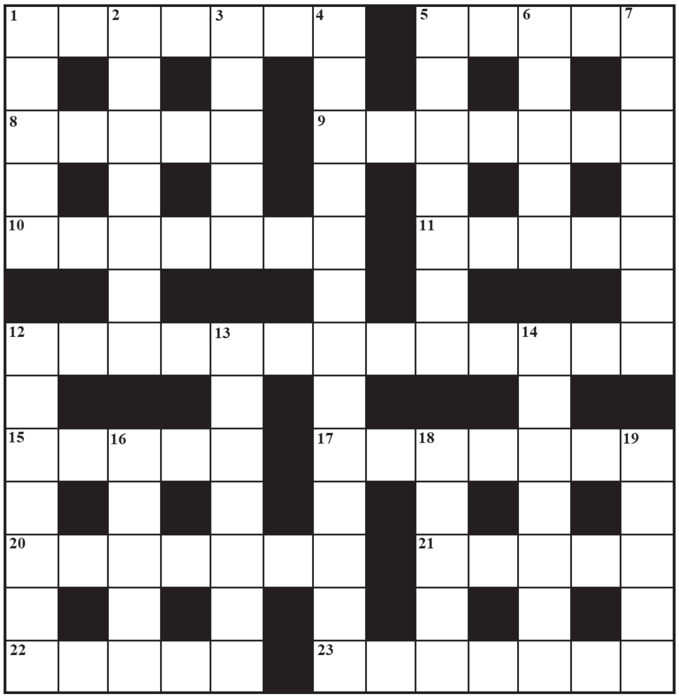
John Percy FRASC is Professor Emeritus, Astronomy & Astrophysics, and Science Education, University of Toronto, and a former President and Honorary President of the RASC. He has studied a variety of rotating stars in the course of his research.

Astrocryptic

by Curt Nason



ACROSS

1. A lark is fluttering near Dragon's Head (7)
5. A lunar scarp is superfluid (5)
8. Old luminance measure backlit in antimony (5)
9. I lumber awkwardly around Uranus (7)
10. A degree of horizontal motion (7)
11. After time a main-belt asteroid orbits Jupiter (5)
12. Boreal backdoor asterism (8,5)
15. Upset about the preparation for imaging (3-2)
17. Moon plays around in company (7)
20. Real bio written about star in a leading role (7)
21. Europa landed here in secret elopement (5)
22. Comet discoverer was perhaps a nerd (5)
23. Harlan's crater is a cowboy's overhead (7)

DOWN

1. Confused, Astraea dances and emits radium (2,3)
2. Good mount for observing in Washington, despite apparent weather (7)
3. Mount up for a western star party (5)
4. Turn hose around to angry little asterism (8,5)
5. Mr. Dick to return Index Catalogue for our telescope (7)
6. Indivisible number for a reference meridian (5)
7. Funny Phil refurbishes mirrors (7)
12. Bun has a strange alter ego for Alnasl (7)
13. Such film was revered for efficiency and overblown colour (7)
14. Argonaut musician instrumentally following Hercules (7)
16. Herschel's mountain in the sky (5)
18. A Society president was once clocked with no beginning or end (5)
19. A stormy one appears before the Full Moon (5)

Answers to previous puzzle

Across: **1** CENTAUR (an(u)ag); **5** PLUTO (PL+U+T+O); **8** ALVAN (hid); **9** DARK BAY (2 def); **10** ELECTRA (elect Ra); **11** SHINE (2 def); **12** CLARKE (2 def); **14** SKYLAB (SK+ly (rev)+AB); **17** CERES (hid); **19** DAYSTAR (2 def); **21** ALSHAIN (Als+ha+in); **22** OCULI (an(U)ag); **23** TULIP (2 def); **24** EVENING (2 def)

Down: **1** CLARENCE CHANT (2 def); **2** NOVAE (an(a) ag); **3** ALNITAK (anag); **4** RADIAL (2 def); **5** PARIS (2 def); **6** UMBRIEL (um+brie+l); **7** OXYGEN BURNING (anag); **13** AEROSOL (anag); **15** KEYHOLE (2 def); **16** ODENSE (anag+E); **18** SCARP (anag+p); **20** TAURI (homonym)

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Great Images

by Carl Jorgensen

Carl Jorgensen sketched the partial eclipse from Greenfield, Quebec. He viewed it through his refractor at 60x power using a 15-mm eyepiece. Of his several sketches, he says: "It is my favourite sketch because, of my six sketches, this is the one that shows the greatest amount of the Sun's disk covered by the Moon."

Journal

Blake Nancarrow took this image of what was the partial eclipse from Bradford, Ontario. He took it with his Celestron 8″, with a Canon 40D, a Kendrick solar filter, a Vixen Super Polaris with GoToStar tracking 1/10th of a second at ISO 100.