The Journal of The Royal Astronomical Society of Canada

Journal

Le Journal de la Société royale d'astronomie du Canada

PROMOTING ASTRONOMY IN CANADA

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Volume/volume 114
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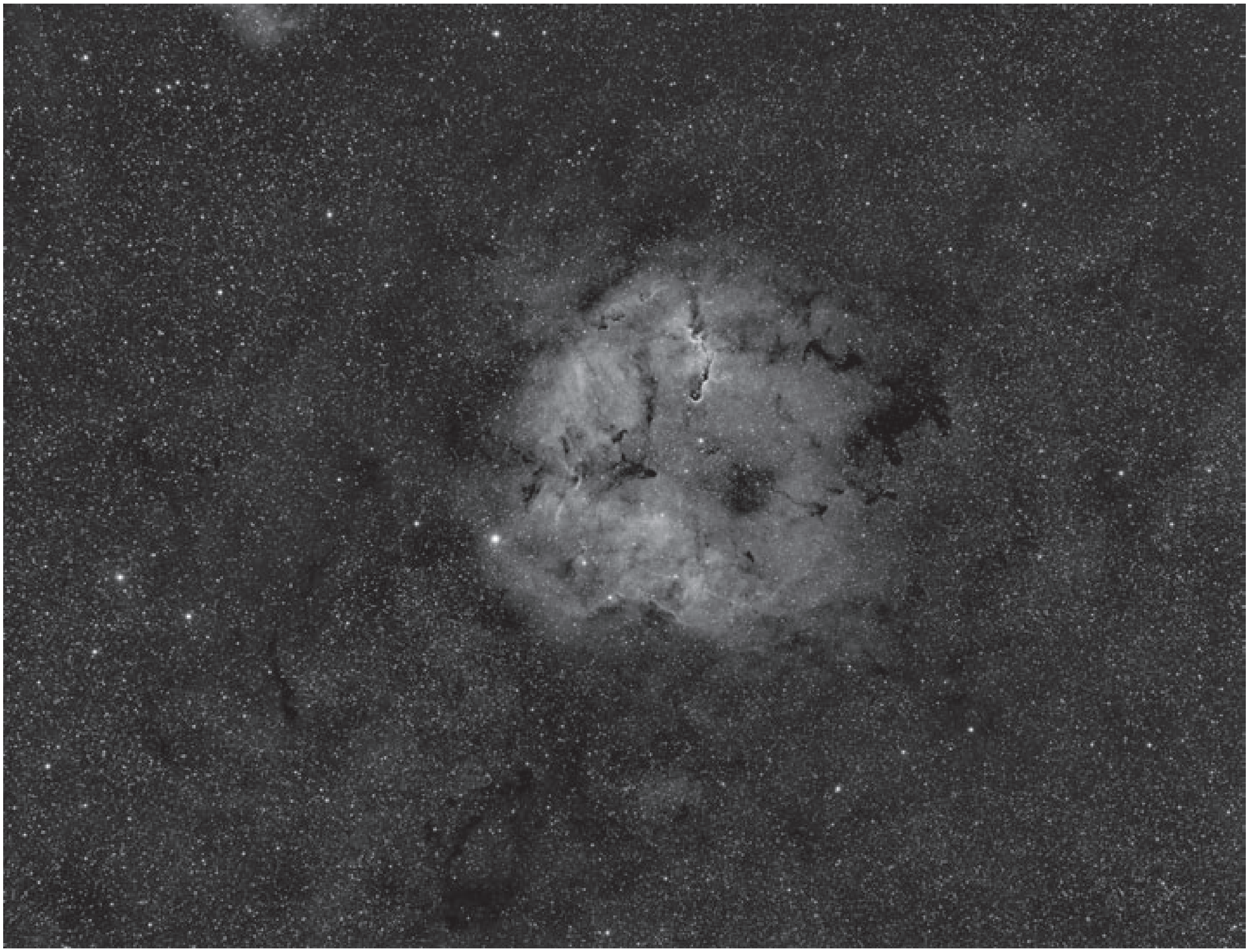
The Best of Monochrome.

Drawings, images in black and white, or narrow-band photography.



This image was acquired by Adrian Aberdeen who used a Rokinon 135mm lens, a ZWO ASI1600MM-COOL camera and a Baader Hα filter on a Sky-Watcher AZ-GTi mount. Adrian says, "Most people who use lenses know how difficult it can be to focus them without affecting the alignment of the mount. To combat this, I installed a homemade autofocuser that comprises of a stepper motor, an Arduino motor controller and a hand-sown drive belt. Not being a technical person by trade or hobby, astrophotography has shown me that I have many skills I didn't know I possessed!"

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Société Royale d'Astronomie du Canada

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This is a collaboration between Kerry-Ann Lecky Hepburn and Stefano Cancelli. The astrophotography duo call this image of M106 the "Franken-Galaxy" due to the fact that they used "varied gear at different focal lengths used and shot from two different locations." In total, there is 19 hours and 40 mins of data collected. Kerry-Ann used a C6 @ ƒ/10 with a QHY-8 on a CGE mount and Stefano used a Vixen VC200L @ƒ/9 with a ST10XME on a Tak EM200. Tragically, Stefano passed in June after a battle with pneumonia. A talented musician and astrophotographer, Stefano will be greatly missed.

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
(arforet@shaw.ca)

Let me begin with a heartfelt thanks to our outgoing President, Dr. Chris Gainor. After working with Chris these past six years, I've come to know him and to respect him in every way. It has been an absolute pleasure doing so!

As an organization, we've used newsletters, lecture halls, and magazines to reach our target audience. We've held local and national meetings periodically to make important business decisions and to connect with our members and the public, and we've used city parks and other venues to bring astronomy to the masses. In this COVID-19 world and in the post-COVID-19 world to come, our methods are challenged. A new norm is unfolding, and here are some interesting observations for you to ponder.

The biggest change has been in how we connect. Social media has been in our toolbox for a long time, but it hasn't been fully utilized nor have its benefits been fully realized. Our YouTube site has been in place since 2011! www.youtube.com/c/rascanada. You have to check out the very first video posted by Roland Dechesne in 2011: How the RASC got its Royal Name, with a LEGO Queen Elizabeth narrating.
Fast forward to 2020 and we are using Zoom and YouTube streaming and archiving to overcome the isolation imposed by COVID-19. Virtual meetings and webinars are the new norm and members are loving it. Self-isolation Star Parties, The Insider's Guide to the Galaxy, #astrono**my**time, and the RASC Speaker Series all spun up since the onset of COVID. With 949 subscribers and over 36,000 views, we're reaching more people and overcoming financial and social barriers that otherwise might hinder attendance.

Our General Assembly, an annual gathering of 100 to 200 leaders and members, has been completely uprooted. Attending a GA has always been a privilege and hearing top-notch keynote speakers, and gaining insight from other members doing important work across the country and across our field firsthand, along with the social aspect of meeting face-to-face, has been an enlightening and enjoyable aspect of Society membership. Attending a GA is not without its challenges, though, and attendees have had to give up three to five days of their time and carry a financial burden, too.

The planned GA for 2020 took a severe blow from COVID-19. The host Vancouver Centre team under the leadership of Hayley Miller took those COVID-19-laced lemons and made lemonade and then took that lemonade and made strawberry lemonade margaritas, skinny sparkling mint pineapple lemonade, etc. You get my drift. Not only did they create a virtual General Assembly, they held one of the most successful General Assemblies in some respects. Panelists attended by Zoom and it was live-streamed on YouTube, where the most-viewed YouTube segment had 915 views at the time of this writing. That is the best attended General Assembly ever! And it's not over. While the June 7 segment featured an astronaut, a renowned Canadian astrophysicist and planetary scientist, and a Canadian science celebrity, there are four more days and 12 more talks up and coming. It's too late to capture the total attendance for this deadline, but it's conceivable that instead of reaching 1 to 2 percent of our members, this GA could top 25 percent or more. That is astounding.

The possibilities to deliver on our strategic objectives in a new and more powerful way become more and more evident as our methods evolve. Our Universe truly is expanding. ✶

News Notes / En manchette

Compiled by Jay Anderson

Missing: Population III stars

New results from the NASA/ESA *Hubble Space Telescope* suggest the formation of the first stars and galaxies in the early Universe took place sooner than previously thought. A team of astronomers led by Rachana Bhatawdekar of the European Space Agency have found no evidence of the first generation of stars, known as Population III stars, as far back as when the Universe was just 500 million years old.

Based on a scheme developed by Walter Baade and Jan Oort in the 1940s, astronomers classify stars into two populations based on their metal content—that is, the percent of elements heavier than hydrogen and helium, collectively known as "metals." In the Milky Way, old metal-poor stars are yellowish or red in colour and tend to inhabit globular clusters and the central parts of the galaxy. Younger stars with higher metal abundances are found selectively in the spiral arms and are typically blueish in colour. The former are Population II stars, the latter, Population I. Our Sun has a metal abundance of 1.4 percent and belongs to the Population I class.

Though metal abundances are very low in Population II stars, the fact that elements heavier than lithium can be seen at all in their spectra suggests an earlier population of stars without any metallic content that formed in the primordial material created during the Big Bang. These Population III stars then formed the heavier elements in their cores during fusion reactions, and the resulting material then seeded the early Universe with metals as a consequence of supernovae and other explosive events. Ever since, the metallic content of stars has been steadily increasing as ongoing generations create and then seed interstellar space.

One of the major goals of cosmological research and observation is to find signs of these very first Population III stars. We do not know when or how the first stars and galaxies in the Universe formed. These questions can be addressed with the *Hubble Space Telescope* through deep-imaging observations that allow astronomers to view the Universe back to within 500 million years of the Big Bang.

The ESA researchers set out to study the first generation of stars. Population III stars must have been made solely out of hydrogen, helium, and lithium, the only elements that existed before processes in the cores of these stars could create heavier elements, such as oxygen, nitrogen, carbon, and iron.

Bhatawdekar and her team probed the early Universe from about 500 million to 1 billion years after the Big Bang by studying the cluster MACSJ0416 and its parallel field with the *Hubble Space Telescope* (with supporting data from NASA's *Spitzer Space Telescope* and the ground-based Very Large Telescope of the European Southern Observatory).

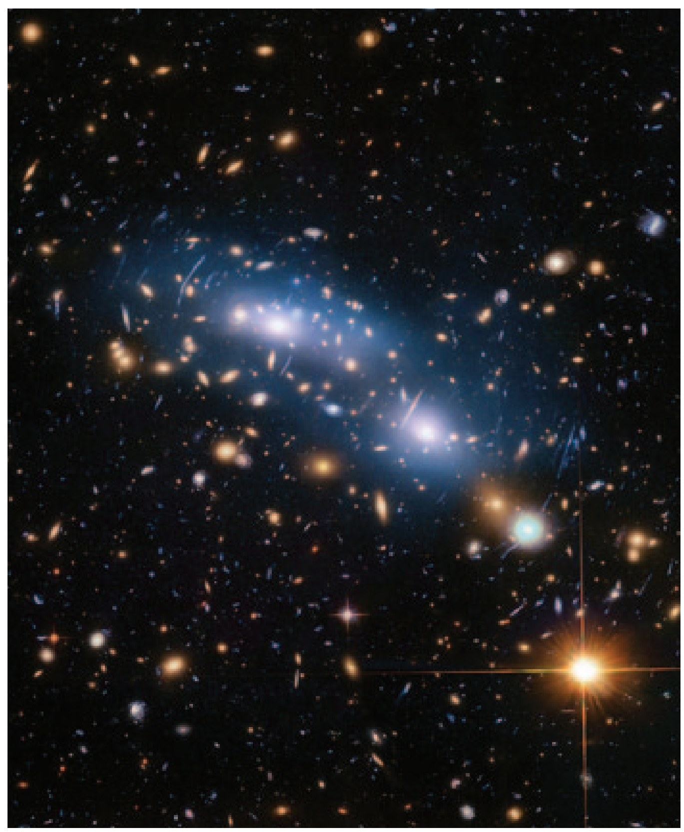

Figure 1 — This image from the NASA/ESA Hubble Space Telescope *shows the galaxy cluster MACS J0416 and a surrounding field of background lensed galaxies. MACS J0416 is one of six galaxy clusters being studied by the Hubble Frontier Fields program, which together have produced the deepest images of gravitational lensing ever made. Scientists used intracluster light (visible in blue) to study the distribution of dark matter within the cluster. Credits: NASA, ESA, and M. Montes (University of New South Wales)*

"We found no evidence of these first-generation Population III stars in this cosmic time interval," said Bhatawdekar of the new results.

The result was achieved using the *Hubble Space Telescope*'s Wide Field Camera 3 and Advanced Camera for Surveys, as part of the Hubble Frontier Fields program. This program produced the deepest observations ever made of galaxy clusters and the galaxies located behind them, which were magnified by the gravitational lensing effect, thereby revealing galaxies 10 to 100 times fainter than any previously observed. The masses of foreground galaxy clusters are large enough to bend and magnify the light from the more-distant objects behind them. This allows Hubble to use these cosmic magnifying glasses to study objects that are beyond its nominal operational capabilities.

Bhatawdekar and her team developed a new technique that removes the light from the bright foreground galaxies that constitute these gravitational lenses. This allowed them to discover galaxies with lower masses than ever previously observed with Hubble, at a distance corresponding to when the Universe was less than a billion years old. At this point in cosmic time, the lack of evidence for exotic stellar populations and the identification of many low-mass galaxies supports the suggestion that these galaxies are the most likely candidates for the reionization of the Universe. This period of reionization in the early Universe is when the neutral intergalactic medium was ionized by the first stars and galaxies.

"These results have profound astrophysical consequences as they show that galaxies must have formed much earlier than we thought," said Bhatawdekar. *"This also strongly supports the idea that low-mass/faint galaxies in the early Universe are responsible for reionization."*

These results also suggest that the earliest formation of stars and galaxies occurred much earlier than can be probed with the *Hubble Space Telescope*. This leaves an exciting area of further research for the upcoming NASA/ESA/CSA *James Webb Space Telescope*—to study the Universe's earliest galaxies.

Compiled in part with material provided by ESA/Hubble Information Centre

Apollo 17 lunar sample still revealing secrets

New research published in the journal *Nature Astronomy* reveals a type of destructive event most often associated with disaster movies and dinosaur extinction may have also contributed to the formation of the Moon's surface. A group of international scientists led by the Royal Ontario Museum (ROM) has discovered that the formation of ancient rocks on the Moon may be directly linked to large-scale meteorite impacts.

The scientists conducted new research of a unique rock collected by NASA astronauts during the 1972 *Apollo 17* mission to the Moon. They found the rock contains mineralogical evidence that it formed at a temperatures in excess of 2300 °C that can only be achieved by the melting of the outer layer of a planet in a large impact event.

Figure 2 — Apollo 17 *scientist-astronaut Harrison H. Schmitt collects lunar rake samples at the Taurus-Littrow landing site. This rake was used to collect samples ranging in size from 1.3 centimetres to 2.5 centimetres.*

In the rock, the researchers discovered the former presence of cubic zirconia, a mineral phase often used as a substitute for diamond in jewellery. The phase would only form in rocks heated to above 2300 °C, and though it has since reverted to a more stable phase (the mineral known as baddeleyite), the crystal retains distinctive evidence of a high-temperature structure.

While looking at the structure of the crystal, the researchers also measured the age of the grain, which reveals that the baddeleyite formed over 4.3 billion years ago. It was concluded that the high-temperature cubic zirconia phase must have formed before this time, suggesting that large impacts were critically important to forming new rocks on the early Moon.

Fifty years ago, when the first samples were brought back from the surface of the Moon, lunar scientists raised questions about how lunar crustal rocks formed. Even today, a key question remains unanswered: how did the outer and inner layers of the Moon mix after the Moon formed? This new research suggests that large impacts over 4 billion years ago could have driven this mixing, producing the complex range of rocks seen on the surface of the Moon today.

"Rocks on Earth are constantly being recycled, but the Moon doesn't exhibit plate tectonics or volcanism, allowing older rocks to be preserved," explains Dr. Lee White, Hatch Postdoctoral Fellow at the ROM. "By studying the Moon, we can better understand the earliest history of our planet. If large, super-heated impacts were creating rocks on the Moon, the same process was probably happening here on Earth."

"By first looking at this rock, I was amazed by how differently the minerals look compared to other *Apollo 17* samples," says Dr. Ana Cernok, Hatch Postdoctoral Fellow at the ROM and co-author of the study. "Although smaller than a millimetre, the baddeleyite grain that caught our attention was the largest one I have ever seen in Apollo samples. This small grain is still holding the evidence for formation of an impact basin that was hundreds of kilometres in diameter. This is significant, because we do not see any evidence of these old impacts on Earth."

Dr. James Darling, a reader at the University of Portsmouth and co-author of the study, says the findings completely change scientists' understanding of the samples collected during the Apollo missions, and, in effect, the geology of the Moon. "These unimaginably violent meteorite impacts helped to build the lunar crust, not only destroy it," he says.

A new test of dark energy and the Hubble Constant

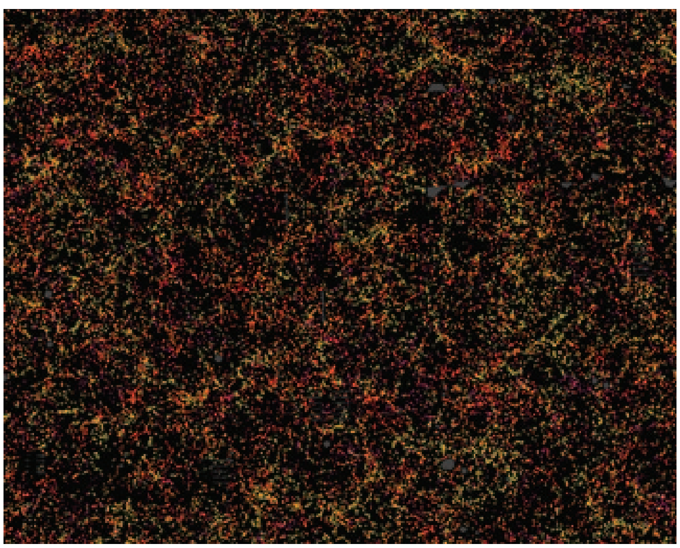

Figure 3 — A slice through the map of the large-scale structure of the Universe from the Sloan Digital Sky Survey and its Baryon Oscillation Spectroscopic Survey. Each dot in this picture indicates the position of a galaxy 6 billion years into the past. The image covers about 1/20th of the sky, a slice of the Universe 6 billion light-years wide, 4.5 billion light-years high, and 500 million light-years thick. Color indicates distance from Earth, ranging from yellow on the near side of the slice to purple on the far side.

Galaxies are highly clustered, revealing superclusters and voids whose presence is seeded in the first fraction of a second after the Big Bang. This image contains 48,741 galaxies, about 3% of the full survey dataset. Grey patches are small regions without survey data. Image: Daniel Eisenstein and the SDSS-III collaboration

A new paper has shown how large structures in the distribution of galaxies in the Universe provide the most precise tests of dark energy and cosmic expansion yet.

The study uses a new method based on a combination of cosmic voids—large expanding bubbles of space containing very few galaxies—and the faint imprint of sound waves in the very early Universe, known as baryon acoustic oscillations (BAO), that can be seen in the distribution of galaxies. This provides a precise ruler to measure the direct effects of dark energy driving the accelerated expansion of the Universe.

Baryon acoustic oscillations are fluctuations in the density of normal matter that developed in the plasma of the early Universe before it had cooled to a temperature at which electrons and protons could combine into neutral atoms (about 3000 K). Before this moment, the primordial plasma formed high-density (and high-gravity) regions where dark matter, normal matter (baryons), and photons collected and where high temperatures were generated by interactions among baryons and photons. The contest between gravitational contraction and outward pressure created by heating led to the generation of oscillations analogous to sound waves. These acoustic waves were frozen in place when neutral atoms formed and light could escape from the condensing Universe. They are visible today in the patterns formed in the cosmic microwave background and in the distribution of galaxies.

This new study gives much more precise results than the technique based on the observation of exploding massive stars, or supernovae, which has long been the standard method for measuring the direct effects of dark energy. The research makes use of data from over a million galaxies and quasars gathered over more than a decade of operations by the Sloan Digital Sky Survey.

The results confirm the model of a cosmological constant dark energy and spatially flat Universe to unprecedented accuracy, and strongly disfavour recent suggestions of positive spatial curvature inferred from measurements of the cosmic microwave background (CMB) by the *Planck* satellite.

Lead author Dr. Seshadri Nadathur, research fellow at the University of Portsmouth's Institute of Cosmology and Gravitation (ICG), said: "This result shows the power of galaxy surveys to pin down the amount of dark energy and how it evolved over the last billion years. We're making really precise measurements now and the data is going to get even better with new surveys coming online very soon."

Dr. Florian Beutler, a senior research fellow at the ICG, who was also involved in the work, said that the study also reported a new precise measurement of the Hubble constant, the value of which has recently been the subject of intense debate among astronomers. Depending on the assumptions made in the model, a value of the Hubble constant was measured to be 72.3±1.9 km s^{-1} Mpc^{-1}. This compares favourably with an average value of 71.8±3.0 determined from ten other studies conducted in 2019.

Dr. Beutler noted, "We see tentative evidence that data from relatively nearby voids and BAO favour the high Hubble rate seen from other low-redshift methods, but including data from more distant quasar absorption lines brings it in better agreement with the value inferred from *Planck* CMB data."

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

Hawaiian astronomers unveil the magnetic field of the solar corona

While the world has been dealing with the coronavirus pandemic, researchers at the University of Hawaii Institute for Astronomy (IfA) have been hard at work studying the solar corona, the outermost atmosphere of the Sun that expands into interplanetary space. This stream of charged particles radiating from the surface of the Sun is called the solar wind and expands to fill the entire Solar System.

The properties of the solar corona are a consequence of the Sun's complex magnetic field, which is produced in the solar interior and extends outward. A new study by IfA graduate student Benjamin Boe used total solar eclipse observations to measure the shape of the coronal magnetic field with higher spatial resolution and over a larger area than ever before.

The corona is most easily seen during a total solar eclipse—when the Moon is directly between the Earth and the Sun, blocking the bright surface of the Sun. Significant technological advances in recent decades have shifted much of the focus to space-based observations at wavelengths of light not accessible from the ground, or to large ground-based telescopes such as the Daniel K. Inouye Solar Telescope on Maui. Despite these advances, some aspects of the corona can only be studied during total solar eclipses.

That is why Boe's advisor and coronal research expert, Shadia Habbal, has led a group of eclipse chasers making scientific observations during solar eclipses for over 20 years. The so-called "Solar Wind Sherpas" travel the globe chasing total solar eclipses, transporting sensitive scientific instruments on planes, helicopters, cars, and even horses to reach the optimal locations. These solar eclipse observations have led to breakthroughs in unveiling some of the secrets of the physical processes defining the corona.

"The corona has been observed with total solar eclipses for well over a century, but never before had eclipse images been used to quantify its magnetic-field structure," explained Boe. "I knew it would be possible to extract a lot more information by applying modern image-processing techniques to solar eclipse data." Boe traced the pattern of the distribution of magnetic field lines in the corona, using an automatic tracing method applied to images of the corona taken during 14 eclipses across the past two decades. This data provided the chance to study the changes in the corona over two 11-year magnetic cycles of the Sun.

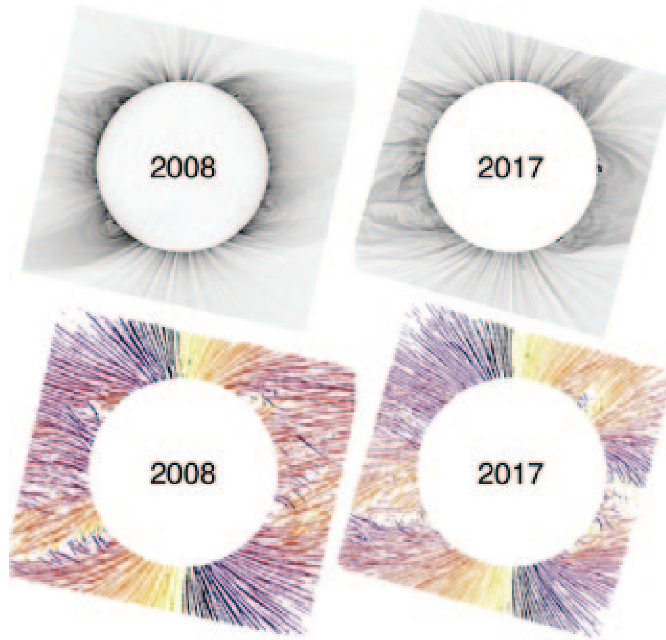

Figure 4 — High-resolution images of the solar corona. The top panels show the visible light (color inverted), while the lower panels show the magnetic field shape. Fine details, quantified for the first time, are visible throughout the corona. Credit: B. Boe/IfA

Boe found that the pattern of the coronal magnetic field lines is highly structured, with structures seen at size scales down to the resolution limit of the cameras used for the observations. He also saw the pattern changing with time. To quantify these changes, Boe measured the magnetic field angle relative to the Sun's surface.

During periods of minimum solar activity, the corona's field emanated almost straight out of the Sun near the equator and poles, while it came out at a variety of angles at mid-latitudes. During the solar activity maximum, on the other hand, the coronal magnetic field was far less organized and more radial.

"We knew there would be changes over the solar cycle," remarked Boe, "but we never expected how extended and structured the coronal field would be. Future models will have to explain these features in order to fully understand the coronal magnetic field." These results challenge the current assumptions used in coronal modelling, which often assume that the coronal magnetic field is radial beyond 2.5 solar radii. Instead, this work found that the coronal field was often non-radial to at least 4 solar radii.

The astronomers also found that the most non-radial coronal field topologies occur above regions with weaker magnetic-field strengths in the photosphere, while stronger photospheric fields are associated with highly radial field lines in the corona. In addition, the team found an abundance of field lines that extend continuously from the solar surface out to several solar radii at all latitudes, regardless of the presence of coronal holes.

This work has further implications in other areas of solar research, including the formation of the solar wind, which impacts the Earth's magnetic field and can have effects on the ground, such as power outages. "These results are of particular interest for solar-wind formation. It indicates that the leading ideas for how to model the formation of the solar wind are not complete, and so our ability to predict and defend against space weather can be improved," said Boe.

The team is already planning their next eclipse expeditions, with the next one slated for South America in December of this year ✶

Compiled with material provided by the University of Hawaii

Research Articles / Articles de recherche

The Shadow Geometry for NLC

by Alister Ling, Edmonton Centre (dawnskygaze@gmail.com)

Abstract

Noctilucent clouds (hereafter NLC) become visible during the summer twilight hours, when normal tropospheric clouds lie in Earth's shadow, but the Sun has yet to set for altitudes around 80 km, near the mesopause. Ground-based observers have been surprised by the non-occurrence of NLCs at their longitude and latitude when a nice display was visible only two time zones (30°) farther east or more rarely farther south. Is it possible that NLCs were present but lying in shadow? The geometry for this situation is examined. Shadows cast by tropospheric clouds do not play a role. Latitude ranges for potential Sun-blocking NLC shields and light-transmitting vacancies are identified. Further investigation is required to confirm or rule out whether shadows from the NLCs themselves play a role in the irregularity of NLC visibility.

Introduction

Noctilucent Clouds, an *Observer's Handbook* Supplement, provides some background on these gossamer "night-shining" clouds, which form at Earth's mesopause, about 80 km above sea level. They become visible to ground-based observers when the sky is sufficiently dark, but the upper atmosphere remains in sunlight.

Often a nice display in the evening is followed by an absence in the morning twilight or vice versa. Observers note there is no night to night correlation of visibility. The record displays of 2019 highlighted another issue: nothing was seen at one location when sightings were made significantly to the south or to others differing by 15° of longitude. Alan Dyer prompted the author to examine the geometry of NLC shadows by posing the question: could shadows from thick cirrus shields or thunderstorms explain the bewildering inconsistency of NLC displays?

Here is an outline of this article:

Section 1—Review of basic geometry;

Section 2—"What is the latitude of that NLC?";

Section 3—Shadow geometry of tropospheric clouds;

Section 4—Shadow geometry of NLC;

Section 5—The need for followup research.

Figure 1 — Panorama of the 2019 June 29 09:10 UT (dawn) display from Edmonton, Alberta. Credit: Alister Ling

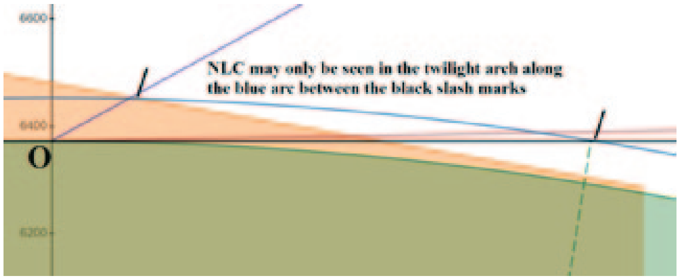

Figure 2 — Basic NLC geometry to scale (units in km from Earth centre), seen in cross section. The reader can manipulate the variables and see the changes in real time at this link www.desmos.com/calculator/iqyy9zvbmp.

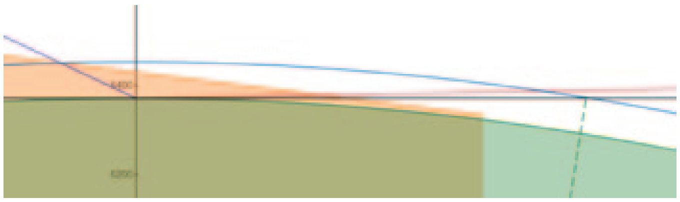

Figure 3 — As above except the Sun's altitude is −7°. NLC are now potentially visible past the zenith and behind the observer, to 155°. The differences between Figure 2 and Figure 3 confirm the very rapid change in NLC altitude that takes place between −7° and −10°. Timetables for maximum NLC altitude for any night and any geographic location can be quickly generated at 162.246.157.211/nlc/basic.html

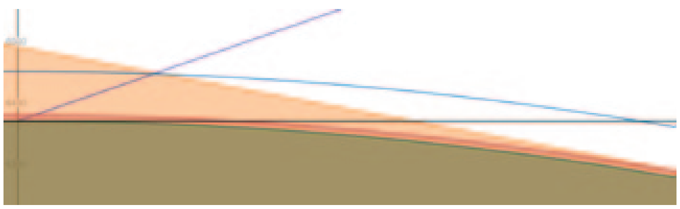

Figure 4 — Clouds in the troposphere cannot create shadows in the primary twilight arch. The curving red line indicating the troposphere lies 10 km above the surface while the orange line is the grazing ray tangent to the troposphere. Note that any object in the troposphere that might cast a shadow is already dark and at best would ensure a sharper cutoff at the very top of the NLC arc. Any cloud closer to the observer (above the black horizon line and below the red) appears directly in front of the distant NLC in silhouette, occulting the NLC, so it cannot play a role in casting a shadow onto the NLC in the twilight arch to the upper right.

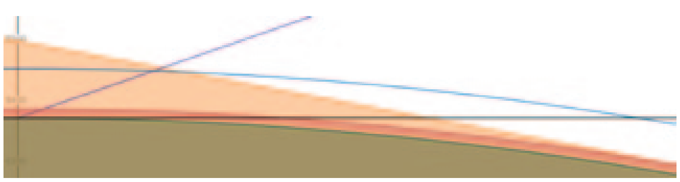

Figure 5 — Screening height increased to 15 km. If there were a large mesoscale convective complex higher than the average 10 km lying to the north of the observer, their shadow would marginally obscure the uppermost part of the NLC display. In this case, the maximum altitude (purple line held constant from Figure 4) would need to be reduced by 3°. Practically speaking, thunderstorm tops of this height (in aviation terms, 49,000 feet) would be quite rare north of 58° N latitude.

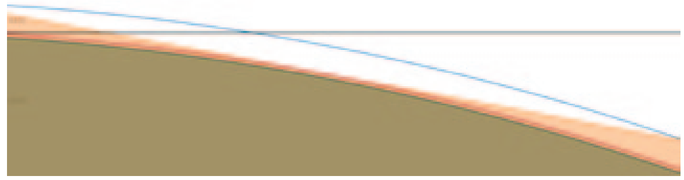

Figure 6 — Clouds well beyond the horizon, regardless of their latitude, cannot cast a shadow on NLC in the twilight arch. Those clouds, all lying below the curving red line of the troposphere, also lie below the orange line of the grazing sunlight ray. Clouds at the far north (right in the diagram) would be in direct sunlight, but they would cast shadows onto the solid ground at higher latitudes.

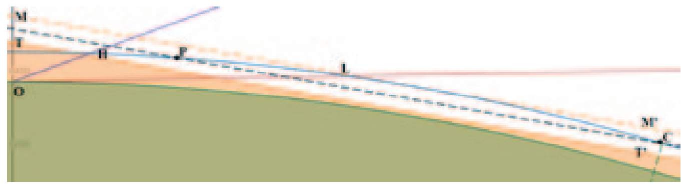

Figure 7 — NLC element at point C casts a shadow onto NLC at point P. The Sun is to the lower right, projecting parallel rays tangent to the top of the mesosphere M and M', and tangent to the top of the troposphere T and T'. The dashed green line from Earth's centre to C is the radial associated with Ldiff, the difference in latitude from the observer to that of the NLC patch casting the shadow. The red line is here set to 1° above the observer's horizon, while the black horizon line has been removed to reduce clutter.

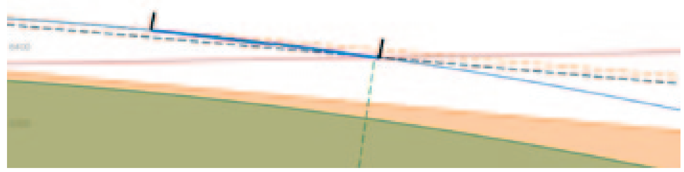

Figure 8 — NLC closer to the horizon (between the black slash marks) lies in direct sunlight for solar altitude −5° and cannot be in shadow. The tangent solar ray, dashed orange, comes from "above."

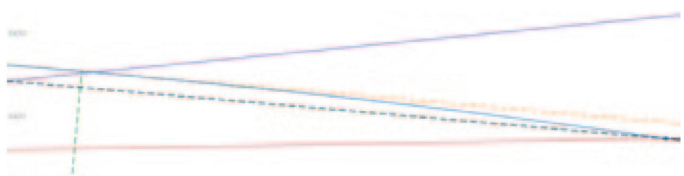

Figure 9 — Close-up of the left of centre portion of Figure 8 depicting the tangent solar ray above the mesopause for a solar altitude of −5° (with the Ldiff dashed green radial line set to +5°). The NLC along the blue arc appearing in the observer's field from the purple line at 5.6° altitude down to the red line at 1° lies in direct sunlight and can never be in a shadow.

The October *Journal* deadline for submissions is 2020 August 1.

See the published schedule at
www.rasc.ca/sites/default/files/jrascschedule2020.pdf

Section 1: Review of basic geometry

For the sake of clarity, the preceding schematics are presented as cross sections with the Sun directly north (to the right), west into the page, and the view rotated in latitude to place the observer at the top, making their zenith straight up. The term altitude here is used in the angular sense where the horizon is zero and the zenith 90, with all stated values in degrees.

Most published diagrams depicting the geometry of NLC are not to scale in order to emphasize the overall situation. However, this creates a challenge for the observer to reconcile the schematic with their experience. The ones here are to scale.

- Observer at O, centre-left, zenith straight up
- Solid green is Earth in cross-section, with west into the page
- Horizontal black line is the horizon extending northward, to the right
- Blue arc is the mesopause at 81 km; NLC reside here
- Purple line is the visible upper limit of NLC as seen by the observer (in this case 25°)
- Red line is a common lower limit of NLC as seen by the observer (1°)
- Orange line is a ray from the Sun, in this case at altitude of –10°, tangent to the tropopause (here 10 km). The lower left is in shadow while the upper right is in sunlight
- Green dashed line, radial from Earth's centre, shows how many degrees of latitude to the north NLC at the horizon can be, refraction not included.

Produced with the on-line free graphing utility at www.desmos.com.

Refraction by the atmosphere in the lowest couple of degrees is neglected in these diagrams, likewise the oblateness of Earth. Detailed discussion of these effects is beyond the scope of this article but does not impact the conclusions to a significant extent.

The diagrams can be interpreted in the same way for any dusk to dawn azimuth of the Sun, but the "angular difference in latitude" (variable Ldiff) becomes that of a great circle extending from the observer in the direction of the Sun.

Observers familiar with the details of lunar eclipses will be aware that the calculated size of the umbra is larger than for an airless Earth. The lower atmosphere where active weather occurs (the troposphere), replete with cloud and particulates, is effectively opaque due to the long paths taken by nearly grazing solar rays. Those rays below this so-called screening height Ht will not make it through to illuminate NLCs at the upper edge of the twilight arch. A typical value is 10 km (Taylor, Hapgood, Simmons, 1984), confirmed by the case study in the Appendix.

Section 2: What is the latitude of that NLC?

Angles in the sky and distances by great circle can be deceptive or surprising, even to an experienced amateur astronomer. Keen NLC observers will be very familiar with the AIM *(Aeronomy and Ice in the Mesosphere)* satellite output "daily daisy" that depicts the extent of NLC across the polar regions. For years the author assumed that if that image showed a mass of NLC north of 60° latitude, then at Edmonton (53.5° N) there ought to have been a notable display—but this was incorrect.

Once the math was coded and output made available to the timetable webpage, it became quite obvious that we don't get to see very far north. Table 1 answers the question "when I see NLC at X degrees altitude, how many degrees of latitude farther north is the NLC overhead?"

Altitude (degrees)	Latitude difference
30	1.4
20	2
10	3.7
4	6.1
2	7.5
1	8.4

Table 1

The result is that observers in Winnipeg (49.9° N) cannot see NLC that is north of 60 because it is below their horizon (with the exception of uncommon, extreme atmospheric refraction events).

This table also helps the NLC investigator take a report of NLC due north at 10° altitude from Edmonton (53.5° N) and look for NLC in the corresponding AIM image at a latitude of 57.2° N, instead of mistakenly accepting the cloud mass north of 60° to be the match.

Section 3: Shadow Geometry of Tropospheric Clouds

The question posed to the author by Alan Dyer is paraphrased as follows: Can NLC be present in our skies but lie in shadow and hence be invisible? This might explain the documented sightings and images of NLC in Nevada and northern California in 2019, yet not reported in British Columbia or Alberta.

It is instructive to explore and discuss a case study using typical values. The generalized formula is presented in the appendix.

For the 2019 June 29 event captured in Figure 1, the key parameters are: time 09:10 UT; solar altitude –10.6; maximum altitude of NLC with no tropospheric screening 26.5°; and with a screening height of 10 km the maximum altitude of

NLC is 19.2°. The NLC continues past Capella, altitude 15.8°, just left of centre near the very top of the frame.

Smoke from large, intense forest fires is often lifted into the lower stratosphere, where it can remain for weeks and be transported thousands of kilometres. Due to the limited vertical motion in the stratosphere, largely a result of the stability from the temperature structure (an inversion), such smoke would not reach heights much above the troposphere. Sunsets seen through smoke can range from deep orange to intensely red, therefore it should not be surprising to see the top part of NLC tinged red. As can be seen in Figure 4, tropospheric clouds cannot cast shadows onto NLC.

Section 4: Shadow geometry of Noctilucent Clouds

Some readers may raise the point that NLC must be too thin and translucent to cast shadows. This article deliberately does not address this in order to focus solely on the geometrical limitations.

An important characteristic to note about the geometry, as revealed in Figure 7, is that for NLC at point L (low in the observer's sky) to be in shadow, the opaque patch is relatively closer to the observer (smaller Ldiff). Conversely, for NLC at point H (higher in the observer's sky) to be in shadow, its opaque patch must be located at a latitude difference far larger. In this case it is actually outside the diagram's boundary on the right.

The appendix contains the formula for calculating point C's difference in latitude from that of the observer. The on-line graphical calculator at www.desmos.com/calculator/wg43qytrba allows the reader to extract the approximate values simply by moving sliders.

In the case depicted here (Sun at –10°, top of the NLC arch at 19°, and bottom at 1°), for NLC in that arch to be in shadow as viewed from Edmonton, it would require an opaque shield of NLC to extend from 65.3° to 72° N, that is 13.1° to 19.2° of latitude farther north than the observer.

Now consider the complement of the problem: assuming the higher-latitude NLC to always be opaque enough to cast a shadow onto lower latitude NLC, then in order to see the display in Figure 1 (Sun at –10.6°) there cannot be any NLC shield from 65.4° to 71.5° N. If we find out there is, then the assumption of sufficient opacity generally fails, along with the supposition that the lack of an NLC display can be attributed to shadows.

A distinct difference in shadowing geometry occurs when the local solar altitude is greater than –8.2°. The Sun's tangent rays match the slope of the mesopause somewhere in the arc visible to the observer. All NLC with an Ldiff north of [–1 × solar altitude] will be lit from above and therefore cannot be shadowed by anything.

To see NLC between the given altitudes there must be no opaque NLC in the latitude range to the north		
Solar Altitude	**Altitudes in the Observer's Sky**	**Latitude Difference**
-4	90-173	8.2-12.5
	30-90	6.4-8.2
	8.2-30	4.0-6.4
-5	90-170.1	10-13.5
	30-90	8.7-10.0
	5.6-30	5.0-8.7
-6	90-165	12-14.5
	30-90	10.8-12.0
	3.9-30	6.0-10.8
-7	90-155	14-15.5
	30-90	12.8-14.0
	2.4-30	7.0-12.8
-8	90-125	16-16.5
	30-90	15.8-16.0
	1.2-30	8.0-14.8
-9	30-56	16.8-17.5
	1-30	9.0-16.8
-10	15-25	17.5-18.5
	1-15	11.8-17.5
-11	8-15	17.9-19.5
	1-8	13.8-17.9
-12	1-10	15.8-20.5
-13	1-7	17.8-21.5
-14	1-4.8	19.8-22.5
-15	1-3	21.8-23.5
-16	1-1.7	23.8-24.5

Table 2 — NLC shadow range. To see NLC between the given altitudes there must be no opaque NLC in the latitude range to the north.

This result is more useful to the observer in tabular form:

Altitude of NLC Lit From Above	
Solar altitude	**Range (deg)**
-3	0-12
-4	0-8.2
-5	0-5.6
-6	0-3.9
-7	0-2.4
-8	0-1.2

Table 3 — The range in altitude of NLC in direct sunlight for a given solar altitude. It was created using the realtime online graphing utility.

It should be noted that this situation is almost a moot point from an observer's perspective because the foreground sky is generally too bright to see NLC in the listed ranges. The lack of visible NLC here is due to either physical absence or too low a contrast, not a shadow effect.

Section 5: Further research

To those unfamiliar with the details of the AIM satellite operation, it is a simple but incorrect logical chain to state "if the AIM daily daisy shows a shield of NLC in the occulting zone, but ground observations record a widespread NLC display, the opacity assumption fails." The satellite is in a polar orbit that only sees in strips or "petals," essentially taking 24 hours to cover the majority of the polar region. On many occasions, the satellite pass covering the area to the north may be 8 hours offset from that of the observers'. When one animates the daisy image from day to day the discontinuities or jumps in visible features are of such magnitude that tracking quickly leads to confusion.

In order to confirm or dismiss the effect of shadowing, a thorough analysis of AIM strips concurrent with ground-based observations is necessary.

What about the geometry of those cases when NLCs are well to either side of the Sun-observer azimuth? Although the math is somewhat more complicated by spherical trigonometry and perspective (analogous to the apparent spreading of crepuscular rays when they are in fact parallel), the resulting difference in geometry and values would be minor.

Conclusion

- Tropospheric cloud geometrically cannot contribute to shadowing NLC in the twilight arch. The troposphere however is the well-known cause of the upper limit (southern) extent of the ground-based visible display,

- If NLC is optically thick enough to cast shadows, then a display spanning 1–19° in altitude (solar altitude –10.6°), requires a gap in the NLC shield spanning 13–19° of latitude to the north,

- Notably, the AIM images also show isolated patches farther south, detached from the primary mass. It is possible that displays seen from south of 55° N are these patches, which could explain the perplexing absence in one location when they are present to other observers a thousand kilometres away (roughly equal to an arc of 10° of latitude),

- Further research required: to document cases of simultaneous ground- and space-based observations to confirm or rule out that vacancies and shields play a role in the visibility of NLC displays.

Significant challenges remain, those of spatial and temporal gaps in ground-based observations and limited temporal resolution of satellites ✶

Figure 10 — 2019 June 29 09:23 UT with 3 windows showing the maximum extent of the NLC.

Acknowledgements

The author would like to thank: Alan Dyer (https://amazingsky.net/) for suggesting this line of enquiry; https://www.desmos.com/ on-line free graphing utility.

Appendix

Case study of screening height

The stars and their altitudes are:

23 Uma 27.5; ups UMa 24.1; bet Cam 30.4; alp Per 30.3; del Per 26.8

The NLC has reached delta Persei, not alpha, but it comes close to reaching beta Camelopardalis, which is also very close to the same azimuth of the Sun. From geometry this is the line along maximum altitude (analogous to the meridian). A time-lapse of this event can be viewed here: www.youtube.com/watch?v=faB_Zx7Y7Fc. One can see the maximum altitude increasing with each passing minute as the rising Sun illuminates NLC farther south.

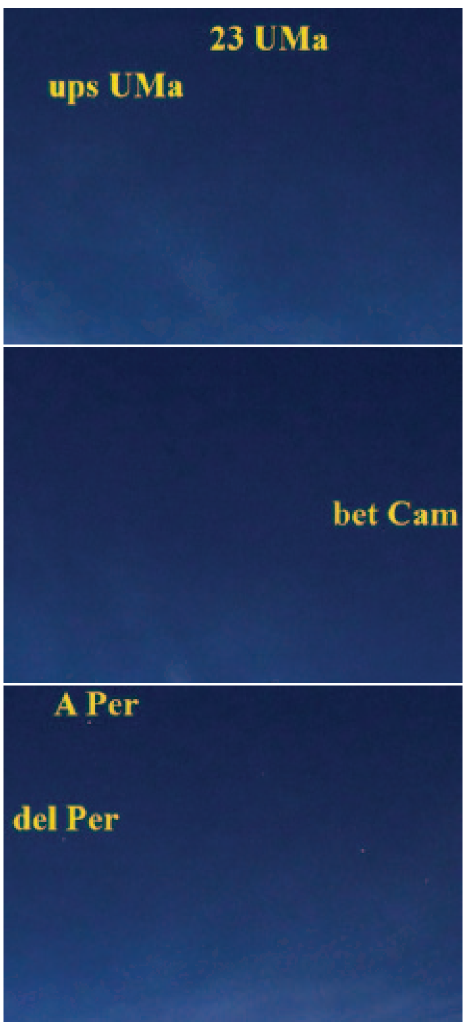

Figure 11 — Close-ups of 3 regions with background stars identified. The star is located just to the lower left of the constellation name label (e.g. lower left of the C in bet Cam).

At 09:23, geometry with a tropospheric screening height (Ht) of zero (airless world) indicates a maximum height of 46.7°, while an Ht of 10 km yields 29.8°, confirmed by beta Cam's altitude of 30.2°.

Calculation of Ldiff (Latitude Difference) to put point P in shadow

In Figure 7, P represents a point at the intersection of the mesosphere and a known angle Vp degrees above the horizon. For that point to be in shadow, how far around the horizon (Ldiff) must the occulting section of NLC be? The reader may use the online graphing tool to quickly obtain approximate values or the following equations can be used for more precision, while remembering the caveat of refraction when very close to the observer's horizon.

R_e : *radius of Earth;* R_m : *radius including mesopause;* V_p : *viewing angle;* S_a : *solar altitude*

$P(x_p, y_p)$ *lies on line* $y_p = \sin(V_p) \cdot x_p + R_e$

also lies on circle $x_p^2 + y_p^2 = R_m^2$

substituting in yields $x_p^2 + (\sin(V_p) \cdot x_p + R_e)^2 = R_m^2$

rearranging: $\left(1 + \sin^2(V_p)\right) \cdot x_p^2 + 2R_e \sin(V_p) \cdot x_p + \left(R_e^2 - R_m^2\right) = 0$

is a classic quadratic equation with all constants known.
Choose the root value that corresponds to the point P

For that point to be in shadow, it lies along the line

$$y_p = \tan(S_a) \cdot x_p + b \quad .$$

Since x_p, y_p, S_a *are known,* $b = y_p - \tan(S_a) \cdot x_p$.

The shadow casting point lies along the same line

$$y_c = \tan(S_a) \cdot x_c + b$$

which intersects the mesopause circle $x_c^2 + y_c^2 = R_m^2$.

Substituting yields: $x_c^2 + (\tan(S_a) \cdot x_c + b)^2 = R_m^2$

and rearranging: $\left(1 + \tan^2(S_a)\right) \cdot x_c^2 + 2b \cdot \tan(S_a) \cdot x_c + \left(b^2 - R_m^2\right) = 0$

One root value corresponds to the point P, the other to point C

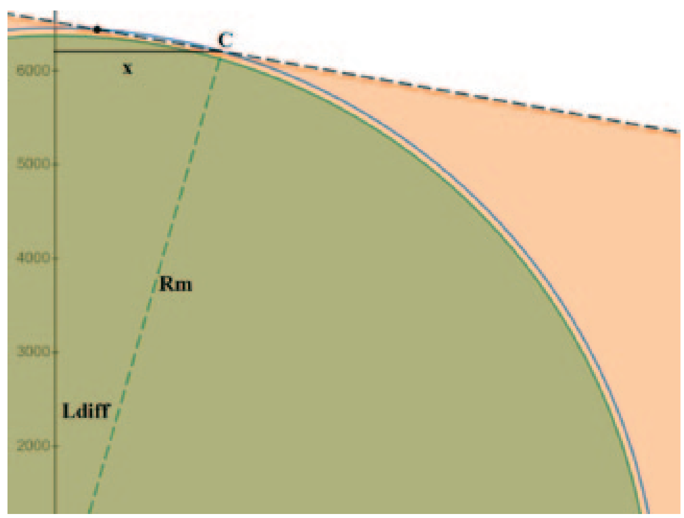

Figure 12a, b — The difference in latitude (Ldiff) between the observer and the occulting path

$$Finally,\ x_c = R_m \sin(L_{diff})\ or$$
$$L_{diff} = asin(x_c / R_m)$$

References

M.J Taylor, M.A Hapgood, D.A.R. Simmons The effect of atmospheric screening on the visible border of noctilucent clouds *Journal of Atmospheric and Terrestrial Physics Volume 46, Issue 4*, April 1984, Pages 363–367, 369–372

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Some Canadian Links to the Herschel family

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Abstract

Connections between the famous Herschel family of astronomers and Canada are found in a variety of contexts. Sir John Herschel took a direct interest in Toronto in particular as an important site in the worldwide network of magnetic observatories. Many relatives and descendants of the Herschels spent periods of time here and left their mark in various facets of Canadian life—in architecture, culture, education, law-enforcement, politics, as well as in astronomy and through gifts of letters and books. Moreover, explorers of the 19th century attached the Herschel name to many geographical features throughout Canada[1] as an indication of their esteem.

Family Ties

In the heyday of the British Empire, individuals made the difficult decision to leave the "old country" for many reasons. The very large families that were the norm until the 20th century increased the odds that some members felt the urge to leave home. Some immigrants, uprooted from farms back home, came out of desperation to escape poverty or even starvation. Those with middle-class aspirations often joined the military in Britain, served and eventually settled here if they received land grants. The nobility sought administrative roles for their younger sons who had no prospect of inheriting titles or family estates. Even as recently as the Second World War, children were sent to Canada to seek the safety that distance provided from enemy attacks at home. The Herschels, certainly by the 1780s, were well off but nonetheless sought opportunities abroad for some of these reasons. In retrospect, however, whatever benefits Canada bestowed on the Herschel clan were more than matched by their contributions to our nascent national life.

William Herschel [WH] and his sisters

In the public eye, William Herschel (1738–1822) made his greatest mark on the world stage with his 1781 discovery of the first planet beyond those known since antiquity. Though Uranus was the name ultimately settled on, the planet was generally called Herschel in popular instructional "geography" books and in almanacs used in Canada before Confederation, so the name was widely recognized even in our colonial backwaters[2]. Today, William Herschel's career as the builder of large reflecting telescopes and his use of them to catalogue double stars and nebulae is regarded as a more far-reaching contribution to the advancement of astronomy. William's youngest sister, Caroline (1750–1848), is remembered for her vital supporting role and her own talent for observing and discovering comets. Though both were born in Hanover (now part of Germany), all their astronomical work was done in England—not so unusual since George III was the ruler of both states. It should also be remembered that it was as musicians that both William and Caroline first gained recognition in England. Jarvis (2007) discusses the large migration of musicians from Germany and their influence in England in the latter part of the 18th century. Hoskin (2011), in his engaging account of the Herschels' lives, credits William and Caroline, after abandoning their musical careers, with transforming our view of the universe "from the unchanging, mechanical creation of Newton's clockmaker god to the ever-evolving, incredibly dynamic cosmos that it truly is."

Of special importance for the purpose of this article is WH's oldest sibling, Sophia Elisabeth (1733–1801). Details of her genealogy and that of her descendants is found in Hoskin (2007; 2011, xiii), Manz et al (2007), and on Local Family Database NLF (2012).

The Griesbach Connections

In 1755, Sophia Herschel married Johann [Joachim] Heinrich Griesbach, a musician, like the Herschels. They immigrated to England in 1778, settling in Windsor, less than an hour's walk from Slough where William and Caroline Herschel later did their observing. Consequently, there were frequent opportunities for the Herschels and the Griesbachs to interact. Among the Griesbach children were Carl Friedrich Ludwig (born 1760) and Friedrich (born 1769).

The older son, Carl (or Charles to use his Anglicized name), married in 1796 and had ten children, one of whom was (Reverend) William Robert Griesbach (born at Windsor in 1802 and died in Yorkshire in 1861). Among the reverend's children was Arthur Henry Griesbach (1839–1916) and among Arthur's children was William Antrobus Griesbach (1878–1945). These last two, a great-grandson and great-great-grandson of William Herschel's sister Sophia, are important in Canadian history.

Arthur immigrated at the time of the sale of Hudson's Bay Company lands to the new Dominion of Canada in 1870. He served as a British Army captain under General Wolseley whose duty was to quell the Red River Resistance. To ensure order, Prime Minister John A. Macdonald sought to establish a permanent police force in the west. Organizational plans were drawn up with the assistance of Arthur Griesbach, but it took until 1873 for the North-West Mounted Police Force (forerunner of the Royal Canadian Mounted Police, or RCMP) to come into being. Griesbach was among the first three to take the enlistment oath. He was charged with establishing discipline and structure within this new police force (Boles 2011). Griesbach was the Regimental Sergeant Major on the famous "March West" in 1874 when a 300-man force, guided by Métis scout Jerry Potts, made its initial foray onto the plains to put down the illicit whiskey trade and to attempt to build good relations with the First Nations. Later, Griesbach was posted to Fort Saskatchewan, Alberta, becoming superintendent there in 1885 where one of his challenges was a mutiny, which he capably resolved. His memory lives on there at the historic site known as the Fort Heritage Precinct. On retirement in 1903, Arthur and his wife Emmeline moved to Edmonton where, following his death on 1916 November 21, he was buried.

Arthur's son, William Antrobus Griesbach, was born on 1878 January 3 at Fort Qu'Appelle, Saskatchewan, and followed his father's military career, becoming Major General W.A. Griesbach OB, CMG, DSO, KC, a member of parliament, and a Canadian senator. A neighbourhood in northwestern Edmonton along with a police training centre, road, park, and community garden are named in his honour.

Sophia and Johann Griesbach's other son, Frederick (the name adopted by Friedrich after he immigrated to England), was one of many Griesbach musicians eventually in the court of George III and Queen Charlotte at Windsor and in fact he married Mary Frances Wyborow, daughter of the first master cook at Windsor Castle, in 1792. Though he was a celebrated oboist and a governor of the Royal Society of Musicians, he died in poverty and ill health in 1825 (Jarvis, p.46). Among their eight children was William Herschel Griesbach, born in 1795.

William Herschel Griesbach had a brief spell of military service in North America—hardly worth mentioning here except for the fact that his name seems to have become confused with that of his famous grand-uncle, the astronomer WH. Within a few years of his service, a number of accounts in rather obscure publications appeared, all purporting to show that great things could be accomplished by those with very humble roots. All claimed that William Herschel's interest in the stars was awakened while on sentry duty as a young soldier in Nova Scotia (See Figure 1). The first item in the list was published by the trustees of Allegheny College (1833), a small liberal arts college founded in 1815, 60 km south of Erie, Pennsylvania. Surely these trustees did not invent the notion that WH served in British North America, but their account is the earliest that I have seen. The likely explanation for the confusion of two William Herschels involved a lot of detective work, mainly done at my instigation by people who are acknowledged at the end of this paper.

> **"Herschel, a British soldier in Nova Scotia, first commenced studying the motion of the planets when walking on the sentry's post at night."** Report of a Committee of the Trustees of Allegheny College, on the Manual Labor System, published in the *Register of Pennsylvania* 12 (18), 2 November 1833, 2
>
> **"Herschel, the great astronomer, was a British soldier in Nova Scotia, and commenced the study of astronomy while watching at the sentry posts at night, and has fixed his name among the orbs."** S, "Pursuit of Knowledge Under Difficulties," *Zion's Herald* (Boston) 6 (no. 28) (15 July, 1835), 1
>
> **"Herschel, once a soldier in Nova Scotia, ..."** Anthony Atwood, *The Young Man's Way to Intelligence, Respectability, Honor, and Usefulness.* (Philadelphia: 1842), 47 and also (Philadelphia: 1850), 46
>
> **"Herschel, the immortal astronomer after whom one of the distant worlds is named, was a common soldier in Nova Scotia, and studied the stars while on duty as a sentry."** *The New England Cultivator* 1 (1852), 175

Figure 1 — Fake news from Antebellum America

From Vallée (2005), we find that late in the War of 1812, William Herschel Griesbach was recruited by the De Meuron regiment on 1814 December 8. He would have arrived on this side of the Atlantic only after peace had been declared. It is possible that his port of entry was Halifax and that he was stationed there for a while, but I have found no confirmation. The regimental records speak of very bad conditions in barracks that winter followed by marches and countermarches the following summer. The De Meuron regiment bivouacked at Burtonville, about 25 km south of Saint-Jean-sur-Richelieu, Québec. Griesbach was promoted from ensign to lieutenant in January 1816, but the regiment was disbanded in July and Griesbach was put on half-pay until 1817. Though many members of the regiment accepted land grants and remained in Canada, Griesbach was among those who left Canada for England in September 1816. According to the *United Service Magazine* for 1831 (p. 566), he—among others—received a commuted allowance for his commission and the half-pay provision was cancelled as of 1831 November 18. At some point, Griesbach had returned to his ancestral Germany and apparently led a difficult life, as may be judged by letters to WH's son, John Herschel, in 1823 and 1827, asking for money. (Brief descriptions of these and most of the known letters to and from John Herschel are found online in *Calendar of the Correspondence of Sir John Herschel Database*, hereafter referred to as *Calendar*). There is one known reply in 1847 wherein John Herschel sent him a £5 note saying he can spare no more, that he has no recollection of ever meeting him, and that their relationship is very remote. Before signing off, John wished him a speedy improvement in his prospects. William Herschel Griesbach died in 1871 in Hanover.

John Herschel [JH]

WH's only child, John (1792–1871), greatly admired and extended his father's work on double stars and nebulae, but also developed much more eclectic interests. Though he had a rather lonely childhood, the same cannot be said for his adult life. Partly because of his father's fame, but also because of his own genius and involvement in many diverse fields, he was constantly in demand. His idyllic marriage was blessed with 12 children. At least three of them had descendants who spent some time in Canada. Before discussing who they were and what they did, John Herschel's own impact on Canada's history should be acknowledged.

In the 1830s, JH joined with others in the British Association for the Advancement of Science in launching a worldwide campaign called the Magnetic Crusade, which gave rise to a network of magnetic observatories, including one in this country (Cawood 1979). Moreover, during his years in South Africa (1834–1838), Herschel had instituted a system of meteorological observations and was keen to combine the study of weather and geomagnetism in "physical observatories" throughout the British Empire. The *Calendar* of his correspondence includes hundreds of letters written between 1835 and 1858 dealing with these subjects, most of them written to JH by Colonel Edward Sabine, the superintendent of colonial observatories from 1839–1853. During this period, Sabine worked at Woolwich with non-commissioned officers in the Royal Artillery, though earlier in his career Sabine had served in Canada at almost the identical period as William Herschel Griesbach (Levere 2003).

The British government established a geomagnetic observatory in Toronto in 1840. The first two officers in charge, Charles Riddell and John Henry Lefroy, received instruction from Sabine and advice from JH himself (Thiessen 1942). Lefroy was far more than a merely obedient observer; he realized there was a connection between appearances of the aurora and magnetic disturbances and in 1847 sent very detailed instructions for recording the aurora to commanding officers at Quebec, Kingston, London and Montreal and hoped to extend the network to stations in Fredericton, Halifax, and Newfoundland. In asking his fellow officers to keep such meticulous records, he wrote, "I cannot give a better proof … that [your] trouble will not be thrown away, than by copying a passage in a letter from Sir John Herschel to Colonel Sabine who favored me with a copy of it." Here is the portion he quoted:

> I have read with a great deal of interest as well as instruction, the journal of the appearances and nonappearances of the Aurora Borealis, kept in the Guard Rooms at Kingston and Quebec by the N.C. officers on duty. The way in which the entries are made, and the clear and intelligible way in which the appearances are described are not only very creditable to the parties making them, but very interesting in themselves when compared *inter se* and with the magnetic observations made in the Observatory of Toronto." (Thiessen 1945).

This letter (not included in the *Calendar*) implies that Herschel's name was familiar to the military personnel stationed in Canada. More generally, the literate population of Toronto (total population about 30,000) would have been acquainted with the Herschels from articles in *The Globe* newspaper. For instance, on 1847 March 20, alongside an article from the *Westminster Review* about the recently discovered planet (Neptune) was another, reprinted from the *Dublin Evening Post*, comparing Joseph Mädler's description of the structure of the Milky Way with John Herschel's. A lecture in the Mechanics' Hall on 1850 March 15 included a discussion of these rival theories. Herschell's [sic] new book, *Outlines of Astronomy*, was advertised in *The Globe* newspaper starting in February 1850. This popular book went on to be published in 11 editions by the time of Sir John's death.

By 1853, the British authorities planned to close the Toronto observatory and withdraw the military personnel who had staffed it. The Canadian Institute (*Canadian Journal* 1853) addressed the issue in a memorial to the Legislative Council of the Province of Canada in which they advocated not only maintaining the magnetic and meteorological work of the observatory but expanding its scope to include astronomy. In support of their cause, they reproduced letters from influential scientists originally addressed to The Earl of Rosse, President of the Royal Society, urging the continuance of the Toronto observatory. One of these letters was from Sir John Herschel (1850); it is among those listed in the *Calendar*.

Aside from the letters listed in the *Calendar* that deal with Canadian contributions to geomagnetism and some that only make passing reference to Canada, there are two to John Galt in 1817, one from George Paxton Young in 1860, and the letter(s) from JH to Charles Babbage already discussed in *JRASC* (Chant 1944; Rosenfeld 2009), which are connected to Canada only by their provenance. The two letters to Galt concern Herschel's editing of mathematical manuscripts by Galt's late friend William Spence but, since they predate any connection of Galt to Canada and since their context has been carefully discussed by Craik (2013), no more will be said about them here. That leaves only the letter from George Paxton Young (1818–1889). At the time of writing his letter in 1860, he was teaching in both the divinity and the preparatory departments at Knox College in Toronto. With his letter he enclosed one of his published papers, likely Young (1859), containing his proof that the solutions of equations above the fourth degree cannot be represented by finite functions and showing how roots of higher degree equations could sometimes be found. This seems to be early evidence of original mathematical research in Canada, though in this case, similar results had previously been published by renowned European mathematicians (Alexander 2010). Herschel's reaction is unknown, but according to Gidney (1982): "Throughout [Young's] life he pursued an early interest in mathematics, publishing in Canadian, American, and English journals a number of papers on the theory of equations which drew high praise from eminent mathematicians of the time."

Descendants of John Herschel

Longtime readers of the *Journal* may recall a three-part series about the Herschel family written by Peter Millman (1980). In the August installment, he included a family tree showing some of William's ancestors and descendants. While it is a helpful resource for understanding what we are about to explore, Millman did not mention any Canadian connections.

John Frederick William Herschel (1792–1871) and his wife Margaret Brodie Stewart (1810–1884) had 12 children. Those whose names appear later on in this paper are:

Caroline Emelia Mary (1830–1909)
William James (1833–1917)
John (1837–1921)
Matilda Rose (1844–1914)
Francisca (1846–1932)

The three women are included in Figure 2; the two men were shown in Millman (1980, p. 280) along with their astronomer brother, Alexander S. Herschel, in a photo taken in 1883.

The first child of JH and his wife Margaret was born in 1830 and named Caroline after John's beloved aunt. Indicative of the social milieu in which this generation of Herschels moved, she married Alexander Hamilton Gordon in 1852; he was a son of George Hamilton Gordon, fourth Earl of Aberdeen, who was just embarking on a three-year term as prime minister of Great Britain. Genealogical details of this branch of the family can be found in Dewar (2001). This prime minister's oldest son to survive him was the fifth Earl and he was the father of the sixth Earl of Aberdeen who served as Canada's governor general from 1893–1898. He was thus the nephew of Caroline's husband. A tangible link to the governor general and his wife still exists: earlier, on a world tour, the Aberdeens had fallen in love with the beautiful Okanagan Valley and purchased a ranch that they named "Guisachan," after Lady Aberdeen's father's estate in Scotland. Today the house operates as a restaurant in Kelowna, appropriately located on Gordon Drive.

Another interesting Canadian connection can be found further down that same line of Herschel descendants. One of Caroline and Alexander's granddaughters was Eileen Hamilton Gordon (1889–1976) who married Patrick Maxwell in 1912. One of their children was Joan Maxwell (1914–1984) who married an RAF officer, John Tomes, in 1936. The Tomeses moved to Toronto during World War II and had three sons who attended Davisville Public School. Before the family returned to England in 1950, Joan Tomes presented a treasured letter in her possession to the David Dunlap Observatory.

The letter was written by her great-great-grandfather, Sir John Herschel. It, along with related documentation, is now in the Fisher Library at the University of Toronto (manuscript collection 82.031). According to a letter that Mrs. Tomes wrote to the DDO Director, J.F. Heard, on [1948] October 8, she had visited the observatory earlier where she had a chat with Professor Ralph E. Williamson. He was, she said, able to tell her more about her ancestors than she knew herself. But she did add:

> My ancestors were so prolific and long-lived (my grandmother died last year at the age of 87) that they got around a good bit, and did everything from finding planets to governing Singapore. The one I admire most had seven daughters, was an impoverished Irish peeress, and got them ALL married to titles! She beat Jane Austen's Mrs. Bennett into a cocked hat—but I more than digress! … We are much looking forward to Tuesday night —I can say that with confidence since you promise not to make me make a speech.

Figure 2 — Some of the daughters of John Herschel ca.1860, probably at the Herschels' country home, Collingwood House, Hawkhurst, Kent. Caroline is leaning on an urn, Francisca is holding a large straw hat, and Matilda is at the extreme right. (© National Portrait Gallery, London x44697)

She was evidently referring to a meeting of the Toronto Centre, hosted by the David Dunlap Observatory, north of Toronto, on Tuesday, 1948 October 12 (Tuck 1949). Retired director, Dr. C.A. Chant, spoke to the group on "The life and work of Sir William Herschel.[3]"

This above correspondence is accompanied by notes about the Herschel family apparently sent to Mrs. Tomes by her mother, Eileen. Other than information that is common knowledge, Eileen speaks of her two great-aunts, JH's daughters, Francisca and Julia who lived into the 1930s:

> [They] kept Observatory House going in Slough, and I remember visiting them as a child and being shown the telescope. A number of the lenses that William had ground had recently been discovered in an attic, and one of the very tiniest ones (about the size of a large pin's head) had been lost, and they had just found it again by sifting through the dust in the attic. I gathered that the box had been opened abruptly with no knowledge of its contents and the lens spilt. …
>
> Observatory House was taken over during the war as offices, etc., and I am not clear who lives there now.

The aunts died just before the war, and John's eldest son (William) married, has a son John, who is clergyman living at Bracknell, but as he is unmarried the title now ceases.

[Sir] John's eldest child Caroline was Woman of the Bedchamber to Queen Victoria … and did a number of water-colour paintings at Victoria's request of their informal picnics etc. which hang in my mother's house now. She also posed for the statue of Victoria which is now at the bottom of Pall Mall, London. … The room at Slough where the Herschel treasures were when I saw them is in the stables and I think it is still kept as a Herschel Museum.

Observatory House, where JH was born in 1792 and where William died in 1822 has been demolished and the site is now occupied by a modern office building. (See https://en.wikipedia.org/wiki/Observatory_House)

John Herschel's Letter

The letter that Joan Tomes donated is endorsed on the outside "Sir John Herschel to Lady Bell on the death of my dear Bana Bell." With the help of Heard's written decipherment of the letter, here is what it says:

Halton Aug 20/65

My dear Lady Bell

We all condole with you very heartily on the sad loss you have so lately sustained in your excellent & valued niece from whose society you received so much comfort as well as such valuable assistance in that labour of love on which you have bestowed so much of your time and care. It is so natural as we advance in years to see our old contemporaries drop away from our sides as to be hardly a matter of lamentation or excite any sadder feeling than the "wish to be with them and at rest" but to lose in age those to whose love we have looked for support & comfort & who we might reasonably have hoped to survive us must be sad indeed. Your letter which was addressed to the Nelsons[4] has been delayed in consequence and has followed us hither and my dear Margaret who is here with me—due to circumstances that she cannot write tonight deputes me to tell you how very deeply she sympathizes with the sorrow of so old and dear a friend—as well as to thank you for your kind congratulations on our Maria's approaching change of state[5]— with every reasonable prospect of its being a very happy one—Good sense, Good talent—amiable disposition—and more than a competency. Such & so mixed are the events & feelings of this life of ours! I shall leave room for the chance of her being able to add a few lines before the post goes out & meanwhile believe me my dear Lady Bell

Yours most truly

J F W Herschel

The letter raises at least four questions that can be partly answered by referring to the *Calendar* of Sir John Herschel's correspondence, although the letter itself is not listed there:

1. Why was Herschel writing from Halton, since that was not his home?

When he wrote this letter, JH was apparently visiting cousins at Halton in Hastings. (See his letter of 1863 April 7 listed in the *Calendar*.) Halton was about 20 km south of Collingwood, near Hawkhurst, Kent, the country estate of the Herschels since 1840[6].

2. Who was Lady Bell?

In the *Calendar*, one finds a letter listed from Marion Shaw Bell (1786–1876), written a year after the one just quoted, and she is evidently the person to whom the above letter was addressed. She was then the widow of a renowned physician, Charles Bell (1774–1842), author in 1830 of a book that made him famous, *The Nervous System of the Human Body*, but usually remembered today for his description of the palsy which bears his name. Marion and Charles married in 1811. Charles Bell became an FRS in 1826 and was knighted in 1831; his wife would then have become Lady Bell. Herschel knew Charles Bell as shown by correspondence between them in 1832 concerning a possible professorship for Herschel at Edinburgh University. Moreover, Lady Bell was conversant with outstanding scientists of the time as is evident in a letter, dated 1847 February 11, to her from Sir Charles Lyell in the Lyell papers, American Philosophical Society.[7]

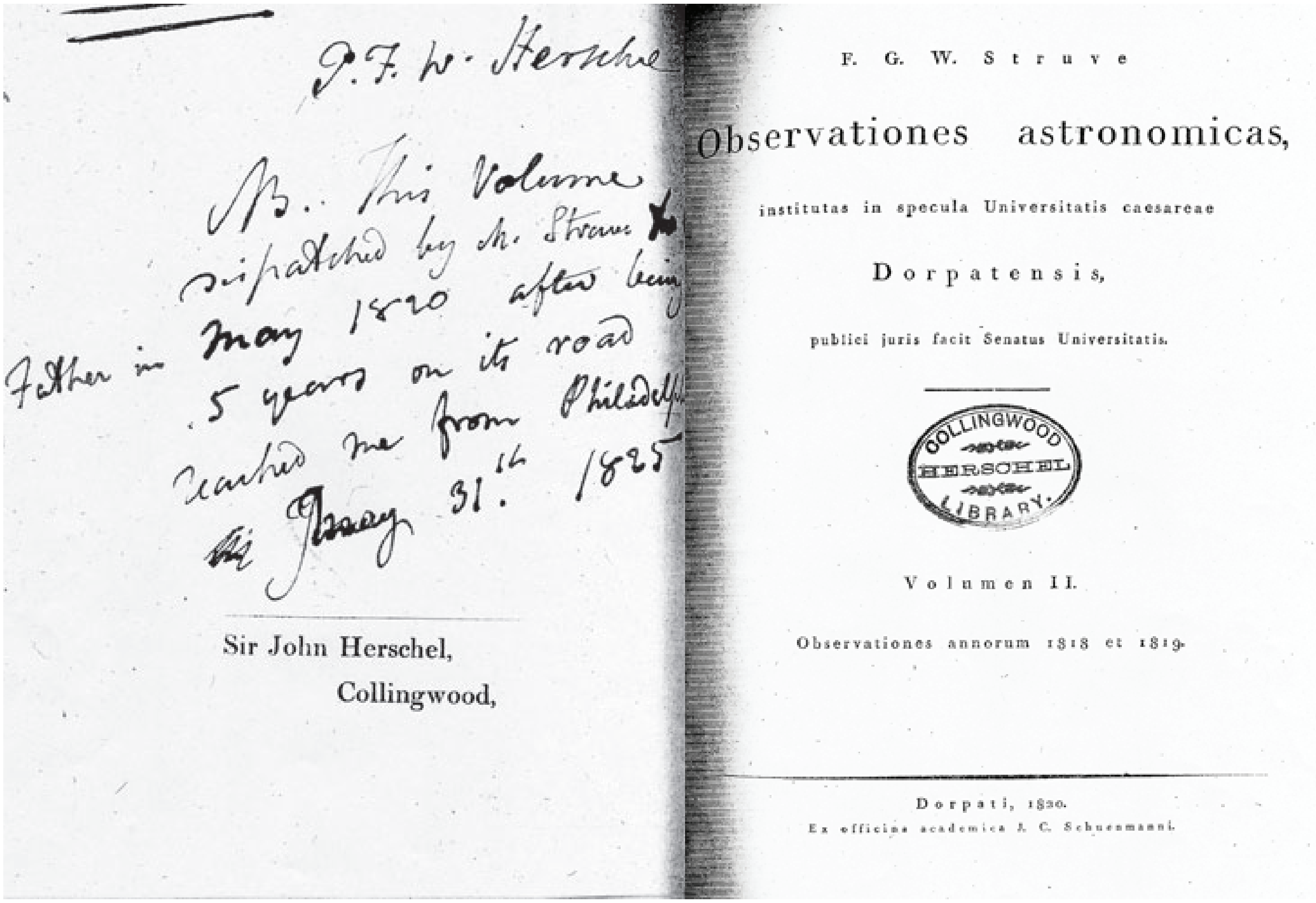
3. Who was Lady Bell's niece that John Herschel spoke of as Bana Bell?

Many years after the death of her husband, Lady Marion Bell (1870) edited the *Letters of Sir Charles Bell*. The letters had been sent by Charles to his brother, George (1770–1843), who married Barbara Shaw in 1806, sister of Marion. (Barbara died in 1827.) George Bell became renowned as a Scottish legal scholar. One of the daughters of George and Barbara was herself Barbara, who at age 56 died unmarried at Broughty Ferry on 1865 August 13 (Shaw 1881?). She was undoubtedly the niece who gave "valuable assistance in that labour of love"—editing the correspondence—on which Lady Marion bestowed so much time and care.

4. Why did this letter end up in the possession of the descendants of the writer, not the recipient?

Since the letter does not appear to have been mailed, it is likely a draft copy, kept by JH as a record of what he said. There are hundreds of draft letters listed in the *Calendar*.

The donation of this letter elicited nothing in the RASC *Journal*, unlike the earlier article by Chant (1944) describing the letters written by John Herschel to Charles Babbage.


J.F.W. Herschel

N.B. This Volume dispatched by M. Struve to Father in May 1820 after being 5 years on its road reached me from Philadelphia the May 31st 1825

Sir John Herschel,

Collingwood,

F. G. W. Struve

Observationes astronomicas,

institutas in specula Universitatis caesareae

Dorpatensis,

publici juris facit Senatus Universitatis.

COLLINGWOOD HERSCHEL LIBRARY

Volumen II.

Observationes annorum 1818 et 1819.

Dorpati, 1820.

Ex officina academica J. C. Schuenmanni.

Figure 3 — The flyleaf and title page from one of many books from Sir John Herschel's library donated by his son to the University of Toronto in 1893.

Perhaps this happened because the letters to Babbage were donated to the RASC rather than to the DDO, or perhaps they were seen to be of greater interest than this personal letter to Lady Bell. In any event, all that came out was an oblique reference to it in a Toronto Centre report (Tuck, 1949). At this first regular meeting of the fall season of 1948, RASC members were guests of the Observatory staff. It was noted that "the presence at the meeting of one Sir William's direct descendants, Mrs. Tomes, added interest to the occasion." The only published reference to the letter seems to be a reproduction of part of it on the cover of the observatory's in-house newsletter, *David Dunlap Doings* Vol. 6, no. 8, 1973 August 28. While J.D. Fernie concluded the same issue of the *Doings* with a delightful essay on John Herschel, he made no further mention of the letter. Its existence is not (yet) noted in the *Calendar*.

Other descendants

JH's eldest son, William James Herschel (1833–1917) spent the early years of his adult life in the Indian civil service where he devised fingerprinting as a means of identification, an innovation for which he is widely remembered. On the death of JH in 1871, William inherited the title Baronet of Slough which had been bestowed on his father in 1838 by Queen Victoria as well as Collingwood, the family estate and library at Hawkhurst, Kent. Sir William Herschel, as he then became, spent little time there even after his return to England. So, when the University of Toronto made an appeal for books following a devastating fire in 1890, Sir William became one of the largest donors. In all, he donated 582 bound volumes and 200 unbound periodicals from Sir John's collection to the University of Toronto library. This magnificent gift and its recent recognition have been described elsewhere (Broughton 2013).

One of the volumes with JH's inscription on the fly leaf is show in Figure 3. From the point of view of provenance, it is one of the most interesting of his UofT books. Wilhelm Struve had sent his published star observations to the older William Herschel, whom he highly esteemed, in the 1820s. Through some error they were sent to Philadelphia. As the note written by John Herschel states, the volumes did not reach England until 1825, by which time WH was dead. An interesting tie-in is found in the *Calendar* of Herschel correspondence for 1822 May 5 where Struve inquires about copies he had previously sent to William Herschel offering to replace them if they have been lost.

The donor of these books, William James Herschel, had married Anne Emma Haldane Hardcastle[8] in 1864 and they had four children, the youngest being Arthur Edward Hardcastle Herschel (1873–1924). Arthur worked for a time in Canada for an important architectural business based in Montreal, by the name of Brown and Vallance. The firm is remembered for designing the campus and six buildings of the University of Saskatchewan starting in 1909, the medical building at McGill University (1910), and two landmark buildings in Calgary—the offices of Canada Life (Figure 4) and Southam Press—both erected in 1913 at the very time that Arthur Herschel was their representative in that city.

One of Arthur's daughters was Caroline Winnifred Herschel (1906–1985) who spent some of her childhood years in Canada (Stott and Fanning 1986). The family returned to England probably in 1914, and many years later Caroline worked to preserve her great-great-grandfather's house in Bath as a museum. Over the years, RASC members have enjoyed a visit to that site where William Herschel discovered what we now know as the planet Uranus in 1781. Though once threatened with closure, the house is still a must-visit museum for any astronomy enthusiast (McGregor, 1984).

Still another descendant—one who actually pursued astronomy in Canada—was William Frederic Herschel Waterfield (1886–1933). He was the son of Rose (JH's seventh daughter) and William Waterfield. A report of a meeting of the British Astronomical Association (Grant 1911) states that a letter had been received "from Mr. W.F.H. Waterfield of Oxford offering to lend any member a 12½ inch reflector for four or five years as he was going abroad." More details in an unsigned obituary (*MNRAS* 1934) tell us that young William Waterfield, while he was an undergraduate at Oxford, had

Figure 4 — Arthur Herschel was the representative of the firm Valance and Brown when they designed and built the Canada Life building, 301-8 Avenue SW, Calgary (Alberta Culture and Community Spirit, Historic Resources Management Branch, 2006; https://open.alberta.ca/licence?fbclid=IwAR1GxjJdMW3XOJ-9Knxd1ms8knw62dp3GaPk5c-cAukFRRUcwd03jBCd65xU). The Southam Building which they also designed at the same time was demolished in 1972.

the use of his father's 5-inch refractor but when his interest in astronomy blossomed, his uncle, Colonel John Herschel, gave him a 12¼-inch equatorially mounted reflector made by [George] Calver. The 1921 Canada census for Nakusp, British Columbia, indicates that William and his wife, Aimée, arrived here from England in 1913—incidentally a year of record immigration that has never been surpassed. They may have been encouraged to immigrate by a relative who was a land agent. In any case, William's move and subsequent war service put his avocation on hold, but once he was settled on his farm, he was able to put the Calver telescope to good use (See Figure 5). With such a sizeable instrument, Waterfield was able to see down to magnitude 14.2—fainter than most other amateurs at the time. On the recommendation of J.S. Plaskett, director of the Dominion Astrophysical Observatory near Victoria, B.C., he joined the American Association of Variable Star Observers in 1921 (Campbell 1921). Their database shows that he submitted several thousand observations to them and to the Variable Star Section of the British Astronomical Association. Within three years, Harlow Shapley (1924), the director of the Harvard College Observatory, called Waterfield "easily one of the best observers" in the AAVSO and (without realizing the origin of his membership) recommended him to Plaskett as a possible replacement when Reynold Young moved from Victoria to Toronto in 1924. (Joseph Pearce filled that vacancy instead.) Waterfield (1923) published an appeal to amateurs to observe variables with examples from his own experience, and went on to author 24 more technical papers between 1926 and 1932 after Shapley hired him, initially as chart curator for the AAVSO, and later as chief assistant at Harvard's Boyden station in Bloemfontein. Sadly, William who had lost his wife in a drowning accident in Canada leaving him with two young children, himself died at age 47 in a motorcycle crash in South Africa. His obituary by Leon Campbell (1933) contains many mistakes but does record Waterfield's considerable ability as a pianist and his great love of classical music, an interesting connection to his ancestors not included in *MNRAS* (1934). His name is immortalized in the heavens and on Earth: minor planet 1645, discovered in 1933 by Karl Reinmuth, was named Waterfield to jointly honour William and his cousin Reginald Waterfield (1900–1986). The latter was a haematologist at London's Guy's Hospital and was an outstanding amateur observer and author of astronomy books. Near Nakusp are Waterfield Road and Herschel Creek (Nesteroff 2018). In the next section we shall explore several more prominent landmarks bearing the Herschel name that dot the Canadian landscape.

Canadian Geographic Features named for Herschel

As already noted, John Herschel had a strong interest in terrestrial magnetism. Explorers like Franklin, Parry, and

Continued on page 170

Ron Brecher is an accomplished astrophotographer who took this lovely photograph of NGC 6366, which he says "is usually overlooked in favour of the splashier globular clusters of Ophiuchus, like M10, M12 and M14." Ron imaged the globular cluster from his SkyShed in Guelph using his Sky-Watcher Esprit 150 ƒ/7 refractor and QHY 16200-A camera with Optolong UV/IR filter. Chrominance was taken using a Takahashi FSQ-106 ED IV at ƒ/3.6 and QHY367C one-shot colour camera with Optolong UV/IR filter. Total imaging time was 13 hours and 32 minutes.

The Crescent Nebula in Cygnus "is a real beauty in my opinion and quite unusual", says Klaus Brasch. This image is a composite of 4 x 8-minute frames taken with his 12.5-inch PlaneWave shooting at ISO 6400 with a Canon 6D Mark II through an IDAS nebula-boosting 2 filter.

Pen & Pixel

A favourite of many astronomers, Michael Watson photographed The Whirlpool Galaxy (M51) from Algonquin Provincial Park in Ontario. Michael used a Nikon D810 camera at ISO 5000 on an Explore Scientific 152-mm apochromatic refracting telescope mounted on an Astrophysics 1100GTO equatorial mount. Exposure: 15 stacked frames at 60 seconds, *f*/8 unguided. Subframes stacked in Registar, processed in Photoshop CS6.

Sheila Wiwchar photographed this stunning shot of the Milky Way in Kaleida, Manitoba, in June. It is a two-pano shot taken with a Canon 6D and a Sigma 20-mm f/1.4 lens at ISO 3200 for 20 seconds.

Continued from page 167

Sabine (all members of the RAS) followed his advice. So, it is no surprise that they would name landmarks after Herschel, especially in Canada's Arctic where the north magnetic pole resided. Of course, Herschel was not the only scientist to be so honoured. Several examples are given by Burn (2009). One even finds the "Astronomical Society Islands" in the Arctic named for the RAS.

The Canadian Geographical Names Database website (www.nrcan.gc.ca/earth-sciences/geography/querying-canadian-geographical-names-database/9170) lists 13 features with "Herschel" in their names—12 currently official, and 1 previously official (See Figure 6). Generally speaking, it is difficult or impossible to find who "christened" these features or even which Herschel was being honoured. For example, the southernmost Arctic landmark to bear the Herschel name is now called Cape John Herschel to distinguish it from two other capes in Nunavut, but that was not so originally. Thomas Simpson, sent overland by the Hudson's Bay Company to explore the Arctic coast, merely wrote on 1839 August 26: "Our people erected another lofty cairn, to commemorate our discoveries; and the place was called Cape Herschel, after that distinguished astronomer" (Simpson 1843).

The earliest naming, in August 1819, and one of the clearest attributions, Cape William Herschel, is found in William Edward Parry's *Journal of a Voyage for the Discovery of a North-west Passage*… "A remarkable headland, on the western side [of Maxwell Bay], I named after Sir William Herschel." Parry had visited William and John Herschel in 1817 and John Herschel was one of the signatories when Parry was elected to the Royal Society in 1821.

Herschel Island was so named by Sir John Franklin in 1826 on his second overland expedition to the Arctic though the traditional name is Qikiqtaruk. This is the one instance where the nomenclature has been the subject of careful study. Chris Burn (2009) published a detailed article on the subject arguing convincingly that John Herschel was being honoured, though Franklin did not specifically say so. Besides their mutual interest in terrestrial magnetism, and their membership in the Royal Society and the RAS, the two men were next-door neighbours in London's Devonshire Street. In recent times, four other features associated with Herschel Island were later given the Herschel name: a territorial park and a settlement on the island as well as two undersea features—a sill and a basin.

Franklin set out on a third voyage to the Arctic in 1845 and never returned. When the earliest British search expeditions failed to locate Franklin or his remains, his widow appealed to the U.S. A wealthy American, Charles Grinnell, financed two expeditions. On the second of these, Elisha Kent Kane (1857) was the captain. In the course of Kane's travels to the very far north, and while icebound during the winter of 1853–1854,

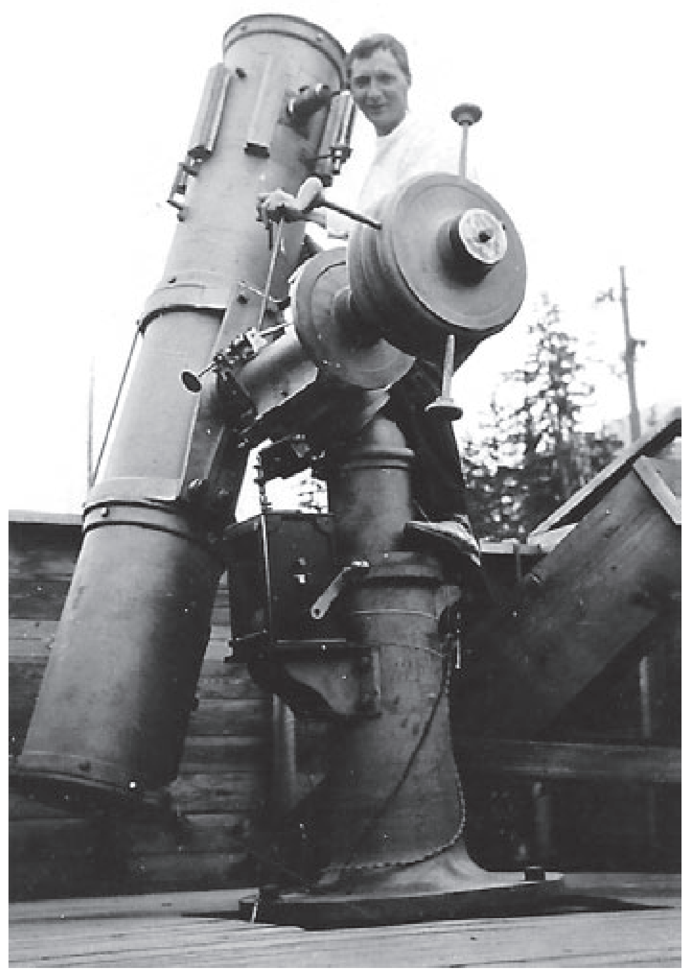


Figure 5 — William "Bill" Waterfield in 1924 with his 31.5-cm Calver reflector in his observatory at Nakusp, British Columbia (AAVSO Archives). It is possible that W.H. Pickering (1926) bought this telescope.

he apparently named dozens of features, including "Herschell Bay.[9]" The name Herschel for the adjacent cape was adopted in 1904 when a Canadian expedition led by Albert P. Low landed there and claimed it as Canadian territory. (See Figure 7).

Though Franklin did follow the North Saskatchewan River on his earlier overland expeditions, he would not have named the hamlet of Herschel, Saskatchewan, at least 100 km to the south. The settlement first appeared on a railway survey in 1910. Though local historians agree it was named for Sir John Herschel, I have not been able to find any first-hand account of who proposed the name or why. A surprising fact, however, is that a popular brand of backpacks is named for this tiny village where the owners of the Herschel Supply Company originated[10]!

In more temperate climes, Herschel's name is attached to one of the 30,000 islands in Georgian Bay. Situated in the northeastern part of the bay near the outlet of the French River, it is found close to two other islands named after the magnetic surveyors, Lefroy and Sabine, so it seems likely that they were named simultaneously. Though Captain Henry W.

Figure 6 — Map showing the approximate location of places named in the article.

Bayfield of the Royal Navy surveyed those waters in 1822–25, and in fact named a prominent bay Parry Sound in honour of the Arctic explorer, W.E. Parry, the date of his survey is too early for the Lefroy and Sabine names.

Also, in southern Ontario is a rural township named Herschel. Until amalgamation in 2000, this township in Hastings County was one of a contiguous group bearing scientific names: Airy, Faraday, Lyell, Murchison, Sabine, and Wollaston. All, including both WH and JH, were Fellows of the Royal Society and eventually each received its prestigious Copley medal. It is tempting to think that the originator of these township names was intimately familiar with the elite of British science though, unfortunately, I have found no definite proof of who named the townships or when, or even whether JH or WH was being honoured. It is much more likely to have been JH with whom all the others carried on copious correspondence. The date of the naming must have been after 1847 when Publius V. Elmore was commissioned to survey the line of a road through the "waste lands of the Crown," and 1851 or 1852 when he drew up a "Plan of a tier of lots laid out from the rear boundary of the Township of Madoc towards the Ottawa River" on which the "scientific" townships were named[11]. It is dubious that the surveyor himself would be given the privilege of assigning official names; a more likely candidate would be John Henry Lefroy. As we have seen, he came to Canada in 1842 to superintend the Toronto observatory, a position he held until 1853. During those years he travelled widely, making magnetic observations in the far northwest, and in 1848, he himself became a Fellow of the Royal Society. In 1846, he married the daughter of Chief Justice Sir John Beverley Robinson, perhaps the most influential member of the so-called Family Compact that held the reins of power in Upper Canada. It would be hard to imagine

Figure 7 — The expedition headed by A.P. Low hoisted the Canadian flag at Cape Herschel on Ellesmere Island on 1904 August 11. A document claiming Canadian sovereignty was placed in the large rock cairn built on the end of the cape. (Photo courtesy Geological Survey of Canada / Library and Archives Canada / PA-038265)

anyone in a better position to get the townships named for British scientists than Lefroy.

Conclusion and Acknowledgements

As I come to the end of this octopod tale with tantalizing tentacles reaching many parts of Canada, I hope that those who know the Herschels mainly through the celestial objects they discovered and catalogued will also feel a terrestrial affinity to the remarkable family that they spawned and the Canadian sites associated with them. Perhaps you will uncover other links lurking unknown in our midst.

I am grateful to a great many people for assistance in researching this paper. Most notable is Woody Sullivan who first alerted me to the possible confusion between William Herschel and William Herschel Griesbach and to Phil Mozel and Frederick Carsted who helped me figure out what Griesbach did in Canada. Mike Saladyga and Sara Beck of the AAVSO were very helpful in connection with W.F.H. Waterfield.

End Notes

1 "Canada" is meant throughout this article to refer to the present extent of the nation rather than the restrictive pre-Confederation meaning.

2 www.canadiana.ca is a convenient website for finding nearly all books relating to Canada that were published more than a century ago.

3 William Herschel was not officially knighted. See Hanham and Hoskin (2013)

4 The Nelsons, one gathers from other Herschel correspondence, apparently managed the Herschel home in Slough

5 Herschel refers to his wife, Margaret, and their daughter Maria's approaching marriage to Henry Hardcastle.

6 Early in 2020, Collingwood House was for sale. See https://open.alberta.ca/licence?fbclid=IwAR1GxjJdMW3XOJ-9Knxd1ms8knw62dp3GaPk5ccAukFRRUcwd03jBCd65xU

7 The same society also has a letter to Herschel from Lyell, dated 1846 July 1, but it is not included in the Calendar.

8 Anne Emma Haldane Hardcastle was the daughter of Alfred Hardcastle of Hatcham House, about 2 km from the Herschel's country home at Collingwood. I have not found Alfred's relationship, if any, to Henry H. Hardcastle (1840–1922), the husband of Maria Sophia Herschel.

9 Herschel's name does not appear in that area on a map of 1856 (PRO: CO700 Canada 64) reproduced in Historical Maps of Canada, though "Dr. Kane 1853" is marked in Smith Strait, "Cape Sabine" on Ellesmere Island, and "Murchison" on features in Greenland.

10 https://en.wikipedia.org/wiki/Herschel,_Saskatchewan

11 Elmore's field book, diary, and report are all in the Archives of Ontario (RG 1-59) and are on microfilm (MS 924, reel 13, past half-way point). In these documents, Elmore only refers to the townships by number. For the plan on which the names appear, see RG1, SR7819, R-V; MNR reference E37; FN 862.

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CFHT Chronicle

Back and Improved

by Mary Beth Laychak, Director of Strategic Communications, Canada-France-Hawaii Telescope
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We're Back! And Improved!

On 2020 May 5, Hawaii's governor David Ige identified the Maunakea Observatories as one of Hawaii's low-risk organizations and businesses safe to reopen with health and safety precautions in place. The announcement paved the way for CFHT to resume operations, which we began on May 7. While we resumed operations, working from home remains mandatory for all our staff able to do so. Operations in our Waimea headquarters and the summit are still limited to essential tasks. I hope by the time you read this article, restrictions in Hawaii will have loosened enough for CFHT staff to be back in the office on a more regular basis. I also hope all the readers of the *Journal* and this column are safe and healthy.

SITELLE Upgrade

I wrote about our instrument SITELLE (Spectromètre Imageur à Transformée de Fourier pour l'Etude en Long et en Large de raies d'Emission or the Wide-field Imaging Fourier Transform Spectrometer) before and want to give an update on a recent upgrade. This update pulls from a combination of a news story on our website and the more technical update provided to SITELLE users. I included clarifications where needed.

As a reminder, SITELLE is an imaging Fourier Transform Spectrograph (iFTS) that has the unique capability of recording over four million contiguous spectra on a field close to 11 x 11 arcminutes in one observation. After four years at CFHT, the team managed to extract even more from SITELLE as its image quality was improved, enhancing the analysis of compact sources. Although SITELLE was originally conceived to study emission lines in extended objects, a large numberof the users is also interested in studying compact sources. Increased interest in this use case motivated the SITELLE team to invest additional efforts into further improving the image quality. It was determined that the improvements could be achieved by introducing additional elements in the camera optics.

"At CFHT, we have a history of undertaking instrument improvements when our users want to test the boundaries of what the instrument can do," said Simon Prunet, CFHT resident astronomer and SITELLE instrument scientist. "Improving SITELLE's image quality and astrometry enables our users to push the potential of SITELLE even further."

The field curvature inherent to SITELLE's design led to unexpected observational and analysis issues. The field curvature led to a global image quality (IQ) that was lower than expected, especially near the edges of the field, which caused a poor, and target-dependent convergence of best focus. Following thorough review and testing of the optical system, an upgrade to the optics was suggested and implemented through 2019. The upgrade consisted of the installation of a field-flattening lens to replace the CCD cryostat windows of both camera ports.

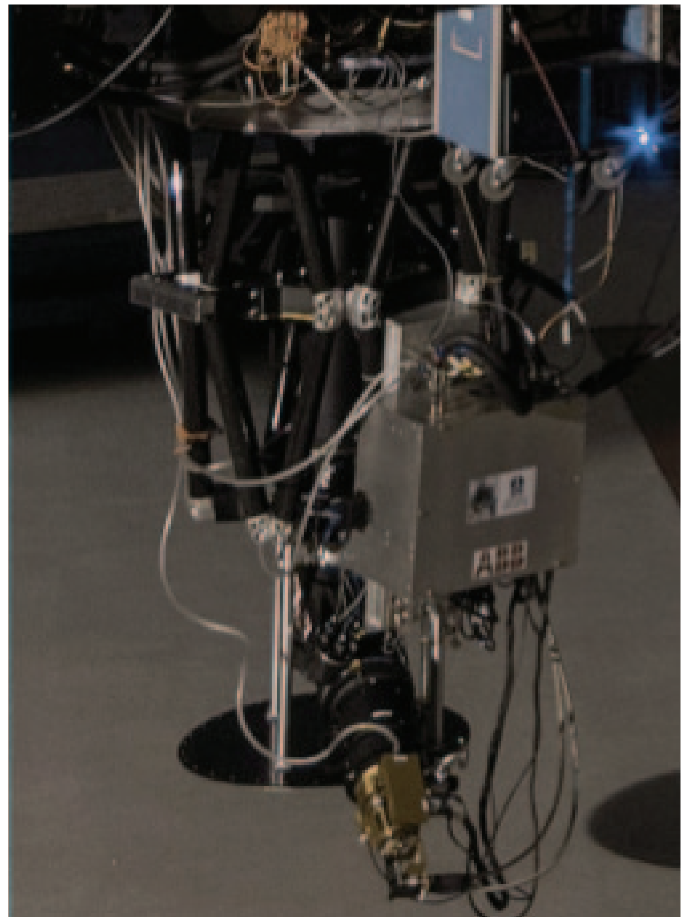

Figure 1 — SITELLE on the telescope

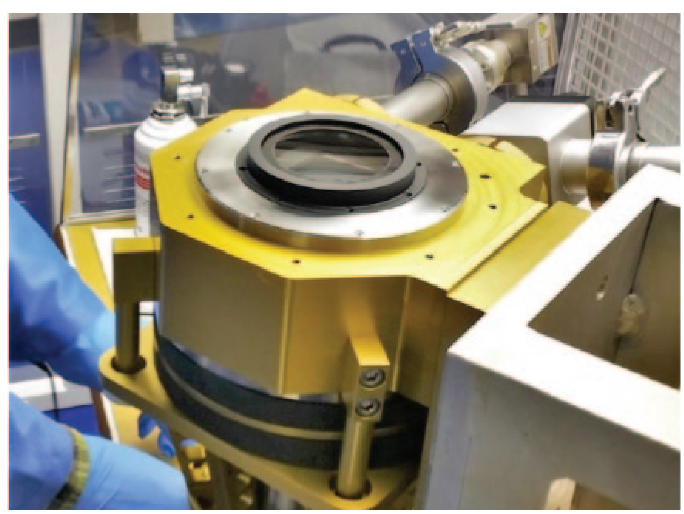

Figure 2 — Installation of the SITELLE corrector lenses on the cryostats

The SITELLE focal plane corrector lenses were received in the spring of 2019 and installed on the cryostats in June (Figure 1). Engineering tests conducted in September 2019 demonstrated the new corrector lens and other changes improved SITELLE's performance. Testing showed an improvement of roughly 0.15″ in IQ across the field of view. The modification helped minimize the field curvature and allowed for a better optimization of the detector focus position. Another positive impact of the upgrade is a more accurate determination of the precise position of stars, known as astrometry, in crowded fields.

The on-sky engineering test performed on September 12 showed that the corrector lenses were operating as expected. In addition to testing the impact of the lenses on the system, the two detector optical axes were realigned prior observing, and the tilt of the CCDs was optimized using on-sky engineering time. A notable effect of the new corrector lens is that SITELLE's field of view has been reduced by 2.6 percent, bringing SITELLE's plate scale to 0.3114″/pixel. Some of the reduction was counteracted by also improving field of view matching between the two cameras working in tandem over the same field of view. Overall, the net field-of-view loss was 0.3 percent. The team anticipated this loss but determined the IQ and focus improvements largely counteracted this minor disadvantage.

With a more consistently flat focal plane, our ability to automatically adjust the telescope focus is improved and is less affected by the position of the stars in the target field. Consequently, we observed the best mean IQ so far with SITELLE; 0.55″ during the October 2019 run, with similar IQ values seen in the 2020A semester. A rough indicator of this global IQ improvement is obtained by comparing the best IQ obtained over long periods before and after the change: This translates roughly into a ~0.15″ global enhancement of the mean IQ of SITELLE.

"Although one makes every effort to avoid surprises in working an optical design like this, it is always satisfying to see those ideas validated by the ultimate test: light travelling through glass, shaping the pinpoint star images CFHT is known to excel at," said Marc Baril, the SITELLE instrument engineer.

SITELLE is used on a wide range of targets to answer a variety of science questions. Although the impact of this upgrade on the science programs must generally be assessed on a case-by-case basis, typically the impact on a given program will depend on whether targets consist of diffuse or point-like sources. Astronomers looking at point sources will likely see the largest benefits, however, the improved IQ and focusing will benefit all SITELLE users.

Let's take a look at how the upgrades will impact both the SITELLE large program and our Principal Investigator (PI) programs.

Our SITELLE large program, The Star Formation, Ionized Gas and Nebular Abundances Legacy Survey or SIGNALS, led by CFHT's own Laurie Rousseau-Nepton. With 54 nights, SIGNALS aims to study 50,000 star-forming regions in nearby galaxies. The main goals of SIGNALS are to: 1) quantify the impact of the surrounding environment on the star formation process, 2) link feedback processes to the small-scale chemical enrichment and dynamics around star-forming regions, and 3) measure variations of the resolved star-formation rate with respect to the indicators used for high redshift galaxies. SIGNALS' datasets will be extremely rich and valuable for investigating many other physical mechanisms as well. It will produce complementary results to study planetary nebula abundance distributions and luminosity functions, supernova remnant ionization conditions, occurrence, and feedback contributions, background emission line objects (e.g. [OII] and Ly-a emitters), and much more.

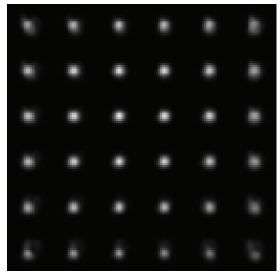

Figure 3 — point spread function of the stars in the SITELLE field of view before upgrade.

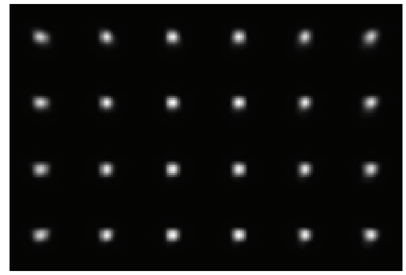

Figure 4 — point spread function of the stars in the SITELLE field of view after upgrade.

"Our SIGNALS large program, which observes a large number of HII regions in nearby galaxies, is one of the many programs that benefit from SITELLE's improvements," said Laurie Rousseau-Nepton, CFHT resident astronomer and SIGNALS PI. "We will be able to detect smaller and fainter HII regions, planetary nebulae, and supernova remnants—objects just at the brink of detection before the upgrade."

PI programs

In addition to programs that might be affected in the same way as SIGNALS, some PI programs are targeting point-like sources, such as stellar clusters and galaxy clusters (z>0.1), as well as extended and diffuse Milky Way objects covering the whole SITELLE field. For these programs, a lower detection threshold is achieved for faint point-like sources 0.15 [mag] dimmer, or with 15 percent less exposure time. The upgrade also globally improves the photometric accuracy, especially in crowded fields.

To summarize, the principal effects of the upgrade on science programs are:

- A field of view reduced by 0.3 percent, for a plate plate scale of 0.3114″/pixel.
- More reliable convergence of the automated focus routine.
- An improved mean IQ of ~0.15″ as a global rough estimate.

- Less "flaring" of the PSF, especially in the field corners, that was leading to large encircled energy diameters above 80 percent encircled energy.
- Better astrometric solutions.
- A lower detection threshold for point-like sources (i.e. 0.15 [mag] dimmer, or a reduction of 15 percent of the exposure time for a given threshold).
- Improved mosaic reconstruction efficiency.
- Increased spatial resolution, especially at the edges of the field.
- Reduced impact of clustering of objects and structures in the target.
- Less cross-contamination of sources in a crowded field.

The efforts in these SITELLE upgrades took a whole team of people not only at CFHT, but in Quebec at ABB, Université Laval, and Université de Montréal. ✶

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.

Skyward

The magical Lyrids and Castor House

by David Levy, Kingston & Montréal Centres

Plenty of telescopes grace my observatory, but I still enjoy watching shooting stars, or meteors, more than anything else. This year, after a break of several months, Earth passed through the Lyrid meteor stream on the night of April 21. The meteor shower takes place when Earth encounters dust from Comet Thatcher, a comet that last appeared in 1861. I captured five meteors with my camera, of which one accompanies this article. As I relaxed outdoors during this time, the memories began to flood back.

My first experience with the Lyrids was on 1963 April 22. At the time, I was a patient at the Jewish National Home for Asthmatic Children in Denver. I wrote it up this way in my diary: "I had a regular day today, until tonight. I went out and saw a fireball (a very bright meteor.) Then a big, fat, hunk of cloud came over. I saw no more meteors."

The next night was also cloudy, and I saw no further meteors despite being outside for several hours. "I officially considered this year's meteor shower the most disappointing failure I have ever had," I wrote.

Not for long, however: I have been blessed with many far more spectacular failures since then.

My love of the night sky goes back many years, to around 1960, but as I grew older, I also developed a strong interest in literature, and that passion stems directly from my father. I honestly feel that if I had not inherited his love of Shakespeare in particular, he might have taken me out of his will. And I believe he was pleased when I took up English literature at Acadia University in the 1970s. But I recall reading about Shakespeare's references to eclipses in *King Lear* and hardly giving them a second thought.

The next Lyrid shower I remember took place on 1976 April 23. At the time, I was engaged to my "practice wife." (That marriage lasted barely two years.) That Friday evening was clear, and I was part of a team organized by the Montréal Centre of The Royal Astronomical Society of Canada, and we saw the sky was clear, and we saw several meteors. As I enjoyed the night, my mind roamed a little. I wondered about how many other amateur astronomers might have enjoyed this particular meteor shower in earlier times. I also thought of writers who might have written about the sky. I was aware that Shakespeare wrote about eclipses (specifically in *King Lear)* and about meteors and comets as well. At that very moment, I decided that for my Master's thesis I would write about poets who have loved the night sky. The poet I concentrated on, at Queen's University, was Gerard Manley Hopkins.

Decades later, I finally received my Ph.D. from Hebrew University, for the dissertation on Shakespeare's many references and allusions to the night sky. Among the hundreds of allusions I found, here is one from *Richard II* that looks on meteors and a lunar eclipse:

> 'Tis thought the king is dead; we will not stay.
>
> The bay-trees in our country are all wither'd
>
> And meteors fright the fixed stars of heaven;
>
> The pale-faced moon looks bloody on the earth. . .
> (2.4.1337-1340)

The Lyrid meteor shower brings me back to the hazy dawn of my life and my passion for astronomy. May a shooting star brighten your nights as well.

Castor House

A number of years ago, my friend Scott Roberts, then of Meade Instruments, sent me and Wendee two small ETX telescopes. We brought them both out to a picnic table we had set up in the yard to the south of our home. We turned on their motors and quickly learned how to move them across the sky. As it was Wendee's first time with a new telescope, she was not as fast as she is now. At one point, Wendee went

Figure 1 — A Lyrid meteor taken on 2020 April 21. (David Levy)

into the house to answer the telephone. She came out again to find both telescopes purring nicely, with me, and an enormous smile on my face, sitting between them. I grinned like a Cheshire cat.

I have never forgotten that night. We now have a small shed at the spot, and Castor, on a tripod, sits inside along with a lawn chair I use for meteor observing. Castor House, as I call it, is now one of my favourite viewing spots. It affords a magnificent view of the night sky, especially for watching meteors. I even installed an outdoor speaker there that carries music from KUAT-FM, our local classical music radio station. I walk out there almost every evening, just to check on the sky.

What do I check for? One never knows when the sky will offer something new and unexpected. What if, since the night before, a distant sun somewhere in our galaxy has awakened, thrown off its covers, and risen in brightness as an exploding supernova or a nova? These events cannot be predicted. In 1572, the Danish astronomer Tycho Brahe peered skyward and saw a brilliant new star in the constellation of Cassiopeia. What he saw was not an "ordinary" nova, wherein the star rises and fades in brightness. His star was a supernova that resulted in the total collapse and destruction of the star. Just 32 years later, his student, Johannes Kepler, discovered a second supernova in the constellation of Ophiuchus. Since then—416 years later—there has not been one visible supernova in our own galaxy.

On 1975 August 30, I stepped out of a car on my way to a card game, looked up, and saw what appeared to be a slow-moving satellite near the bright star Deneb. I went indoors, then stepped outside again to note that the satellite was moving very, very slowly indeed. Then I understood that the "satellite"

Figure 2 — Castor House, its music speaker, and the night sky. (David Levy)

was not moving at all. I had made an independent discovery of an exploding star, not a supernova but an "ordinary" nova. Three years later, on 1978 September 12, from a campground in the Adirondack mountains, I independently found a second nova.

Most of these ordinary novae, like the two I found, can recur, again and again. In fact, there is one star that has already exploded twice in recent memory. On 1866 May 12, the star named T Coronae Borealis, or the "Blaze Star," rose in brightness to almost 2nd magnitude. On 1946 February 9, it erupted again, this time to about 3rd magnitude. There is a very good chance that within the next decade it will explode again. Stars like T Coronae Borealis are called "recurrent novae."

When will the next unexpected stellar event disturb the symmetry of the familiar night sky? We are surely due for one. How about tonight? Wouldn't that be fun? The night sky is lovely and beautiful, but it is also astounding. We just never know what will come next. Maybe tonight I will find one again, as I stroll by Castor House. ✶

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.*

John Percy's Universe

My Career in the Life Sciences

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

As I write this column amidst the novel coronavirus pandemic, I am reminded of my brief career—and long interest—in the life sciences.

As an undergraduate, I majored in astronomy and physics at the University of Toronto, graduating in 1962. It was a golden age of astronomy (and still is): the beginning of lunar and planetary exploration, new techniques such as computer modelling and radio astronomy, and major advances in stellar evolution and cosmology.

It was also a golden age of the life sciences. Crick and Watson had published the double-helix model of DNA, building on the work of Franklin and Wilkins. Biochemistry and biophysics were at the frontiers. Also, my girlfriend Maire (my wife since 1962) was a biochemistry major. She obtained a summer job at the Ontario Cancer Institute—an exciting place! I followed.

In the first summer, I worked with Bob Bruce, a biophysicist and MD, and Bernhard Cinader, an eminent immunologist. Unfortunately, the project involved lab mice, but it did get me my first scientific publication: "A non-specific depressant effect on the immunological response" (Bruce, Cinader, and Percy 1962). I wonder if it is relevant to the novel coronavirus.

The second summer, I worked with Gordon Whitmore, another biophysicist. My project was to try to reproduce a result in a paper in the scientific literature. The topic escapes me, but Maire tells me that it was the work of a high-powered lab in the U.S., and dealt with the ability of polypeptides to direct the synthesis of polyamino acids—the genetic code. This led to a Nobel Prize in 1968. I do remember that I was not successful; the experimental yield that I achieved was much lower than the paper reported. It was back to plan A—astronomy.

Years later, I heard that no one else had been able to reproduce the result in the paper, either. And only much later did I appreciate that Maire and I had been present at the groundbreaking discovery of stem cells. The discoverers—cell biologist Ernest McCullough and biophysicist Jim Till—worked down the hall. We saw them every day.

Of Stars and Immunoglobulins

My Ph.D. thesis focused on modelling the structure, evolution, and pulsation of massive stars. Maire's Ph.D. thesis was on

Figure 1 — One of over 500 fragments of the Tagish Lake meteorite, which fell in British Columbia in 2000. It is a carbonaceous chondrite—a primitive meteorite containing amino acids and other building blocks of life that have formed, naturally and easily, in the solar nebula. Source: University of Toronto

the structure of an immunoglobulin molecule—one of those important molecules that fight things like the novel coronavirus. It got her a nice prize from the Faculty of Medicine (and two engraved silver candlesticks) and a paper in the prestigious journal *Science*, co-authored with future Nobelist Oliver Smithies.

She then studied how these molecules are assembled in the cell from their constituent parts. I noticed that the process was mathematically similar to the chain-like process by which lighter nuclei are fused into heavier ones in the cores of stars, including the relationship between the abundance of each element in the chain, and the rate at which it was created and destroyed. So we collaborated. Our simulations got us a nice paper in a first-rate journal with Maire`s colleague Keith Dorrington: "A theoretical model for the covalent assembly of immunoglobulins" (Percy, Percy, and Dorrington 1975). And I got to attend one of her conferences as something other than an "accompanying guest."

The lesson, perhaps, is that there is much to be gained, in research, from interdisciplinary interaction, rather than having disciplines compartmentalized as they are in so many research universities. I was fortunate to have spent my first 40 years at the University of Toronto Mississauga (Percy 2016), growing the campus from scratch, within a multidisciplinary academic structure.

Eyeballing It

By the 1990s, Maire was a professor in the Department of Physiology. One of her colleagues was Professor Peter Hallett, an expert on vision, an amateur astronomer, and a variable-star observer. Every visual observation of the sky—including observations of variable stars—is a physiological process. In my research on variable stars, I had been using such visual observations for years, and still do, so I have a vested interest in knowing about their nature and reliability. A collaboration with Peter resulted in a short paper at the 1999 Toronto joint meeting of the RASC, the American Association of Variable Star Observers, and the Astronomical Society of the Pacific (Hallett and Percy 2000). That was the RASC General Assembly, on the Canada Day weekend, with the oppressive heat wave.

I had one more connection with Peter, through an outstanding life-science student, Winnie Au. Winnie had worked with me in the prestigious University of Toronto Mentorship Program (Percy 1990) when she was in high school; we published three papers that included her work. In the summer after her first year in university, she completed a massive project in which she used decades of observations of almost 400 Mira-type variable stars to detect the slow expansion of red-giant stars as they age (Percy and Au 1999). Her positive result was only marginally significant, statistically, but Swedish astronomer Thomas Karlsson has recently used two more decades of Mira star observations to confirm her result. Winnie was bound for medical school; I couldn't make an astronomer out of her. But later, I was able to connect her with Peter Hallett for a summer physiology project.

Astrobiology

That was the extent of my dabbling in life-science research, though I can't help absorbing a bit more when sharing a home with a life-science researcher, teacher, and author. As a teacher and outreacher myself, however, I have always been interested in the way that astronomy connects with other sciences, and with the arts and humanities. Among other things, it gives us a more holistic view of our science, its role in culture, and enables us to bring it to broader audiences. My interest goes back at least to 1969, when I assisted the Ontario Ministry of Education in developing *Space and Man*—a highly interdisciplinary, student-centred grade 11 high school course.

In the 1970s, my colleague Bob Garrison created a popular course on *Life on Other Worlds*, which he co-taught with biologist Jack Dainty on the downtown campus of the university. Bob went on to serve the RASC as National President (2000–2002) and Honorary President (2005–2009). After Bob retired, the course was passed around to various interested colleagues. This year, it has been totally revitalized by my award-winning colleague Professor Michael Reid, attracting an enrolment of up to 400 students, with perhaps more in the future.

When Bob created his course, astrobiology was considered rather speculative. Now, with fundamental advances in biochemistry, and a half-century more of human spaceflight, planetary exploration, and the discovery and study of thousands of exoplanets—some of them Earthlike—astrobiology is fully mature. Figure 1 shows a fragment of Canada's famous Tagish Lake meteorite, a very primitive *carbonaceous chondrite*, which contains amino acids and other potential building blocks of life. It shows that such pre-biological molecules can form easily and naturally in the nebula from which our Solar System formed.

At the UTM campus, where I was based, I created a slightly different version of Bob's course—*Cosmic Evolution.* It examined the origin and evolution of atoms, stars, planets, and life, and was intended to bring together students from all of the sciences, and to show how those sciences could be linked through astronomy. There was, and still is, an excellent textbook—*Life in the Universe* by Bennett and Shostak—just to mention one. Sadly, the course faded away after my "retirement" in 2007, but this year, my UTM department and I made a strong proposal for its return and revitalization. And astrobiology is still one of the non-technical lectures that I give to various audiences in libraries and later-life-learners groups.

Epilogue

Scholarly disciplines connect, if they are allowed to, but modern universities tend to be compartmentalized. That should not stop us from reading or attending lectures or discussing with colleagues outside our field. We can learn a lot from other disciplines, and perhaps solve some of our problems that way. In the current pandemic, we are seeing the benefit of bringing the mathematical and physical and social sciences together with the life sciences to deal with one of humanity's greatest challenges.

Acknowledgements

I thank Professor Maire Percy for (among other things) reading and commenting on a draft of this column and jogging my memory about things that happened 60 years ago. ✶

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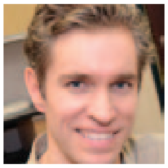
Dish on the Cosmos

The Precocious Galaxy



by Erik Rosolowsky, University of Alberta
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Greek mythology holds that the Universe begins with Chaos. While the scientific explanation of the Universe starts with the Big Bang, we see chaos in the beginnings of many cosmic structures. Stars are born from dark, turbulent clouds of gas, and the earliest galaxies appear as cosmic "train wrecks." The earliest galaxies that we commonly observe are irregular blobs of gas and stars lit up by bursts of star formation as they collide together. In contrast, our surveys of more grown-up galaxies find few systems undergoing such chaotic galactic collisions. Instead, most galaxies that we see are well-organized disk galaxy systems. When did the order emerge from this chaos? Did it come after the chaotic phase of galaxy growth or have we simply not seen the simpler, better-organized galaxies?

Recent work using the Very Large Array (VLA) in New Mexico and the Atacama Large Millimetre/submillimetre Array (ALMA) in Chile has just found an ordered system, quietly spinning like a top, caught a mere 1.5 billion years after the Big Bang. This new discovery shows that organized galaxies can form relatively quickly in our Universe, representing a key discovery in learning out how disk galaxies like our own will form.

The origin story of galaxies is authored by dark matter, which governs where and how quickly a galaxy can grow. Dark matter is the mysterious component of the Universe that makes up five times as much mass in the Universe as ordinary matter (the protons, neutrons, and electrons). While we don't know what it is, we think that dark matter is made from subatomic particles that only interact with themselves and the rest of the Universe through the force of gravity. This limited interaction means that dark matter doesn't feel electric or magnetic fields and light passes through this invisible material. This peculiar set of properties means that dark matter can only do one thing: fall toward itself and other matter because of its gravitational pull. Since most matter in the Universe is dark, the story of how gravity forms structure in the Universe is really just the story of where the dark matter is falling down toward itself.

In the earliest time of the Universe, immediately after the Big Bang, the ordinary matter was smooth. There was the same amount of material everywhere. The pressure of the hot gas and light smoothed out any matter that started to bunch up in one place. Dark matter, in contrast, immediately began to pull together under its own gravity since it was immune to these smoothing-out effects. Regions with slightly more dark matter would have slightly more gravitational force and would then pull material from less-dense regions into clusters of dark matter called "halos." These halos would collapse inward, gathering more dark matter and growing in size and mass.

All the time dark matter was collapsing, the hot gas was cooling off as the Universe expanded, so the gas pressure grew weaker, allowing gas to start to flow. The gravity from the dark-matter halos pulled the cooling gas into the halo, channeling the ordinary matter in the centre where the gas would form stars and become the seed of a galaxy. While these galaxy seeds were building up, the halos continued to grow and were pulled into each other by their mutual gravitational attraction. In this process of halo assembly, the primordial galaxy seeds would follow along their parent halos and crash into the seeds in the middles of the other halos, building up a chaotic bundle of stars and gas.

We see many examples of the chaotic accretion of galaxy seeds in our studies of the early Universe. By taking advantage of the finite speed of light, we can study the most distant visible galaxies and, in doing so, also observe galaxies as they were in the earliest times in the Universe. Our observations support the chaotic story of galaxy evolution. The galaxies we see are small, disordered, and heavily disrupted by their ongoing star formation and galaxy collisions (Figure 1). The central part of our Milky Way galaxy bears the traces of this tortured evolution. Stellar orbits in the central bulge of our galaxy are oriented at random, and this part of the galaxy also has the oldest stars. Thus, this seed of the Milky Way was likely born from the collisional assembly of smaller galaxy seeds.

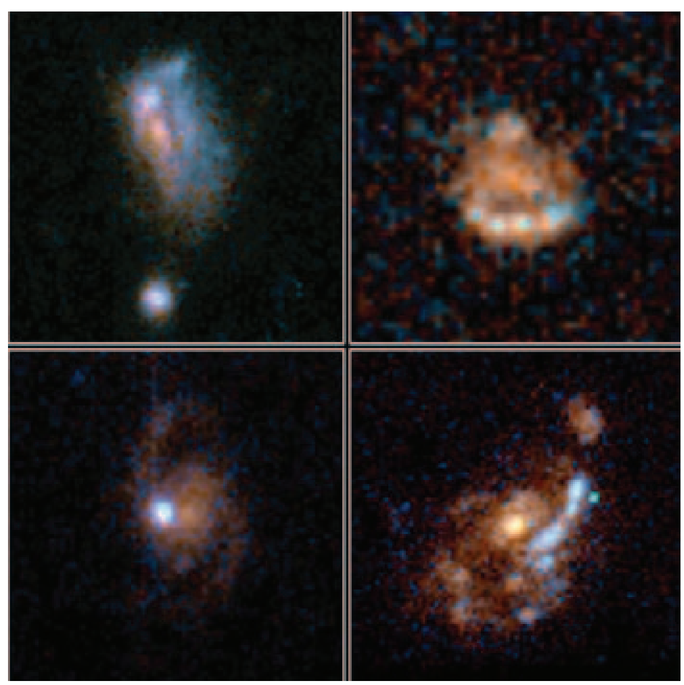


Figure 1 — Young, distant galaxies seen in an early Hubble Space Telescope *survey. These young galaxies are disrupted from irregular star formation and galaxy collisions. Image Credit: R. Griffiths (JHU), NASA*

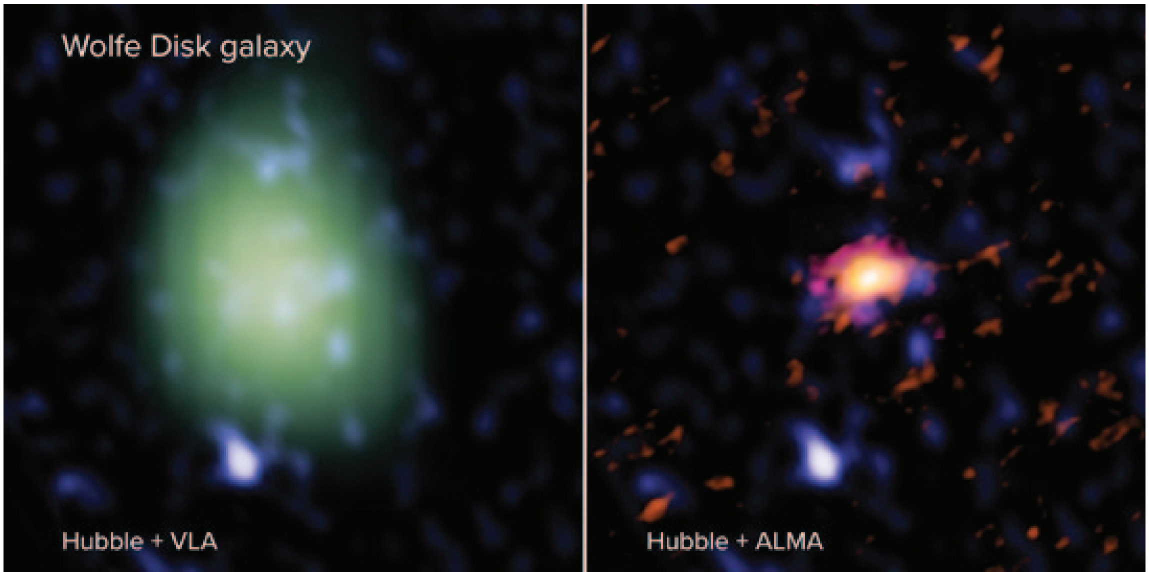


Figure 2 — Images from the VLA, Hubble, and ALMA combine to give a complete picture of a well-developed galaxy in the very early Universe. The different telescopes all combine information to paint a complete picture of the galaxy's matter. The VLA observations show the star-forming gas, Hubble observations reveal the stars in the galaxy, and the ALMA observations provide additional measurements on the gas content. These high-resolution observations from ALMA also finally revealed the well-organized rotation of the disk (not depicted). Image credit: ALMA (ESO/NAOJ/NRAO), M. Neeleman; NRAO/AUI/NSF, S. Dagnello; NASA/ESA Hubble

We live in the disk of the Milky Way, where the motion of the stars is well organized: all the gas and stars are going around the centre of the galaxy in a flat disk in the same direction. This organization is the hallmark of the slow buildup of material through gas settling onto the forming galaxy. Any random parts of the inflow motions of the gas are stopped through gas drag (similar to air resistance), leaving only the circular motions around the centre, similar to how water flowing down a drain eventually organizes into a spiral. Thus, in deciphering galaxy formation, a disordered set of orbits points toward collisions in the past, but a flat disk suggests the slow buildup of an isolated galaxy.

When do disk galaxies start to become common? Our picture would suggest that after halo merging becomes less frequent, galaxies can grow up in peace. This slowing of the merger rate takes some time and should happen well after the initial phase of galaxy formation. However, it may be that our view of galaxy formation is biased: when galaxy seeds collide, they trigger bright bursts of star formation, making them easier to see. Perhaps quietly growing disks are more common than originally proposed, but because they are faint, these systems are passed over in our studies of the early Universe.

A recent discovery has raised these questions directly by discovering that the galaxy DLA0817g (nicknamed the Wolfe Disk) is actually a massive rotating disk galaxy, but is so distant that we must be observing it a mere 1.5 billion years after the Big Bang. This galaxy is the most distant disk galaxy ever observed. While the target has been known for a few years, only a recent suite of observations has revealed its peculiar nature. Since this galaxy is so distant, our best telescopes usually reveal only a small, unimpressive blob. However, the new high-resolution observations with ALMA were sufficient to make a resolved map across the galaxy and use the Doppler shift of a spectral line to determine how the galaxy was rotating. Using this combination of observations from ALMA, the VLA, and the *Hubble Space Telescope*, astronomers now have built a comprehensive picture of a young disk galaxy. The galaxy is only slightly less massive than the Milky Way but is forming stars relatively rapidly, at about 10 times the pace of our own galaxy. This star-formation rate is not extreme, in contrast with those seen in cosmic collisions. Here the elevated rate arises because the galaxy is relatively rich in star-forming material (i.e. gas). Otherwise, the galaxy is not so different from our own, and looks to be a nearly complete galactic system, in the slow process of isolated evolution. What is amazing about the system is when it is found: precociously advanced in its development for so early in the Universe. All the galaxy build-up must have happened before this time, leaving little room in the calendar for disruptions through collision. As is often the rule, this single target points to there being a lurking population of quiet galaxies building up to the galaxies that we see today. In a single new observation, we suddenly must consider the importance of this new path for how galaxies change over time.

Read more at: https://arxiv.org/abs/2005.09661 ✶

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

Great Images

by Kerry-Ann Lecky Hepburn and Stefano Cancelli

Here is another one from the amazing astrophotography duo of Kerry-Ann Lecky Hepburn and Stefano Cancelli. Sadly, Stefano passed away in May. This is the Cone and Fox Fur Nebula (NGC 2264). This HαRGB image was taken by the pair from the Golden Horseshoe area in Ontario. Stefano contributed a two-panel hydrogen-alpha mosaic: 30 subs x 15 mins each with the ST10XME and Tak FS102 @ f/6. Kerry-Ann contributed a two-panel RGB mosaic: 65 subs x 5 min on the Cone and 57 x 5 min on the Fox Fur with the QHY-8 and AT8RC @ f/6.4. Total HαRGB exposure time was 17 hrs 20 min. The photo was a NASA Astronomy Picture of the Day (APOD) on 2010 April 6.

Binary Universe

Explore the Solar System and Beyond

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

Solar System Perspective

Solar System Scope is a fun little program for flying around the Solar System to enjoy three-dimensional renderings of outer space as if you're in your private spaceship.

My first use of an image was in an astronomy presentation circa 2016 and I have continued to use *Solar System Scope* over the years. It's been around since 2010. Several times for my The Sky This Month talks, I took snapshots with Earth strategically placed in the immediate foreground and other celestial objects in the background.

An image of Earth on 2020 Jun 10 (Figure 1) shows Venus just passing us with Mercury well left of the Sun. Note the lens flare above Venus. I think it helps people visualize that Mercury is visible in the evening, imagining you're on the left edge of the Earth, rotating counterclockwise from the North Pole, enjoying the sunset. Venus is moving in the morning sky so early birds should soon see it before sunrise. This also shows how the Sun moves through the zodiacal constellations and is clearly between Taurus and Gemini.

In my presentation slide deck, I also include a screenshot looking the opposite direction to show the nighttime planets.

I'd show the paths of the planets rendered with the constellation stick figures. Obviously, the planets are oversized, fine for demonstrations, but they can be set to display realistically, then as tiny dots moving against the background stars. The interface controls can be hidden from *Solar System Scope* to unclutter the screen and further the illusion of floating in space.

Moons, Planets, And Stars in Motion

Sometimes, I have trundled around the Solar System just for fun. I get a kick out of orbiting high above Saturn (Figure 2) then adjusting the date/time controls to rapidly speed up time, letting the moons zip around the rings.

You can select guided tours of the planets to learn about their place in the Solar System, their structure, the moons that orbit about them. Fun and educational for kids and new astronomers.

It's easy to zoom with a roller mouse or via the slider on the right edge of the screen. The scale shows appropriate units of

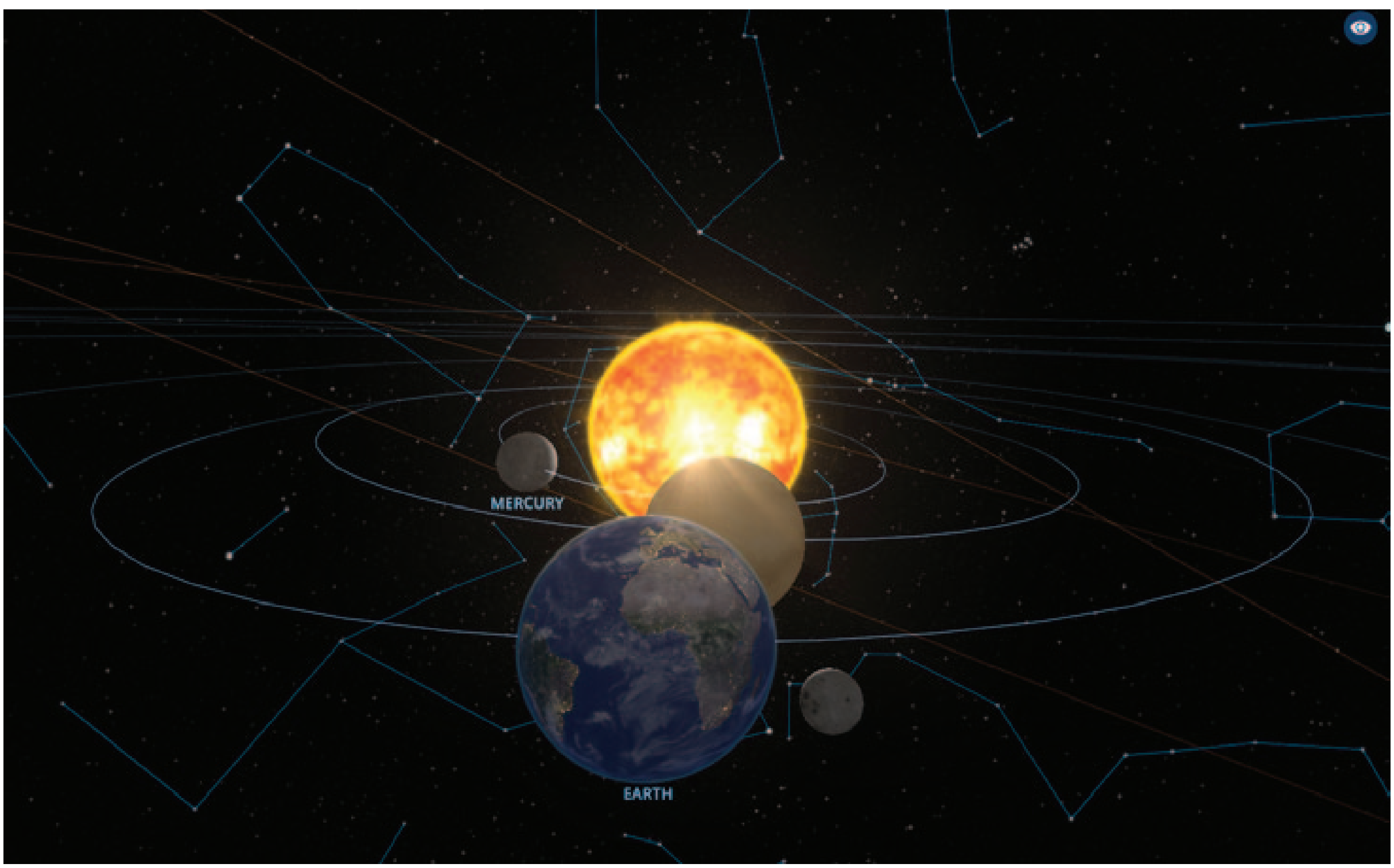


Figure 1 — Looking over the super-sized Earth to the inner planets with Solar System Scope*.*

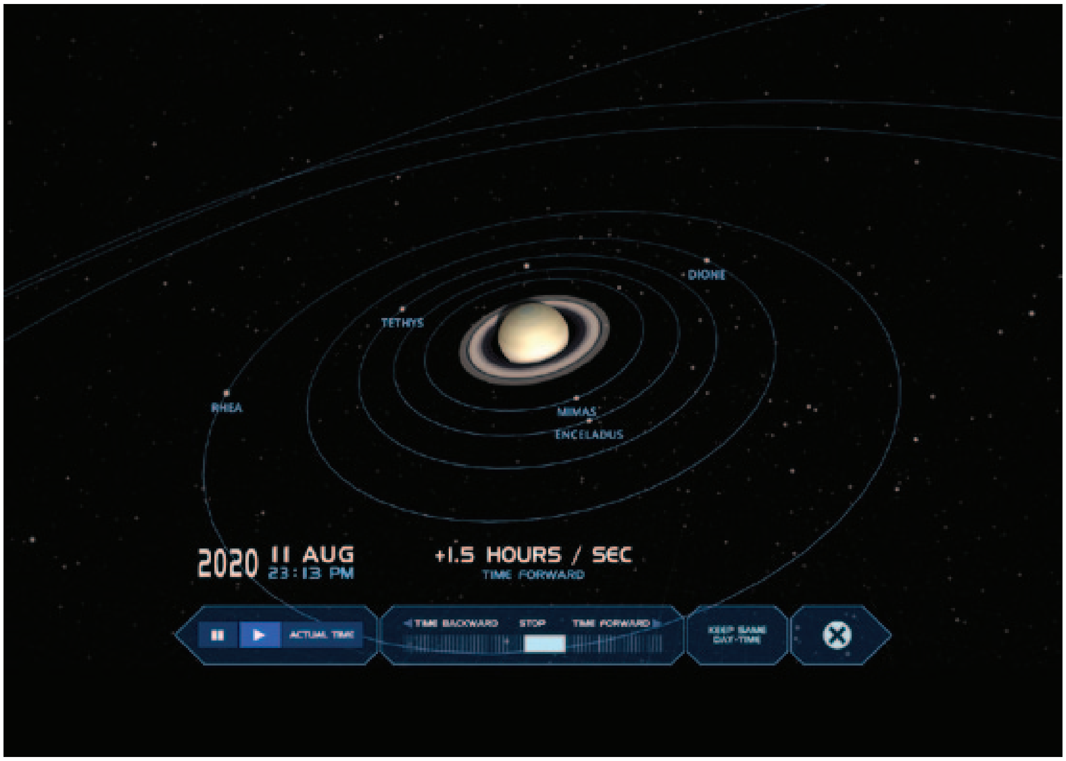


Figure 2 — Some of the Saturnian Moons made to move quickly on the computer.

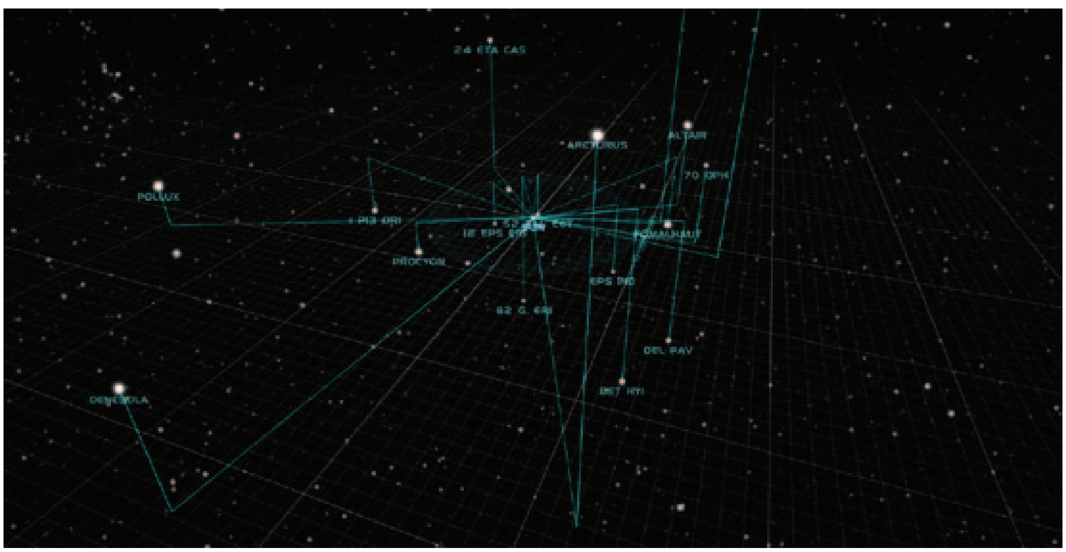


Figure 3 — Our stellar neighbours above and below the grid extended from the ecliptic.

Back further away from home base and you'll fly out of the galaxy! That's a great feature when doing astronomy presentations and you want to show big picture stuff, a "You are Here" galactic context.

In reviewing version 3.2.3 of the app, I discovered a mode I did not know existed. You can "explore stars" and select from a gallery of about 100 targets. The stars are rendered in relative sizes and colours. I gravitated to the doubles and binary systems—surprise, surprise. I increased the time rate to watch The Pup orbit Sirius A.

These static images don't do the application justice as we can't enjoy the dynamic motion of the planets around the Sun, moons about their parent planet, or slow-moving binary star systems.

Other Observations

The application features some other modes. Planet Explore tells use more information about the bodies in our Solar System and shows a cutaway view of their interiors. Messier Objects mode relays information about deep-sky objects and helps us learn where they are located in the night sky. For these objects, sadly, we can't fly up to them, around, or through them. The app also offers Night Sky, a familiar display like other planetarium tools, however I find it rather limited compared to *Stellarium*, *Starry Night*, *Sky Safari*, et al.

The software developers rely on orbital parameters, elevation, and imagery data from NASA and satellite position data from Celestrak. I stumbled across a view once that showed many human-made satellites zipping around our planet like bees around a hive.

measurement, astronomical units within the Solar System, light-years when we travel beyond.

Fly far from the Sun and you'll see the nearest stars highlighted (Figure 3). The elbow connectors reflect the distance in the plane of the Solar System and then the elevation above or below the ecliptic. I don't know why exactly, but I find it mesmerizing to know just where our nearest neighbours are in 3-D. "Ooh, just behind me, down and right there's a star. It's Procyon and it's close!"

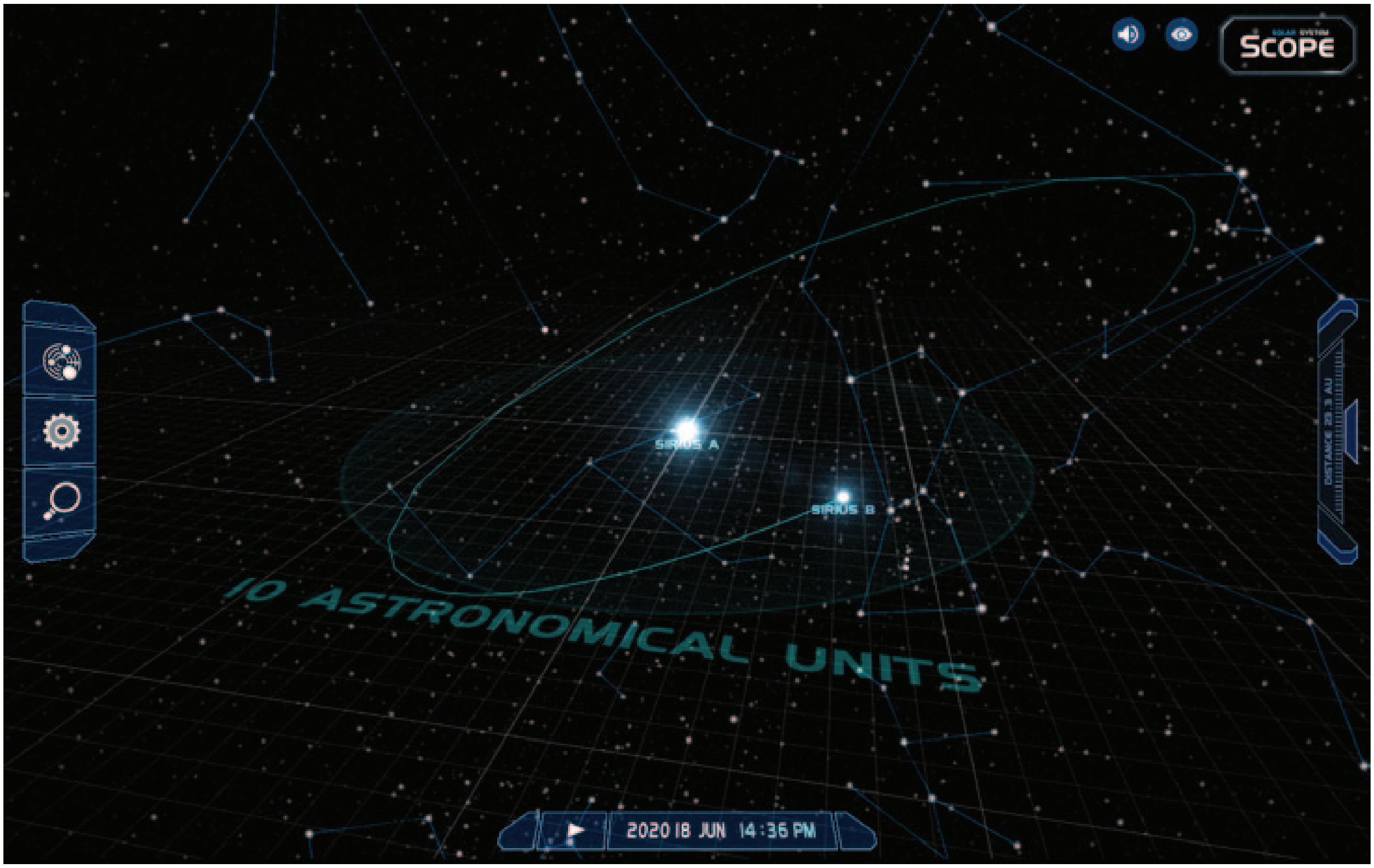


Figure 4 — A fast-moving binary system, quite dramatic when set in motion on a computer.

Comets and dwarf planets can be shown, but there are only a few, and I don't see any update feature or way of adding things. Similarly, spacecraft can be shown, notably the *V'ger1* (reference: Star Trek) and *Voyager 2*. You can watch the launch of *Rosetta* in 2004 and its journey through the Solar System, but only up to 2016. It would be nice if the developers were more active with updates.

Solar System Scope is available in two dozen languages, runs on Windows and Macintosh with apps for iOS and Android. It can also be immediately used in a browser. I have used the browser product over the years, with and without Flash. Mr. Fasung of INOVE graciously provided a complimentary copy for my evaluation and I tested the stand-alone software on Windows 10 (32-bit). It uses WebGL and JavaScript technology. Running the application on the computer (as opposed to in the browser) made for a better experience, fast performance, and higher resolution, but I experienced a number of freeze-ups, crashes, and memory errors.

First use of *Solar System Scope* might be a little startling with rather loud background music. Happily, you can control the volume of both the soundtrack and the sound effects.

You can use the web version for free, so try it out. The PC or Mac products for offline use cost USD $9.80. The iOS and Android apps are free with in-app purchases.

Surf (fly?) into www.solarsystemscope.com to start viewing the Solar System, stellar neighbourhood, and galaxy in three dimensions. If you regularly deliver astronomy presentations, you may find this a very helpful application to illustrate motion of Solar System objects and double stars as well as showing where we are in the Milky Way Galaxy.

Bits and Bytes

A problem was reported when following or clicking the link in my June 2019 article on the *Dark Sky Meter* (DSM) app. When I click the link in the PDF file, it looks like the browser is trying to go to www.darkskymeter.com/index.php, but then I receive a warning in my Chrome browser that shows I'm about to go to www.www.darkskymeter.com which is clearly wrong. Do not use this. The correct address for the DSM website is darkskymeter.com so please follow that. ✶

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 a member of the national observing committee. In daylight, Blake works in the IT industry.

Celestial Review

The *Observer's Handbook* and the Orbit of Io

by David Garner, Kitchener-Waterloo Centre
(jusloe1@wightman.ca)

In the 1600s it was necessary for ships' captains to have an accurate timepiece to determine their longitude. Since timepieces that could be used on a ship were not available, it fell to observing eclipses of Jupiter's moons to serve as a timepiece. These Galilean moons have short periods (particularly Io), and are easily observed through a small telescope.

From 1666 to 1668 while Giovanni Domenico Cassini was in Paris observing eclipses of the moons of Jupiter, he found discrepancies in his measurements that suggested light may have a finite speed. In those days, most people believed that light spread out from its source instantaneously.

In 1672, Ole Rømer, who had been making similar measurements at Uraniborg on the island of Hven, joined Cassini in Paris as his assistant. Rømer and Cassini together observed variations in the times between eclipses of the moon Io in its orbit around Jupiter.

In 1676, Ole Rømer announced to the French Academy of Sciences the results of his observations (see Figure 1) comparing the duration of Io's orbit as Earth moved toward Jupiter (F to G) to when Earth moved away from Jupiter (L to K).

According to Rømer's measurements, the orbit of Io around Jupiter required approximately 42.5 hours. This was based on his measurements of the average orbital period over many years. He used this number of hours to predict the time of all future eclipses of Io.

To understand his illustration, start with the Earth at point L and Io is just emerging from Jupiter's shadow at point D. After several orbits, the Earth would be at point K. Likewise, he made similar measurements when the Earth was at point F and Io was at point C. After several orbits, the Earth would be at point G.

When Rømer made his announcement to the French Academy of Sciences, he noted how the time interval between successive eclipses became steadily shorter as Earth moved toward Jupiter, to the extent they would occur about 11 minutes earlier than his prediction. When Earth was moving away from Jupiter the time interval between successive eclipses became steadily longer, to the extent they would occur about 11 minutes later than predicted.

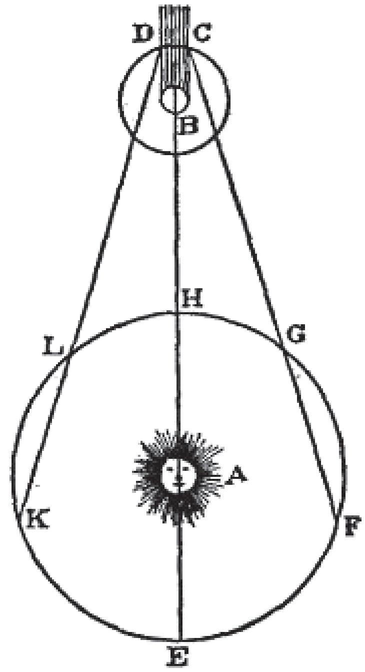


Figure 1 — Diagram showing Earth's orbit around the Sun (A) and Io's orbit around Jupiter (B).

Rømer believed there was a definite speed at which light traveled that was somehow intertwined with the apparent variation in the orbit of Io. After several more years of observations and calculations, Rømer arrived at a relationship between the speed of light and the speed at which Earth orbits the Sun, hopefully to explain the discrepancies in the orbit of Io.

Rømer did not give an actual value for the speed of light, it was Christiaan Huygens that, based on Rømer's data, stated light travelled $16\frac{2}{3}$ Earth diameters per second, or approximately 212,000 km/s. It was not until much later in 1809 that Jean Baptiste Joseph Delambre did more precise observations and calculated the time for light to travel from the Sun to the Earth as 8 minutes and 12 seconds (this value has been slightly improved since then).

In the many years since, there have been several studies of Rømer's work, by such notable figures as Isaac Newton and his contemporaries. Mostly, Rømer is given credit for arguably "demonstrating" that light is not instantaneous but has a finite speed. The critics of Rømer, who tend to discredit his work, point out the timekeeping methods available to him at that time did not have sufficient accuracy for the observations, even though his method was unquestionably valid.

That is the history to it. I thought, what if I used my trusty *Observer's Handbook* to see if I could obtain similar results as Rømer?

On page 230 of the 2020 *Observer's Handbook*, Patrick Kelly presents a year's worth of tables regarding the four great satellites of Jupiter. I noted throughout the pages for the satellite Io, the dates and times for occultation disappearance (OcD) and occultation reappearance (OcR). For example, I started with February 17 at 16:06 UT. At that time, Earth is approaching Jupiter and Io is listed as OcR. Again, on February 19 at 10:36 UT, Io is listed as OcR. The time between those events is 42.50 hours.

This seemed like a fun project, so I continued all through February and up to March 17. Adding up all the hours and orbits came to 679.9 hours over 16 orbits, therefore, 42.494 hours per orbit. I repeated the calculation (Earth still approaching Jupiter) for OcR from April 17 to June 18 (35 orbits) resulting in 42.452 hours per orbit. The difference of 42.494 – 42.452 = 0.042 hours or 2.52 minutes. The orbital periods appeared to be getting shorter.

During that time of February to June, Earth has moved closer and closer to Jupiter. Jupiter and Earth finally reached opposition on July 14 this year.

While Jupiter was at or near opposition from July 9 to 18, and using the *Observer's Handbook*, I used 3 orbits of Io at OcR and 3 orbits of Io at OcD and calculated an average of 42.429 hours per orbit (42 hours, 25 minutes, 45 seconds). I could use this as a basis for comparing orbital times when Earth is approaching and when Earth is receding from Jupiter.

For the next part, Earth is moving away from Jupiter, so studying the tables for Io OcD events from September 2 to November 14 resulted in 41 orbits at 42.478 hours per orbit. The orbital periods appeared to be getting longer. Comparing this value of 42.478 to the previous 42.429 hours per orbit when Jupiter was at opposition, shows the orbital period appears to increase by nearly 3 minutes.

To summarize, when the Earth was approaching Jupiter, the orbital time of Io appeared to decrease by 2.52 minutes. The orbital period appeared to be getting shorter.

But, from September 2 to November 13, as the Earth was receding from Jupiter, the orbital time of Io appeared to increase by approximately 3 minutes. The orbital period appeared to be getting longer.

As we know today, even though the observation time of OcR and OcD events changes, the actual orbital time of Io does not change, it just appears so due to the Doppler effect as the Earth is moving toward and away from Jupiter.

So, there you are. What a wonderful device—the *Observer's Handbook*! ✶

Dave Garner is a retired teacher who now enjoys observing both deep-sky and Solar System objects, especially trying to understand their inner workings.

RASC Awards for 2020

Compiled by Colin Haig

Service Award

The RASC Service Award is a major award of the Society given to a member in recognition of outstanding service to the Society and/or a Centre, rendered over an extended time of at least 10 years.

This year, two individuals who have committed much of their personal lives are being recognized.

Dennis Krause (Okanagan Centre)

Mr. Krause is recognized for over a decade of service, including time as Centre Secretary, Treasurer, Director, and numerous committee roles. He has tackled bylaw reform due to the new BC Societies Act, as well as grant applications and fundraising. Dennis not only the supports the Okanagan observatory, he helped make the facility accessible to mobility-challenged visitors.

Steve Holmes (Kitchener-Waterloo Centre)

Mr. Holmes has served two terms as Centre President and is a passionate advocate for astronomy. He helps people to use the Tilker's Observation site, teaches astrophotography, and he is always ready to provide technical assistance. Mr. Holmes is said to have "volunteered for everything" over many years and continues to inspire stargazers of all ages.

Qilak Award

No RASC member was nominated this year.

In 2018, there were multiple nominations. The committee hopes that those nominees who have continued their effort in public outreach will be nominated again for their work through to 2021.

Simon Newcomb Award

John A. Read (Halifax Centre)

For writing a collection of astronomy-themed books to inspire children and beginning observers. John has created several books, and at least one is now available in over ten languages. He has a clear, direct writing style that appeals to first-time stargazers, making astronomy fun and reducing technical complexity. John is now assisting others in publishing new books.

Chant Medal

The Chant Medal of the Society was established in 1940 in appreciation of the great work of the late Prof. C.A. Chant in furthering the interests of astronomy in Canada. It is awarded to an amateur astronomer, resident in Canada, on the basis of the value of the work carried out in astronomy and closely allied fields of the original investigation.

Dr. Michel Duval (Centre francophone de Montréal)

Dr. Duval is a chemist and amateur astronomer, recognized for his work in successfully determining that the Black Drop Effect seen during transits of Venus and Mercury is caused by the formation of diffraction halos. His insight from the 2004 Venus transit was validated with the 2012 Venus and 2016 Mercury transits. In 2017, he showed the diffraction halo effect contributes to the solar eclipse Diamond Ring effect.

Ken Chilton Prize

The prize, named for Kenneth E. Chilton of the Hamilton Centre is awarded annually to an amateur astronomer, resident in Canada, in recognition of a significant piece of astronomical work carried out or published recently.

Peter Pekurar (Kitchener-Waterloo Centre)

For work on advancing the coating process for telescope mirrors. Mr. Pekurar developed a new method to apply reflective silver coatings to telescope mirrors. This process is an advancement over previous methods, simplifying the process for amateur use.

Fellow of the RASC

This is the Society's most senior award and the highest honour the Society can pay to a member. Candidate's service and contributions to the Society must have had a significant positive impact on the work of the Society over an extended period, beyond that of the Service Award. Fellows must have contributed to the Society's success in attaining its stated objectives, mission, and vision, with at least half of their service at the Society level, in addition to any contributions at the Centre level.

There are two outstanding individuals recognized as belonging to Fellows of the RASC.

Randall Rosenfeld (National Member)

For over a dozen years, Randall Rosenfeld has served our Society in a multitude of ways. He has led Committees on History, Membership & Promotion, and Green Laser Pointer safety. As the Society's archivist, he has opened windows into our history and created over 50 insightful and engaging articles for the *Journal* of the RASC. He is a wonderful ambassador to the CASCA professional community and most recently is curating the new Dorner Telescope Museum.

David M.F. Chapman (Halifax Centre)

For over 30 years, Mr. Chapman has been an inspiring communicator and champion of good science. A life member of the Society active since 1984, he has served as Centre Librarian, Vice President, and President of the Halifax Centre. His innovative approach resulted in the Halifax Centre's Simon Newcomb Award becoming a Society Award. His dark-sky programs led to the Kejimkujik National Dark-Sky Preserve, he forged relationships with the Acadia First Nation and has brought awareness to Mi'kmaw calendrical systems, plus he has shared this through news media. David's international outreach efforts, editorial leadership of the *Observer's Handbook*, contributions to JRASC and other publications, participation on national committees and contributions to the Society are outstanding.

President's Award

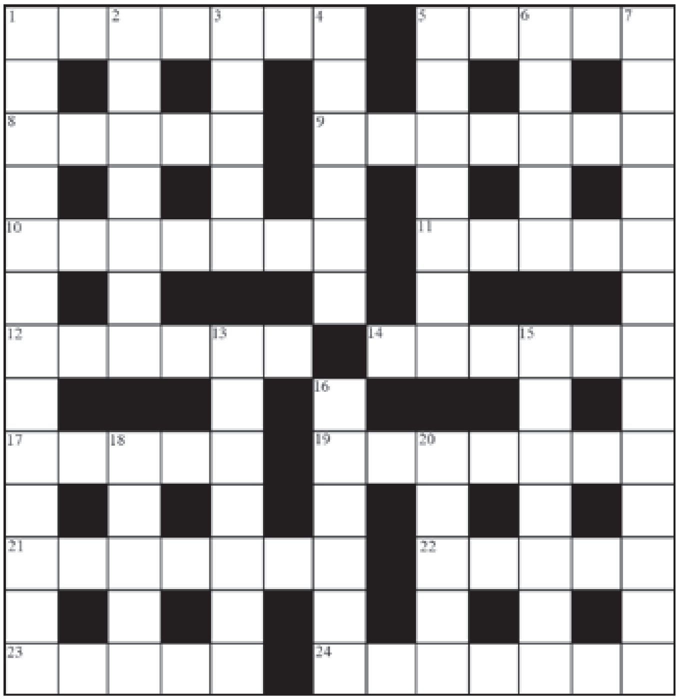
This award is given at the President's discretion, usually once a year, to a member (or members) who has/have made an important contribution to the Society.

Barry Shanko (Vancouver Centre)

Mr. Shanko served as speaker coordinator for the Vancouver Centre for 31 years and was active in RASC public outreach efforts in the Vancouver area. In his life he had to overcome many economic and health challenges but became known for his ability to attract outstanding speakers from around Canada and the U.S. for Vancouver Centre events. Unfortunately, Mr. Shanko passed away unexpectedly just before his 60th birthday on 2020 May 2.

Astrocryptic

by Curt Nason



ACROSS

1. Each to his own potentially hazardous asteroid (7)
5. Mostly home by morning star on the horse's neck (5)
8. Solar probe had perhaps seen such rarefied elements (5)
9. Solar wind explorer transiting July's sessions (7)
10. Unusual violin note struck in some meteorites (7)
11. Rare one rotates in Cepheus (5)
12. Trigger's meal room with indoor stars in New York (6)
14. Maintain pressure when on the line (6)
17. Bolide boom scattered icons on the desktop (5)
19. Home plate star of October's sky diamond (7)
21. Probe looked into America's sinister division (7)
22. Observatory where tide cycle comes to a point (5)
23. Early rendition of tune from a harp (5)
24. Leo lionized by the Society (7)

DOWN

1. A Class 1 trophy awarded for a journal (13)
2. Little work a large town can do about light scattering property (7)
3. I head out to see Auriga's kids (5)
4. A flying one is a curse, perhaps, for us (6)
5. Poor eyepiece to probe Titan with (7)
6. Blurry smear of an amplified radio source (5)
7. Eastern jet crime boss scrambled from M82, for example (7,6)
13. Curie development and French backing for an achondrite (7)
15. Trussing the energy source of a star (7)
16. Asteroid crystal found in some lethal items (6)
18. Rains ruined his Persian observatory for refining the Ptolemaic system (5)
20. Common swamp creature ate half an astrogator (5)

Answers to June's puzzle

ACROSS: **1** GROUP (org (rev)+up); **4** NEWCOMB (2 def); **8** ALGORAB (anag+or+AB); **9** DATED (2 def); **10** SINAI (anag); **11** CENTRES (an(n)ag); **12** RANDALL BROOKS (R+and+all+syn); **16** ALNILAM (anag); **18** MEADE (m(e+ad)e); **20** TERRA (arret(rev)); **21** JODRELL (2 def); **22** SHATNER (anag); **23** NADIR (anag)

DOWN: **1** GIAUSAR (an(1au)ag+r); **2** ORGAN (anag); **3** PORRIMA (por+rima); **4** NEBECULA MAJOR (anag); **5** WODEN (anag); **6** ONTARIO (anag); **7** BODES (an(e) ag); **13** NINURTA (anag); **14** RAMSDEN (anag+den); **15** STELLAR (anag); **16** ATTAS (at+sat(rev)); **17** LEARN (L(ear)N); **19** AREND (a(re)nd))

The Royal Astronomical Society of Canada

Vision

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

Mission

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

Values

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

Great Images

by Daniel Meek

Daniel Meek photographed the supernova SN 2020jfo in Messier 61. Meek imaged it using a single 900-second luminance exposure with the RASC robotic telescope rasc.ca/telescope

Journal

Noctilucent clouds are an alien-like formation high up in the atmosphere and best viewed from the northern hemisphere in spring and summer. Debra Ceravolo captured this stunning display on June 2 from Anarchist Mountain, Osoyoos, British Columbia. Image is a five-second exposure at ƒ/4, ISO 100 using a Canon 6D and 100mm lens.