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Journal

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PROMOTING ASTRONOMY IN CANADA

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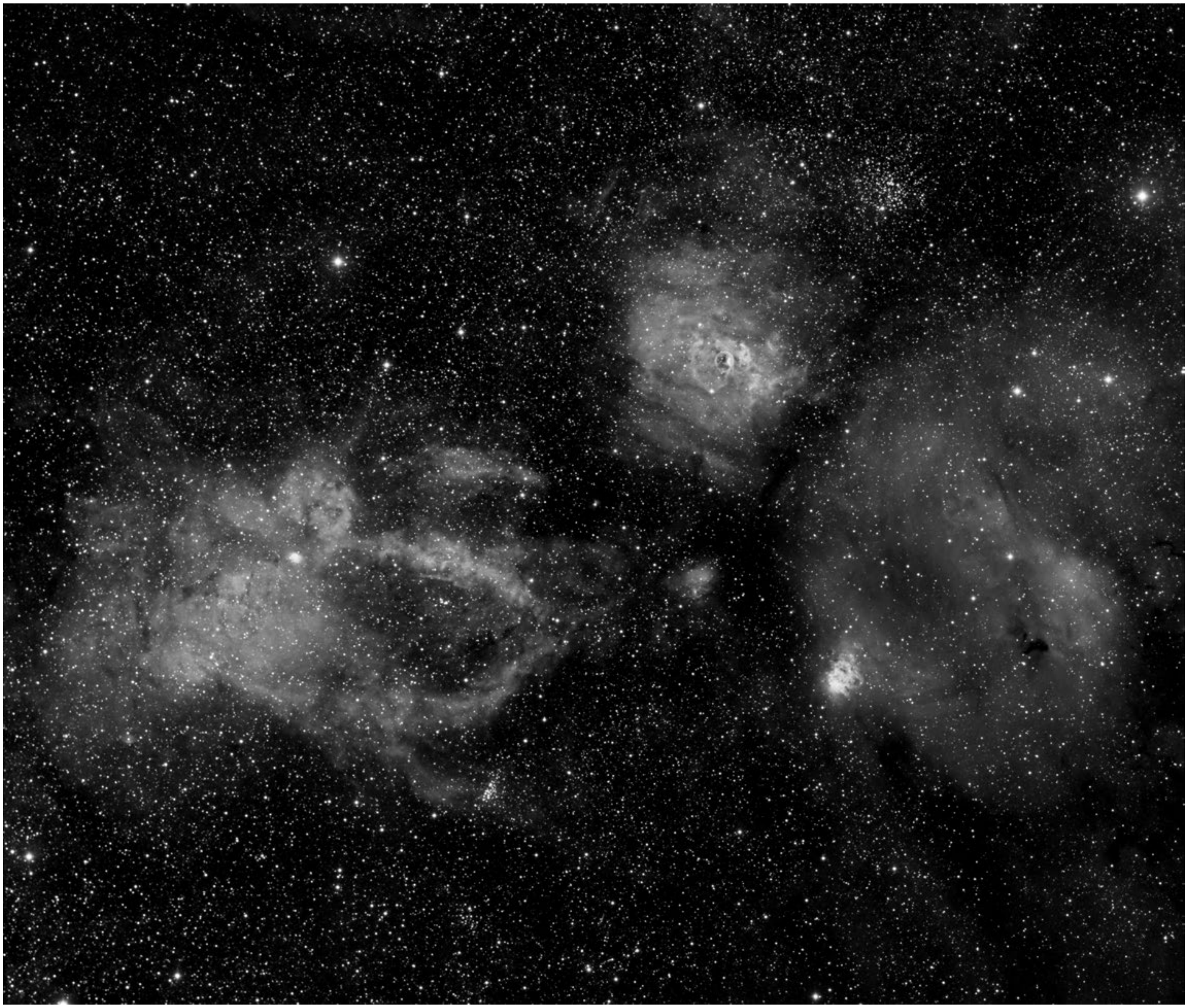
Inside this issue:

Southern Night

The Best of Monochrome.

Drawings, images in black and white, or narrowband photography.



Ron Brecher imaged this wide-field view of the region around the Bubble Nebula in Cassiopeia that is rich with targets. The well-known Bubble Nebula (NGC 7635) is seen just right of centre; the open star cluster M52 is in the upper right of the Bubble and Sh2-161 is at lower right. The large Sh2-157, the Lobster Nebula, is left of centre and just beneath the lobster's "claw" is open cluster NGC 7510. But that's not all: in the centre is Herbig-Haro 170 (also known as MWC1080) and Sh2-159 is a small patch of nebulae lying below the Bubble in this image.

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

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Kerry-Ann Lecky Hepburn took this stunning image, saying, "My first time south of the equator was truly an amazing experience. The sky was exploding with stars. Here we found this lonely tree standing proudly with the sparkling winter Milky Way in the Atacama Desert, Chile." She took this image with a Canon 6D, Sigma ART 14mm lens at f2.0, 25 sec and ISO 6400.

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

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(astronome@outlook.com)

As Orion heads toward the western horizon, and sunrise becomes a bit earlier each day, it's time for a mid-term update. If there was a report card on our Society and our Board, we might get a B+ overall, however there are a few areas that are "showing improvement" or need some improved focus.

Our fundraising efforts are starting to show early results, and will need further attention. Fundraising consultant Lisa Di Veto has reached out to many of our supporters, the 150-or-so active donors, and has made some significant strides in this area. With over 5000 members, we can do better. Response rates to a recent campaign were just above 1%, whereas other organizations see closer to a 10% rate. Please consider making a modest gift to the Society to support our charitable work, whether through a donation online, mail, when you renew, or through planned giving, in your estate. We have kicked off the next phase of fundraising, and Lisa is working on sources outside the membership, including several grant applications, and working to secure summer student funding to tackle several exciting projects. Our Fundraising Committee recognizes there are opportunities to become more of a donor-culture, and we have adopted two new projects specifically for fundraising: a new historical archive display room, and a remote telescope project. This is in addition to outreach, education, free publications, and the fight to save our dark skies. We do want to acknowledge the huge amount of volunteer time that makes so much happen across our organizations, and our volunteers get an A for their work. For the rest of us, stepping up with a donation would go a long way to achieving greater results.

Financially, we always face challenges, and as of this writing, we're completing the 2017 fiscal year end. I'll keep my comments brief until we have final results. Costs continue to rise with inflation. The Board is reviewing our finances with the Finance Committee and the National Council. Our first-term Treasurer Anthony Gucciardo wrapped up the 2018 budget in February. On the revenue side, some highlights were around publications. Please show your appreciation by purchasing our publications. That's a wonderful way to applaud the 75+ people who help create them. Publication revenue beat budget targets by approximately 10%. The new USA Edition Handbook is a significant contributor. Our Publications Committee is working on two new books, and I think they deserve an A+ for the results they achieved in 2017.

We are looking for a new chair for the Education Committee. Andrea Misner is busy completing her Master's degree, and we're hoping for a successor to come forward. If you enjoy this kind of work, the time commitment is a few hours a month, and there are some wonderfully talented people on the committee. Please contact Robyn Foret or myself. This highlights the needs for succession planning, that is, having a backup person ready to step in and lead the efforts. We wish Andrea all the best in her pursuit, and hope to hear more from her soon. Our Education committee has noted a need to consider separating Education, Outreach, and to create a new focus on Inreach. It might be best served with two new committees. Can you help?

The Board has a big set of Strategic Plan objectives. Some committees are on board and running with them, and frankly, others are not engaged or need some new or additional talent. We need to revitalize some of the committees and/or help the existing teams move forward. I sometimes think our old structure was better at finding people either on Council or elsewhere to aid committee work. This area might get a B-, or perhaps we need better prioritization. There is room for improvement here as well.

From a growth perspective, we're doing well. Membership is approximately 5200 people, the best it has been in decades. Centres are making people feel more welcome and engaged. Thank you for your efforts. Customer service from our Society Office continues to be excellent, and I personally have handled a very small number of issues with stray Handbooks, renewal problems, or requests falling through the cracks. I'm amazed what I've learned by spending a few days in the Dundas St. West office in Toronto with our staff. Julia, Renata, and Randy run a tight ship, and are very responsive. I hope you agree they deserve an A or A+. Next time you need to contact the office, make a point of showing your appreciation.

We're also improving our connection with the public through media and outreach. I'd like to congratulate the team that pulled off an amazing cross-country 150th kick-off celebration. It was a privilege to participate and to see friendly faces bring greetings from locations across Canada. Host Paul Delaney did a great job coordinating the realtime broadcast over YouTube. People joined from university labs, backyard observatories, and their homes. The first new podcasts are ready, hosted by Heather Laird. These are high quality, with help from sound editor Chelsea Body and archivist Randall Rosenfeld. You can find the first podcast as follows:

Episode 1: Beginnings—Documentary Traces & Tatters is up and available on the website

https://www.rasc.ca/rasc-2018-podcasts

and for download on iTunes

https://itunes.apple.com/us/podcast/rasc-history-podcast/id1333749186?mt=2

You can find the supplementary page here to learn more about the subject matter here

https://www.rasc.ca/podcast-1-supplementary-material

Media outlets including Global TV News and CTV News have interviewed our Executive Director Randy Attwood and myself on a number of hot topics, including the first new rocket capable of getting us to Mars, and a certain billionaire's missing Tesla orbiting the Solar System. We would like to know what your Centre is doing with local media. We seem to be entering the Digital Media Age and increasing popularity of @RASC and @RASCobserving on Twitter are in evidence. Please follow! High marks for all concerned. These new ways of outreach simply weren't natural for us just 5 years ago. Please show your support.

As amateur and professional astronomers, we have a duty to encourage more people of diverse background to participate and feel welcome and engaged. The Board is in final steps of updating our policies and I hope we will be able to introduce them at the February council meeting. We appreciate hearing that your Centre is making the efforts to recognize, invite and engage more people, young and old, more women, and under-represented groups in your area. Together, we will provide a welcoming, safe, and inclusive environment for all people. Our aspiration is that new and existing members would give us at least a B+ and that this will continue to improve in 2018, with a goal of 50% gender balance, and a wider range of engaged, satisfied members.

As we continue our 150th anniversary celebrations, please join us at the Calgary General Assembly. Let us know what you plan to do in your Centre. Bake a cake, have a star party, find some old photos (ok, those glass plates are tricky). Share in the celebration. Keep looking up and making observations. Share the joy of casual observing, and the fun of problem solving and discovery.

We can imagine our Society's "parents" who founded the RASC in 1868 would be very pleased with our report card. *Our business is looking up!* ✶

News Notes / En Manchette

Compiled by Jay Anderson

SpaceX opens new windows to space

SpaceX pried open the window to space a little more on February 7 when it successfully tested its brand-new *Falcon Heavy* rocket, delighting the huge crowds watching at Cape Canaveral and millions of Internet viewers. It was an impressive send off, evoking memories of the moon launches of the 1960s and '70s and the early *Shuttle* take-offs. The spectacle was made even more Facebook-worthy by the nature of the cargo carried on this initial test flight: CEO Elon Musk's Tesla Roadster, complete with a spacesuited driver and appropriate logos and mementos.

The *Falcon Heavy* is the largest of the suite of rockets offered by SpaceX, capable of lifting nearly 64,000 kg to low-Earth orbit. This is more than twice the payload of the previous record holder, the *Delta V*, and the fourth most powerful of historical launch vehicles. The *Heavy*'s first stage is composed of three *Falcon 9* nine-engine cores giving 27 engines that together generate more than 5 million pounds of thrust at liftoff. The second stage is based on SpaceX's *Falcon 9* booster that has had several notable launches in the past few years.

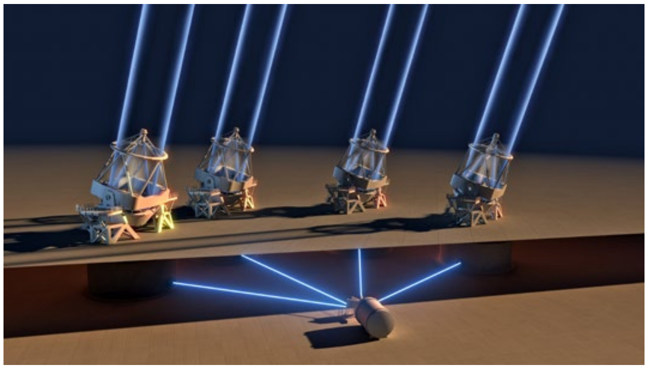
Almost as exciting as the launch was the successful landing of two of the three rocket boosters back at Cape Canaveral after they'd separated from the launch vehicle. Crowds lining the beaches along the north Florida coast broke into cheers as the two engines ignited to slow their descents to a gentle landing. The sight of the two rockets landing in tandem was only muted by the failed landing of a third core booster, which instead fell into the ocean when some of the engines failed to ignite.

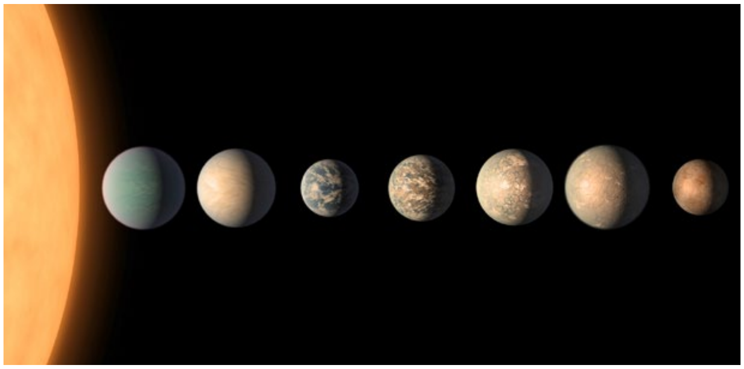
Figure 1 — (opposite, top) Ryan Chylinski had remote cameras set up at the 39A launch pad and snapped stunning images, demonstrating the raw power of the Falcon Heavy *rocket. This is just one of several taken at early liftoff. Image: Ryan Chylinski IG: @ScienceTripper Volunteer for SpaceFlightInsider*

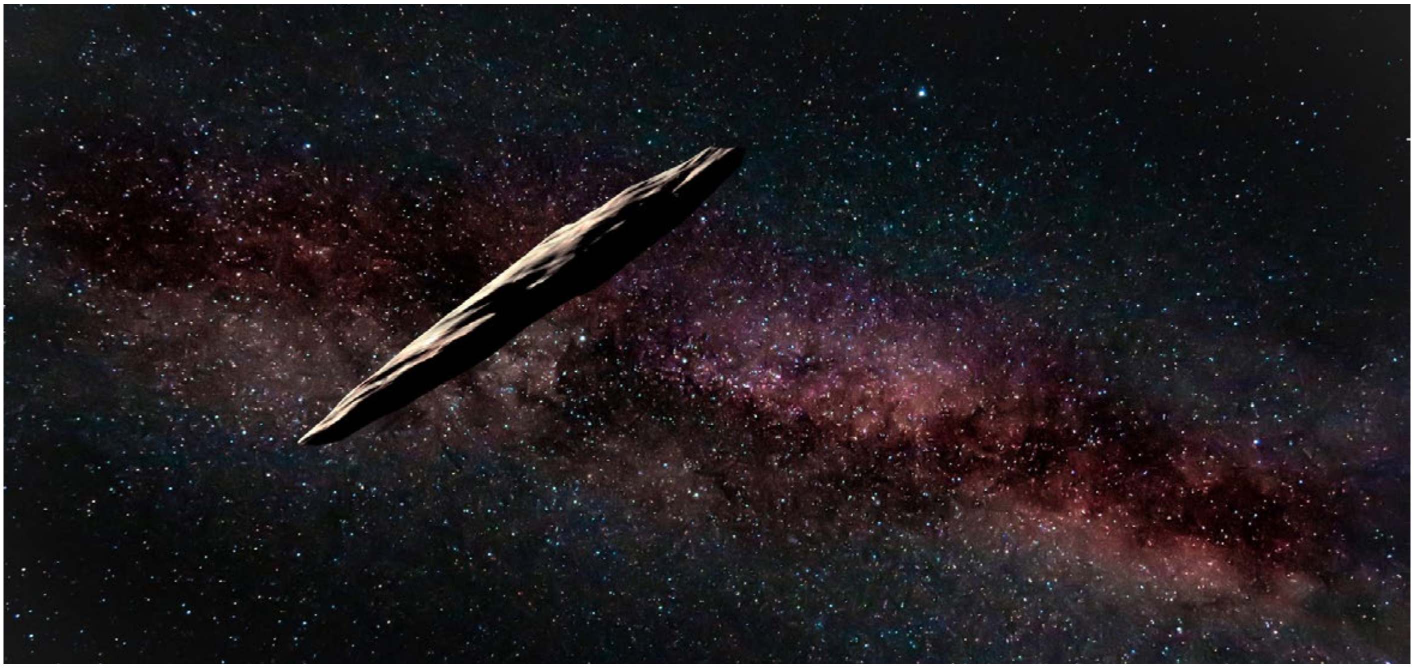
Figure 2 — (opposite, centre left) The ESPRESSO instrument on the ESO's Very Large Telescope in Chile has used the combined light of all four of the 8.2-m telescopes for the first time. This image shows a simplified view of how the light collected by each telescope is combined in the ESPRESSO instrument. Image ESO/L. Calcada.

Figure 3 — (opposite, centre right) This artist's concept shows what the TRAPPIST-1 planetary system may look like, based on available data about the planets' diameters, masses, and distances from the host star, as of February 2018. Source: NASA

Figure 4 — (opposite, bottom) This artist's impression shows 'Oumuamua. Image credit: Joy Pollard / Gemini Observatory / AURA / NSF







In the meanwhile, the Tesla Roadster is on its way beyond Mars, a little farther than planned, but not quite to the asteroid belt. According to NASA, the trajectory will take the Roadster only about half-way, to 257,000 km (1.34 au) or a little beyond Mars, in a 687-day orbit. The auto will return to the Earth's vicinity in March 2021, when it passes at a distance of 45 million km. It will pass Mars at a distance of 45 million km on 2020 October 8.

Notwithstanding the attention given to this launch, the SpaceX achievement is a big milestone in the history of space exploration and business. The payload is huge, the cost is low, and public enthusiasm for space exploration and commerce has taken a jump. The show doesn't seem to be over, as SpaceX's next venture, the "*Interplanetary Transport System*," is under development. That project features an even larger "BFR" or "*Big Falcon Rocket*" (though there are other translations) that will generate 28 million pounds of thrust, about four times that of the *Saturn V*. Now the big question: what to do with all of this capability?

The biggest ESPRESSO

The European Southern Observatory has announced that the light from all four its 8.2-metre telescopes has been combined to create what is effectively a 16-metre telescope. This four-unit telescope has the largest collecting area currently in existence.

A system of mirrors, prisms, and lenses transmits the light from each Very Large Telescope to the ESPRESSO spectrograph up to 69 metres away. ESPRESSO can either collect the light from all four Unit Telescopes together, increasing its light-gathering power, or alternatively receive light from any one of the Unit Telescopes independently, allowing for more flexible usage of observing time. ESPRESSO was specially developed to exploit this infrastructure.

Two of the main scientific goals of ESPRESSO are the discovery and characterization of Earth-like planets and the search for possible variability of the fundamental constants of physics. The latter experiments require the observation of distant and faint quasars, a goal that will benefit most from combining the light from all four Unit Telescopes in ESPRESSO. Both rely on the ultra-high stability of the instrument and an extremely stable reference light source. ESPRESSO instrument scientist at ESO, Gaspare Lo Curto, explains the historical significance of this event: "*ESO has realized a dream that dates back to the time when the VLT was conceived in the 1980s: bringing the light from all four Unit Telescopes on Cerro Paranal together to feed a single instrument!*"

Due to the complexity involved, the combination of light from all four Unit Telescopes, at what is known as an "incoherent focus," had not been implemented until now. However, space for it was built into the telescopes and the underground structure of the mountaintop from the start. The word "incoherent" means that the light from the four telescopes is simply added up, without the phase information being considered in the way that it is in the VLT Interferometer. Light from the four telescopes is routinely brought together in the VLT Interferometer for the study of extremely fine detail in comparatively bright objects. But interferometry, which combines the beams "coherently," cannot exploit the huge light-gathering potential of the combined telescopes to study faint objects. The new incoherent combination of light has the light-collecting power comparable to a 16-metre aperture telescope. The angular resolution remains that of a single 8-metre telescope, unlike the VLT Interferometer where the resolution is increased to that of a (virtual) telescope with an effective aperture equal to the maximum separation between the constituent telescopes.

Project Scientist Paolo Molaro comments: "This impressive milestone is the culmination of work by a large team of scientists and engineers over many years. It is wonderful to see ESPRESSO working with all four Unit Telescopes and I look forward to the exciting science results to come."

Feeding the combined light into a single instrument will give astronomers access to information never previously available. This new facility is a game changer for astronomy with high-resolution spectrographs. It makes use of novel concepts, such as wavelength calibration aided by a laser frequency comb, providing unprecedented precision and repeatability, and now the capability to join together the light-collecting power of the four individual Unit Telescopes.

Prepared in part with material provided by the ESO.

Water, water, everywhere?

A new study published in the journal *Astronomy and Astrophysic*s has revealed that the seven planets orbiting the nearby ultra-cool dwarf star TRAPPIST-1 are all made mostly of rock, and some could potentially hold more water than Earth. The planets' densities, now known much more precisely than before, suggest that some of them could have up to five percent of their mass in the form of water—a huge amount; by comparison the Earth has only about 0.02% water by mass! The hotter planets closest to their parent star are likely to have dense steamy atmospheres and the more-distant ones probably have icy surfaces. In terms of size, density, and the amount of radiation it receives from its star, the fourth planet out is the most similar to Earth. It seems to be the rockiest planet of the seven and has the potential to host liquid water.

Planets around the faint red star TRAPPIST-1, just 40 light-years from Earth, were first detected by telescopes at ESO's La Silla Observatory in 2016. In the following year, additional observations from ground-based telescopes, including ESO's Very Large Telescope and NASA's *Spitzer Space Telescope*, revealed that there were no fewer than seven planets in the system, each roughly the same size as the Earth. They are named TRAPPIST-1b,c,d,e,f,g, and h, with increasing distance from the central star.

Observations from the *Hubble Space Telescope* first revealed that at least three of the TRAPPIST-1 planets—d, e, and f—do not seem to contain puffy, hydrogen-rich atmospheres like the gas giants of our own Solar System. Hydrogen is a greenhouse gas and would make these close-in planets hot and inhospitable to life. Now, a team of scientists led by Simon Grimm at the University of Bern in Switzerland have applied very complex computer modelling methods to all the available data and have determined the planets' densities with much better precision than was possible before. As Simon Grimm explains: *"The TRAPPIST-1 planets are so close together that they interfere with each other gravitationally, so the times when they pass in front of the star shift slightly. These shifts depend on the planets' masses, their distances, and other orbital parameters. With a computer model, we simulate the planets' orbits until the calculated transits agree with the observed values, and hence derive the planetary masses."*

The form that water takes on TRAPPIST-1 planets would depend on how much heat they receive from their ultra-cool dwarf star, which is only about 9 percent as massive as our Sun. Planets closest to the star are more likely to host water in the form of atmospheric vapour, while those farther away may have water frozen on their surfaces as ice. TRAPPIST-1e is the rockiest planet of them all, but is still believed to have the potential to host some liquid water. *"Densities, while important clues to the planets' compositions, do not say anything about habitability. However, our study is an important step forward as we continue to explore whether these planets could support life,"* said Brice-Olivier Demory, co-author at the University of Bern.

TRAPPIST-1b and c, the innermost planets, are likely to have rocky cores and be surrounded by atmospheres much thicker than Earth's. TRAPPIST-1d, meanwhile, is the lightest of the planets at about 30 percent the mass of Earth. Scientists are uncertain whether it has a large atmosphere, an ocean, or an ice layer.

Scientists were surprised that TRAPPIST-1e is the only planet in the system slightly denser than Earth, suggesting that it may have a denser iron core. It is mysterious that TRAPPIST-1e appears to be so much rockier in its composition than the rest of the planets. In terms of size, density, and the amount of radiation it receives from its star, this is the planet that is most similar to Earth.

TRAPPIST-1f, g, and h are far enough from the host star that water could be frozen into ice across their surfaces. If they have thin atmospheres, they would be unlikely to contain the heavy molecules that we find on Earth, such as carbon dioxide.

"It is interesting that the densest planets are not the ones that are the closest to the star, and that the colder planets cannot harbour thick atmospheres," notes Caroline Dorn, study co-author based at the University of Zurich, Switzerland.

The TRAPPIST-1 system will continue to be a focus for intense scrutiny in the future with many facilities on the ground and in space, including ESO's Extremely Large Telescope and the NASA/ESA/CSA *James Webb Space Telescope*.

Compiled with material provided by NASA and the ESO.

'Oumuamua had a tough life

The first ever interstellar asteroid to our Solar System, now known as 'Oumuamua, has had a violent past that is causing it to tumble around chaotically, a study team led by Queen's University Belfast scientist Dr. Wes Taylor has proposed. The team was made up of researchers from elsewhere in the UK, the US, Canada, Taiwan, and Chile, and seven researchers from Queen's.

'Oumuamua was detected as it flew through our Solar System in October and was originally thought to be a comet; it was later revealed as an elongated asteroid. Its dimensions, estimated from assumptions about its albedo, give it a length of 230 m and a width of 35 m. Its interstellar speed afforded astronomers only a short time to conduct observations before it faded beyond visibility by the end of 2017.

The research team discovered that ʻOumuamua wasn't spinning periodically like most of the small asteroids and bodies that we see in our Solar System. Instead, it is tumbling, or spinning chaotically, and could have been for many billions of years.

While it is difficult to pinpoint the exact reason for this, it is thought that ʻOumuamua impacted with another asteroid before it was fiercely thrown out of its system and into interstellar space. Dr Fraser explains: "Our modelling of this body suggests the tumbling will last for many billions of years to hundreds of billions of years before internal stresses cause it to rotate normally again.

"While we don't know the cause of the tumbling, we predict that it was most likely sent tumbling by an impact with another planetesimal in its system, before it was ejected into interstellar space."

Until now, scientists had been puzzled that ʻOumuamua's colour varied between successive measurements. However, Dr. Fraser's research has now revealed that its surface is spotty, and that when the long face of the cucumber-shaped object was facing telescopes on Earth, it was largely red, but the rest of the body was neutral coloured, like dirty snow. As Dr. Fraser explains: "Most of the surface reflects neutrally, but one of its long faces has a large red region. This argues for broad compositional variations, which is unusual for such a small body."

Professor Alan Fitzsimmons, part of the Queen's University team, commented: "We have discovered that the surface of ʻOumuamua is similar to small Solar System bodies that are covered in carbon-rich ices, whose structure is modified by exposure to cosmic rays."

Compiled in part with material provided by Queen's University, Belfast.

New Horizons—one last job before bed

NASA's *New Horizons* spacecraft recently turned its telescopic camera toward a field of stars, snapped an image—and made history.

A routine calibration frame of the "Wishing Well" galactic open star cluster, made by the Long Range Reconnaissance Imager (LORRI) on December 5, was taken when *New Horizons* was 6.12 billion kilometres (40.9 astronomical units) from Earth—making it, for a time, the farthest image ever made from this planet. LORRI broke its own record just two hours later with images of Kuiper Belt objects 2012 HZ84 and 2012 HE85—further demonstrating how nothing stands still when you're covering more than 1.1 million kilometres of space each day.

"*New Horizons* has long been a mission of firsts—first to explore Pluto, first to explore the Kuiper Belt, fastest spacecraft ever launched," said *New Horizons* Principal Investigator Alan Stern, of the Southwest Research Institute in Boulder, Colorado. "And now, we've been able to make images farther from Earth than any spacecraft...."

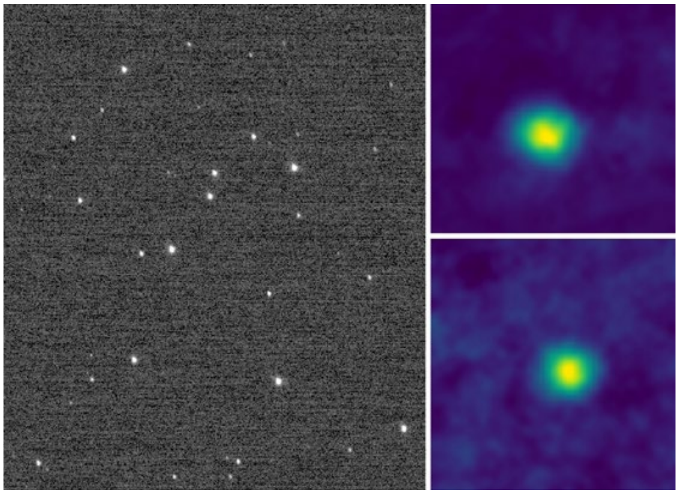


Figure 5 — The LORRI instrument on NASA's New Horizons *spacecraft obtained these deep-space images from beyond the orbit of Pluto, well above the Earth's atmosphere. On the left is a short exposure of the "Wishing Well" cluster. On the right are images of two Kuiper Belt objects, 2012 HZ84 (bottom) and 2012 HZ85 (top). The position of the spacecraft enables it to examine the KBOs at unique angles in a search for rings or dust. Images: NASA/JHUAPL/SwRI*

New Horizons is just the fifth spacecraft to speed beyond the outer planets, so many of its activities set distance records. On December 9, it carried out the most-distant course-correction maneuver ever, as the mission team guided the spacecraft toward a close encounter with a KBO named 2014 MU69 on 2019 January 1.

During its extended mission in the Kuiper Belt, which began in 2017, *New Horizons* is aiming to observe at least two-dozen other KBOs, dwarf planets, and "Centaurs," former KBOs in unstable orbits that cross the orbits of the giant planets. Mission scientists study the images to determine the objects' shapes and surface properties, and to check for moons and rings. The spacecraft also is making nearly continuous measurements of the plasma, dust, and neutral-gas environment along its path.

The *New Horizons* spacecraft is healthy and is currently in hibernation. Mission controllers at the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland, will bring the spacecraft out of its electronic slumber on June 4 and begin a series of system checkouts and other activities to prepare *New Horizons* for the MU69 encounter.

Compiled with material provided by Johns Hopkins University ✶

Feature Articles / Articles de fond

Wizards' Apprentices: University of Alberta Students and the Evolution of the DRAO Synthesis Telescope

by D. Routledge (dr2@ualberta.ca)
and J.F. Vaneldik (fredvan@shaw.ca)
Emeritus professors, Electrical and Computing Engineering Department, University of Alberta

It is a truth universally acknowledged, to misquote Jane Austen, that an observatory in possession of a good telescope must be in want of acolytes—graduate students, say, who can help expand its capabilities. What follows tells how a loose cooperation between the Electrical and Computer Engineering Department at the University of Alberta (henceforth "ECE") and the Dominion Radio Astrophysical Observatory ("DRAO") at Penticton became a tight collaboration lasting more than three decades, in which the primary beneficiaries were graduate students lucky enough to spend time at the observatory.

Fig. 1 — DRAO's versatile John A. Galt 26-m telescope, commissioned in 1960 and in constant use ever since. Before the advent of the Synthesis Telescope, this was the observatory's main instrument for cm-wavelength observations. At the atomic hydrogen λ21-cm line, it resolves angular detail of about half a degree.

Since 1960, the main instrument for cm-wavelength astronomy at DRAO had been the 26-metre paraboloid (now called the John A. Galt telescope; see Figure 1), in steady use at 21-cm wavelength producing continuum and atomic hydrogen ("HI") spectral-line images with 0.5° angular resolution—the diameter of a full Moon. In a parallel endeavour, DRAO's two huge decametre-wavelength tee-arrays of wire dipoles had achieved 1.4° resolution for a sky survey at 13.5 metres, and 2.2° resolution for another at 30 metres.

Initially (see first seven thesis topics in Table 1) ECE's efforts in radio astronomy had targeted decametric wavelengths. Desiring sharper long-wavelength resolution, Galt, then director of DRAO, had enlisted ECE in locating an interference-free site in SW Alberta with good ionospheric properties, for a next-generation decametric tee-array. His goal: resolution better than 0.5°. Four ECE academic staff responded, though none had astronomical interests. They hired a technician, Irwin Grisch, and a postdoctoral fellow from the radio astronomy program at Queen's University, David Routledge. A year later, Fred Vaneldik joined ECE as associate professor with expertise in microwave circuitry and feedback control systems, and also joined the project.

For 0.5° resolution at 20–30-m wavelength, the telescope needed dimensions of several kilometres. The ECE group had located a potential site in the Rocky Mountain foothills and had begun testing with interferometers up to 5.5-km baseline at 24-m wavelength[1]. This did show the site would be suitable. However, by that time the Canadian astronomical community had rallied behind the new optical telescope on Mauna Kea (the CFHT), and radio astronomers were busy either with the 46-m "big dish" telescope at Algonquin or with a magical new technique—Earth-rotation aperture synthesis—for arcminute resolution at the astrophysically important wavelength of 21 cm.

ECE's involvement in radio astronomy then shifted to centimetre wavelengths, centring on the new Synthesis Telescope (the "ST") at DRAO. As Table 1 shows, this shift established ECE's radio astronomical trajectory into the 21st century. ECE's story now joins that of the ST.

In its initial form the ST operated at 21 cm only, with two 9-m antennae on an E–W precision railway track 300 metres long. Designed by Rob Roger and Carman Costain of DRAO—the first two practitioners in Canada of this art of Earth-rotation synthesis—the ST had been producing arcminute-resolution images since 1972. Because the antenna spacing was changed day-to-day, rotation of the Earth allowed the ST to produce images equivalent to those from a 300-m aperture.

Though skeletal and therefore slow—a single image required 70 days—the two-antenna ST was a functioning synthesis telescope. It produced both continuum images and 80 channels of λ21-cm HI-line images, all with 2′ resolution[2]. Crucially for

Fig. 2 — The DRAO Synthesis Telescope, seen from the west in 2000. Seven 9-metre equatorially mounted antennae stretch eastward along a 600-m baseline. (Someone vetoed naming them Happy, Sleepy, Dopey, Grumpy, Bashful, Sneezy, and Doc.) Three are on wheels, for positioning along a 300-m track. Buried cables connect receiver front ends in the focus boxes to additional electronics and digital correlators in the concrete building near the middle of the array.

its future, it imaged a 2.5-degree field. A new era of wide-field, high-resolution 21-cm astronomy had dawned in Canada.

Immediately DRAO began planning to add two more 9-m dishes and to extend the baseline to 600 m. From this time forward, improvements would never cease. The ST would evolve into a much faster instrument (see Figure 2) with expanded capabilities, eventually becoming the primary instrument for the Canadian Galactic Plane Survey ("CGPS").

How did the skeletal instrument of 1972 become the enhanced ST of the new millennium? This is the story of a three-decade collaboration in which the DRAO staff would mentor ECE students in graduate research projects, with a dozen theses resulting as the ST evolved. The core of this collaboration would be DRAO's wizards, striving to ensure the ST did not stagnate. Its capabilities and power had to advance, otherwise the telescope would obsolesce, and the observatory would be closed—as was threatened repeatedly during the coming decades.

The Collaboration Commences

In 1978, Fred Vaneldik arrived in Penticton on sabbatical from ECE. Working with Tom Landecker, a DRAO scientist elbow-deep in upgrading the ST, wishing to learn the arcana of Earth-rotation synthesis, Vaneldik dug into redesigning the ST's local oscillator ("LO") system.

In a synthesis telescope, the LO system down-converts the astronomical signals arriving at the antennae to the intermediate frequency ("IF"), to reduce cable losses en route to the central correlator. Despite cable-length changes with temperature, the LO system must maintain precise coherence of the wavefront arriving across the aperture being synthesized.

In optical telescopes, if local "seeing" changes across a large mirror, loss of coherence of the wave front degrades the image. In the ST, phase errors between IF signals would produce similar degradation.

Designing a stable LO system was made more difficult by delay in the long cables. Nevertheless, at the time of writing 37 years later, 7 of the Vaneldik-Landecker LO systems[3] are still in constant use on the ST.

Why expand the ST from two antennae to four? For two reasons: to speed up imaging by recording "fringe visibilities" from six antenna pairs at once, and to extend the ST's baseline to 600 m to achieve 1′ resolution, improved from 2′.

In changing focus from decametric to centimetric astronomy, the ECE group shrank to Vaneldik, a research associate (Graham Walker), a technician (Lyle Holroyd), a Ph.D. student (Bryon Kasper), and Routledge. The new cm-wavelength liaison with DRAO and the ST, however, was about to pay dividends.

An Example of 21-cm Imaging

By 1982, the ST had four antennae on a 600-m baseline. As this wide-field, high-resolution telescope hit its stride, it began to reveal astonishing objects looming huge but unseen in the sky. Figure 3, for example, shows supernova remnant VRO 42.05.01 (G166.0 + 4.3) at 21 cm. This distant SNR sits in Auriga, nearly invisible optically[4].

Missing short-baseline data (the antennae cannot be moved too close together) have been added to the ST data to produce Figure 3. Without these low Fourier components, a synthesis telescope is blind to large-scale angular structure. To show the complete object, i.e. not just "the hair on the elephant while omitting the elephant," DRAO had already made this step standard practice, often using data from the 26-m telescope.

Could VRO 42.05.01 be one physical object, or was it two SNRs on the same line of sight? One prominent astronomer wrote "Congratulations! You have obtained the first image of the collision of two supernova remnants." But, perhaps he was wrong. We needed the radio spectrum for each of the two components. The steepness of their spectra would reveal the energy distribution of the radiating particles, and if the spectra differed, we were likely seeing two SNRs. However, to separate emission from the two components, and to exclude unrelated sources, we needed similarly detailed—yet complete—images at other wavelengths. In 1982, at longer wavelengths, such images had yet to be made.

VRO 42.05.01 illustrated why DRAO took the next step in the development of the ST: adding a second wavelength, to be observed simultaneously with 21 cm. The question of which wavelength was readily answered: a 74-cm sky survey was being completed with three "big dish" telescopes—Jodrell Bank, Effelsberg, and Parkes—from which short-baseline Fourier components could be derived to complete the ST images. No elephants would slip past unnoticed in DRAO's long-wavelength, image-making process. In addition, 74 cm lay within a wavelength band legally protected for radio astronomy.

Fig. 3 — One of the first images from the 4-antenna Synthesis Telescope (1982): supernova remnant VRO 42.05.01 at 21 cm. Angular resolution is 1.0′ EW X 1.4′ NS. This is the central degree of the telescope's 2½° field of view. Though 6000 light-years distant in the Perseus Arm of the galaxy, the circular shell in the NE presents the same angular diameter as a full Moon. Optically, only faint emission-line filaments are visible. Small-diameter sources sprinkling the field are distant galaxies, not stars.

Graduate Students from ECE

With the start of adding 74-cm reception to the ST, another new era dawned at DRAO: students began arriving from ECE. They would carry out graduate research projects with on-site supervision from DRAO scientists, plus generous assistance from all the observatory personnel.

An incident illustrates the DRAO environment. During one of the authors' earliest visits to the observatory, on a Friday evening, dinner time arrived. Employees were laying down tools, turning off oscilloscopes, putting on coats to go home. Suddenly running feet were heard in the corridors—a contractor had unwittingly dug through a cable with his backhoe, meaning IF signals from one of the ST's antennae were not reaching the correlator. It was as if an anthill had been disturbed. No one left for home until the cable was repaired and the ST was fully functional again. This was the all-shoulders-to-the-wheel ethos that ECE students would be absorbing.

Adding 74-cm imaging would be a large task. The 74-cm "front-end" and "back-end" systems would be handled as two separate graduate projects.

74-cm Imaging: digital signal processor project

Wing Lo, an M.Sc. student, undertook the "back" half of the 74-cm system. His supervisor at DRAO would be Peter Dewdney. No fan of analogue circuitry, Lo wanted to accomplish as much as possible in digital electronics—or preferably in software.

Given digitized versions of the IF signals from the four antennae in the ST, and forming six pairs of antennae simultaneously, Lo's task for each pair would be to correct for the geometric delay between antennae (varying as the source crosses the sky), then to cross-correlate the two signals. To extract full information, this "in-phase" operation had to be twinned for each pair to produce a "quadrature" output data stream as well. For this, Lo invented a version of the Hilbert transform which, after delay correction, simplified to a "dot product." This he could implement in software. Thus, he avoided having to build twelve analogue correlators and six bulky ensembles of switchable lengths of coaxial cable, plus twelve analogue fringe-rotation circuits to keep each antenna pair (interferometer) centred electrically in the field of view.

Luckily, a high-speed microprocessor had just appeared, the Motorola 68000, which accepted 16-bit data. Lo designed his digital signal processor (DSP) around it[5]. The 68000 was so new, however, that he had to write his own operating system, as well as a "monitor" program for controlling the entire DSP. To minimize expense, he resided in a one-man trailer on the observatory grounds throughout the winter.

74-cm Imaging: front end project

Some components of the receiving system ahead of Lo's DSP could be reproduced from the 21-cm system. This was not true, however, for the "feed antennae" at the foci of the 9-m dishes, or the feedback-controlled LO system for 74-cm signals reaching the focus boxes.

DRAO stipulated that 74-cm modifications must not degrade 21-cm operation. Also, only three coaxial cables lay buried alongside the array from each antenna to the central correlator building. Since two were in use for the 21-cm system, 74-cm had to use only one.

Bruce Veidt tackled both antenna modifications and the LO system for his M.Sc. thesis. His supervisor at DRAO would be Landecker.

Veidt designed new feed antennae for simultaneous 21- and 74-cm operation, to replace the existing feeds on the 9-m dishes. He optimized for 21 cm, but added four probes for 74 cm with negligible effect on 21-cm performance. The new feed achieved low "spillover" at 21 cm—it picked up little noise power from terrain seen above the rim of the dish. DRAO installed Veidt's dual-wavelength design on the four ST antennae.

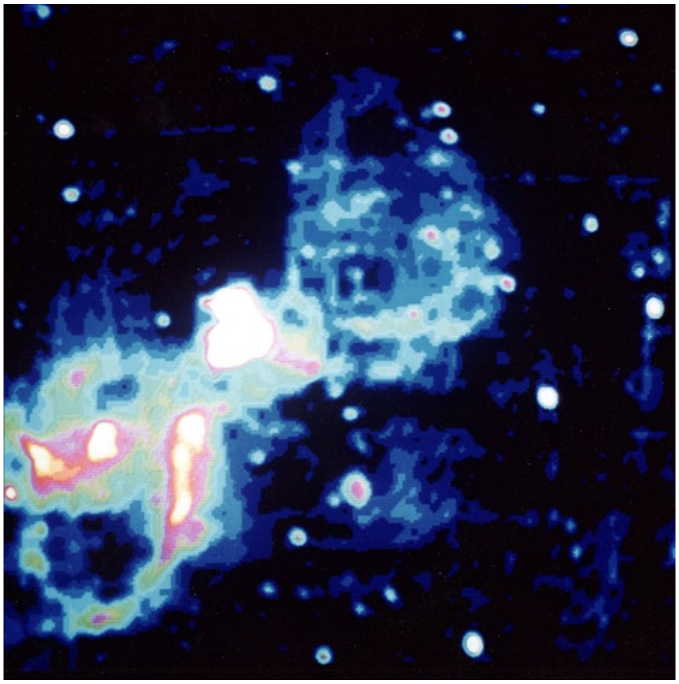


Fig. 4 — The first image (1984) from the ST at 74 cm, resulting from thesis work by Wing Lo and Bruce Veidt. This shows the central 4 degrees of a circular 8-degree field in Cassiopeia. E to W, objects are HII regions W4 (IC 1805) and W3 (IC 1795), then the faint supernova remnant HB3—all three at distance 6500 light-years. False-colour intensity increases from indigo, through magenta, to white

Tackling the LO next, Veidt invented a single-cable system. Feedback corrected not only changes in LO phase, but also in the IF signal, from focus box to Lo's DSP in the central control building. He then obtained low-noise amplifiers (LNAs) employing Gallium Arsenide Field Effect Transistors (GaAsFETs) to install in the four focus boxes, and the new 74-cm system was complete.

The time had arrived for a test of the ST at 74 cm[6]. A field containing the faint SNR HB3 (G132.7 + 1.3) was chosen, and 24 days' worth of observations produced the image shown in Figure 4**.** In 1984, this was the highest-resolution image (3.5′ EW X 4.0′ NS) ever made of HB3 at wavelengths longer than 11 cm.

In achieving wide-field 74-cm imaging with the ST, Veidt and Lo had played central roles.

Low Noise Receiver Development

In 1984, DRAO-oriented work also got underway on the University of Alberta campus in Edmonton. The ECE group contracted to design and build a dual-channel low-noise receiver for the DRAO 26-m telescope (Figure 1).

The new LNAs would employ cooled GaAsFETs. Walker used a closed-cycle helium refrigerator to hold the two amplifiers at low temperature (12 kelvin) in a cryostat inside the telescope's focus box[7]. With the new receiver installed, Galt immediately used the 26 m to observe hydroxyl molecules released by Comet Halley leaving the Sun in early 1986. He monitored the λ18-cm OH line in emission for three months, integrating the weak spectrum several hours each day. In any spectrometer channel the signal power was the equivalent of one visible photon arriving every six minutes.

The ST also required 21-cm receivers. ECE built a set of 16 LNAs. Again, these used GaAsFETs, but would operate at ambient temperature. In 1989, Walter Wyslouzil of DRAO visited ECE to work with Walker and Vaneldik, modifying the LNA design to use the new High-Electron-Mobility field effect transistors (HEMTs). Wyslouzil returned to DRAO, which thereafter became self-sufficient in LNA design.

The two DRAO contracts had launched the ECE group into receiver development. Over the next decade and a half, five ECE graduate students (Eric Valk, Henrik Johansen, Gavin Miller, Bruce Veidt, and Angel Garcia) and three research associates (Graham Walker, Ken Westra, and Kevin Kornelsen) would explore where this path led. Miller, for example, co-supervised by Landecker, investigated cooling only the first transistor in a three-stage LNA using a small electric device called a Peltier cooler. His results showed promise, but also problems, and Peltier-cooled LNAs were not installed on the ST antennae.

In 1988, receiver development in ECE also branched to much shorter wavelengths: the James Clerk Maxwell sub-mm telescope required a focal-plane array of low-noise receivers operating at 0.87-mm wavelength. Having imaginative ideas for this multi-pixel device, Tom Legg and Morley Bell of the Herzberg Institute of Astrophysics in Ottawa suggested that ECE help develop cryogenic receiver front-ends integrated with planar feed antennae. Microscopic superconductor-insulator-superconductor (SIS) mixers would be fabricated on silicon wafers using integrated-circuit techniques, in collaboration with thin-film expert Michael Brett of ECE and with the Alberta Microelectronic Centre. The project developed momentum and results were promising[8] but ultimately no HIA–ECE focal-plane arrays would be ordered by the JCMT consortium.

ECE involvement in 21-cm receiver development would, however, continue at DRAO—in 2002. Even as the CGPS proceeded (see below), M.Sc. student Angel Garcia would be striving to improve the noise performance of the LNAs on the ST. Supervised at DRAO by Veidt and Landecker, she would design HEMT receivers that probed the waveguide "throat" of the feed antenna for a 9-m dish. In a second LNA design, she would achieve the same noise performance with simpler installation. By 2005, DRAO would build and install a set of Garcia's second type of LNA on the ST.

New 21-cm Continuum Correlator for the ST

Returning to our chronological narrative, in 1986, the number of antennae in the ST sat at four, receiving both left-hand (LH) and right-hand (RH) circular polarization at 21 cm. A fifth was being constructed, with two more planned for increased imaging speed. Thus the ST would soon comprise seven antennae, three of them movable.

The DSP for 21 cm had to expand to accommodate the increase from 6 to 21 antenna pairs. DRAO decided that at the same time two more enhancements—increased bandwidth, and finer digitization—should be made to improve the signal-to-noise ratio in 21-cm continuum images. Furthermore, that was the time to implement a fourth enhancement: the new correlator should provide the potential for polarization imaging, though considerable engineering would still be required after the correlator began producing the required data streams.

David Karpa shouldered redesigning the 21-cm continuum correlator for his M.Sc. thesis. Landecker would be Karpa's on-site supervisor, with Dewdney and Gary Hovey providing input and experience.

The ST's bandwidth doubled, splitting into 4 sub-bands. Redesigned digitizers quantized each sub-band into 14 levels instead of the previous 3. Karpa also incorporated a fifth enhancement: "built-in self-testing," in which on-line diagnostics detected electronic faults. The DSP he prototyped and tested could handle 28 simultaneous antenna pairs, with 2 cross hands and 2 matched hands of circular polarization each, both in-phase and quadrature, in 4 frequency bands. Operating under the ST system computer, the new DSP managed its own operations autonomously.

With expansion of the ST from 4 antennae to 7 (see Figure 2), imaging time at 21 cm dropped from 35 days to 12 days. The signal-to-noise ratio in 21-cm images improved by 70 percent. Karpa's thesis work had made a major impact.

Furthermore, now the ST stood on the verge of polarization imaging.

An Enigma in the Perseus Spiral Arm

In 1986, while Karpa was designing his DSP, Marcus Anderson joined the ECE group. A serious amateur astronomer (having built a 45-cm optical telescope with dome and photometer in his backyard), he chose an M.Sc. research project with two separate components: to investigate improvements to the antennae of the ST, and to use the ST to study an enigmatic nebula—object 183 on Sharpless's 1959 list of HII regions.

Optically Sh 2-183 appeared as a faint emission nebula. However, despite its being labelled an HII region (gas ionized by stars) radio telescopes of medium resolution showed both a steep radio spectrum—implying synchrotron emission—and internal shell structure. Could it actually be an SNR?

The ST produced images at 74 cm and 21 cm with by far the best resolution to date. Anderson found the radio spectrum was flat, implying thermal radiation from translucent ionized gas. The radio object—almost 1° in diameter—did have shell structure, however. The ST's λ21-cm-line images revealed a surrounding HI shell, whose velocity placed Sh 2-183 in the Perseus Arm at 6500 light-years distance. Sh 2-183 was an HII region, the HI shell being what remained of a stellar wind bubble blown by its ionizing star[9].

Battling Antenna Noise in the ST

Anderson also investigated the 9-m antennae of the ST at 21 cm by measuring contributions to the broadband noise picked up by the feed. Two major sources were (1) spillover, and (2) ground radiation propagating through the reflector mesh ("leakage"). He would model the total noise from the antenna as the "antenna temperature" T_A, which a fictitious resistor at the receiver input required to produce the same power. To evaluate the system noise T_{SYST} one had to add to T_A the noise from the receivers, plus noise from the object being observed. The lower T_{SYST}, the higher the signal-to-noise ratio in the images would be.

Anderson calculated all contributions to T_A for an antenna pointed at the zenith, and found 20 K. Calibrated power measurements, however, showed 26 K. What had he overlooked?

He installed a low-power 21-cm transmitter on a hilltop. Scanning the eastern-most ST antenna through its range of hour angle and declination took him three days. He then plotted transmitter power reaching the feed antenna from different directions, including areas behind the 9-m reflector. That image—the antenna's reception pattern—showed the ground noise picked up from different directions.

Spillover was indeed important, but in the reception pattern there also appeared bright arcs—"scatter cones" through which ground radiation reflected from feed-support struts, and entered the feed. Incorporating these, he re-calculated and T_A rose by 6 K. The mystery was solved[10].

Changing the struts from round to triangular would project the scatter cones onto the sky, reducing the ground noise[11]. The ST antennae were not identical—see[12]—but DRAO decided to implement triangular feed struts where applicable.

In 1989, the reflectors and feeds were studied by another M.Sc. student, Pushp Trikha. He, too, placed a transmitter on a hill, this time measuring the 74-cm reception pattern. Since the feeds and reflectors were now much smaller in wavelengths, he found the sidelobe level to be higher by a factor of 20. Spillover was therefore worse at 74 cm, raising T_{SYST}. Solar interference entering through the sidelobes also contaminated daytime ST data at 74 cm.

Trikha investigated four feed designs, built one, and measured its reception pattern using a computerized outdoor antenna range. DRAO concluded, however, that no design improved the reception pattern enough—without compromising 21-cm performance—to justify replacing Veidt's earlier design. Solar interference in 74-cm ST data would be avoided by scheduling, or excised off-line.

Polarization Imaging with the ST at 21 cm

By 1989, all cross-correlations of all combinations of LH and RH circular polarizations from the ST's seven antennae were available from the Karpa 21-cm correlator. High-fidelity polarization imaging was therefore a possibility, and much desired.

Polarization images would provide a window into the magnetic field, B, within objects radiating by the synchrotron mechanism. Though achieving accurate images was

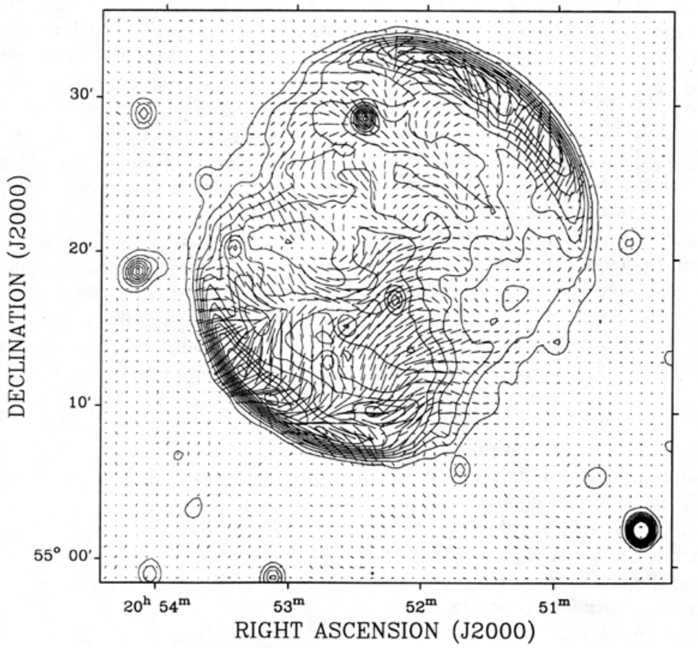


Fig. 5 — The first polarization image from the ST (1995): SNR DA530 in Cepheus, demonstrating Rick Smegal's data-correction algorithm. Angular resolution is 1′ EW X 1.2′ NS. Contours show total intensity "I" and vectors show linear polarization intensity and position angle. On the SE and NW limbs, polarization exceeds 50% of "I".

daunting—the fractional polarization would be typically a few percent—the orientation ("position angle") of linear polarization would reveal the direction of B running transverse to the line of sight. This would be true even when the source of emission was the interstellar medium ("ISM"), the supposedly empty space between the stars.

The position angle would rotate, however, as the 21-cm wave travelled toward us if a component of B parallel to the line of sight threaded ionized regions of the ISM along the way. This phenomenon, Faraday rotation, depends strongly on wavelength. The four-band redesign of the ST had therefore opened a second polarization window, this time into the "magnetoionic medium" between the emitting object and the telescope.

Neither of these polarization windows was yet being used by the ST.

A linearly polarized wave is equivalent to a LH and RH wave travelling together. Ideally, the circularly polarized ST feeds would pick these up with equal sensitivity. If the astronomical source was unpolarized, these waves would maintain no steady phase relation with each other (would be uncorrelated), and while the total intensity "I" image would show the object faithfully, the polarization image would be blank.

However, leakage of unpolarized "I" signal between the LH and RH channels would cause some spurious correlation, and the telescope would show false polarization where there should be none.

Rick Smegal enrolled in a Ph.D. program and tackled accurate 21-cm wide-field polarization imaging with the ST. He would evaluate the ST antennae, and devise a method of compensating for defects by mathematically correcting the data streaming from the Karpa correlator. His on-site DRAO supervisor would be Landecker.

Immediately Smegal encountered a difficulty unique to the ST: the 9-m antennae were equatorially mounted and their feed antennae were not rotatable. Therefore, the beam patterns would not rotate on the sky as the antennae tracked a source, and the position angle of any instrumental polarization that they imprinted on the signal would remain fixed on the sky. Spurious polarization would thus be difficult to separate from polarization inherent to the object.

The feed antennae would contribute most of the spurious polarization the 9-m antennae contributed. Smegal built an antenna test range to establish the severity of LH-RH leakage ("lack of orthogonality"). This would be the range Trikha would use as well (see above).

The range consisted of two 6-metre towers. On one, Smegal mounted horns as field probes, and on the other, a turntable carrying one of the seven feeds. Reflections from buildings and ground were minimized. He supplemented his measurements with data from the ST itself, the percentages of "I" showing up as unwanted correlation between LH and RH when the ST observed a strong unpolarized source. He concluded that the ST antennae did "leak" a few percent between LH and RH, enough to produce spurious polarization amounting to several percent of "I".

This was serious. How could he reduce the effect of this leakage?

After extensive analysis, Smegal developed a mathematical data-correction procedure. Using observations of unpolarized sources and measured LH-RH correlations, it calibrated the orthogonality of the LH and RH channels on each antenna. Correction proceeded in three increasingly more complicated stages giving progressively better results.

Stage 1 was the same process as for normal "I" imaging. Stage 2 produced data equivalent to that from a set of antennae with good orthogonality—though with elliptical polarization, not circular. Stage 3, which used one antenna as reference and made no mathematical approximations, should reduce all antennae to circular polarization and true orthogonality. However, without the precise polarization properties of the reference antenna—and the outdoor range was not capable of such precision—there would be no point in performing Stage 3.

Smegal anticipated, nevertheless, that good polarization images would result from Stage 1 plus Stage 2, with spurious polarization at field centre reduced to about ¼ percent of "I". Stage 3 ought not to be required.

Student	**Sup**	**Deg**	**Year**	**Thesis Topic (*bold italics indicate DRAO ST-related project*)**
Shaw, R.		M	’72	Digital-Analogue Minimum Detector
Kerchum, W.		M	’73	Corner Reflector for Radio Astronomy
McLarnon, B. D.		M	’73	Feeder System for a Large Antenna Array
Wynne, D.A.		M	‘73	Physical Tapering of Large Antenna Arrays
Bierman, K.		M	’75	Radio Frequency Radiometer for Calibration of Noise Sources
Wilkinson, W.J.		M	’76	Range-Tested Dual-Polarized Log Spiral Antenna
Kasper, B.L.		P	’81	Interference-Rejecting Correlator
Lo, W.F.	***PED***	***M***	***’82***	***Digital Signal Processor for Synthesis Radio Telescope***
Veidt, B.G.	***TLL***	***M***	***’84***	***408 MHz Synthesis Radio Telescope***
Karpa, D.R.	***TLL***	***M***	***’89***	***Digital Correlator for Aperture Synthesis***
Steiger, D.R.		M	’89	Measuring System for SIS Junctions
Anderson, M.D.	***TLL***	***M***	***’90***	***Reducing Antenna Noise / Observations of HII Region***
Valk, E.C.	***TLL***	***P***	***’90***	***Techniques of Microwave Noise Measurement***
Johansen, H.		M	’91	Cryogenic Noise-Parameter Measurement System
Miller, G.K.	***TLL***	***M***	***’91***	***Low Noise Amplifier Design with Peltier Cooled HEMTs***
Trikha, P.K.	***TLL***	***M***	***’91***	***Improving Radiation Pattern of Radio Telescope Antenna***
Smegal, R.J.	***TLL***	***P***	***’95***	***Polarimetry with Wide Field Aperture Synthesis Radio Telescope***
Veidt, B.G.		P	’95	Enhancements to mm- and submm-wave Integrated Circuit Receivers
Thorsley, A.	***TLL***	***M***	***—***	***Holography of the Antennas of the DRAO Synthesis Telescope***
Belostotski, L.	TLL	M	’00	L.O. and Focal Length System for Large Adaptive Reflector
Ng, T.C.W.	***TLL***	***M***	***’03***	***Noise and Polarization of DRAO Synthesis Telescope Antennas***
Davison, O.	***TLL***	***M***	***—***	***Calibration of the DRAO Synthesis Telescope***
Foster, T.J.		***P***	***’04***	***Structure and Dynamics of the Milky Way Galaxy***
Garcia, A.A.R.	***BGV***	***M***	***’05***	***Low Noise Amplifier Design for the DRAO Synthesis Telescope***
Reid, E.	TLL	M	—	Focal Plane Array for Large Adaptive Reflector

Table 1 — Radio astronomy thesis topics in the ECE Department from 1972 to 2005. Key: Sup = DRAO supervisor; Deg = degree; M = Master's; P = PhD. Projects before 1982 were oriented toward decametric radio astronomy. Though many other DRAO personnel gave much-valued assistance, primary on-site DRAO supervisors were TLL (Tom Landecker), PED (Peter Dewdney), and BGV (Bruce Veidt)

To test his data correction process, and assess the ST's usable field of view for polarimetry, Smegal chose an extended source: a shell-type SNR of 0.5° diameter called DA530. From a 100-m telescope image at 6 cm with 3′ resolution, he knew this object showed up to 60% linear polarization. By chance, DA530 was also being imaged with the Very Large Array at 20 cm with 0.75′ resolution.

Figure 5 shows Smegal's 21-cm polarization image of DA530, made using his new data-correction procedure[13]. The polarization as imaged by the ST is highly consistent with that seen at Effelsberg and the VLA.

To establish the polarization field of view, Smegal repeated the ST observation but placed DA530 off-axis by 30′. He repeated the calibration and correction procedure, and re-made the polarization image. The result was virtually indistinguishable from the on-centre image. He concluded that the ST's field of view for polarization was at least 1.5°, much larger than the VLA's.

While Smegal was striving to achieve 21-cm polarization imaging, a parallel study was also being conducted. Leonid Belostotski, who would later do an M.Sc. on a different topic (see Table 1), investigated the polarization properties of the ST at 74 cm. Switching Veidt's 74-cm probes from RH to LH cyclically, he performed calibration observations in 1995. He found that the feeds, though far from ideal, were useable—Smegal's new algorithm could correct for their polarization defects. Unfortunately, overwhelmed by the need for the observatory to survive (see below), the DRAO staff were unable to take on another project. At the time of writing in 2017, polarization imaging at 74 cm with the ST is a capability still awaiting implementation, preferably using Trikha's improved feed design.

The Canadian Galactic Plane Survey

By 1987, an idea had germinated among the DRAO scientists: why not capitalize on the wide field of view and good resolution of the ST at 74 cm, by surveying the Milky Way on a couple of dozen field centres spaced 5° in galactic longitude, Cygnus to Auriga? Furthermore, though sparsely sampled, why not piggy-back λ21-cm HI images?

By 1993, this 74-cm survey was underway. However, with the ST now three times faster, the idea burgeoned into a much larger concept: an ST Galactic Plane survey including 74 cm, but primarily 21 cm—"I" plus polarization, plus HI spectroscopy—on close field centres for complete sampling at 21 cm.

This ambitious idea caught on, both within Canada and internationally. Previous surveys had been made, e.g. a 21-cm continuum survey with the Effelsberg 100-m telescope covering Cygnus to Auriga with a 9′ beam. However, with 1′ resolution, the ST would reveal two orders of magnitude more detail per square degree. If the 21-cm and 74-cm observations were each mosaicked seamlessly together, who knew what structures the ST would reveal?

The survey fit the enhanced capabilities of the ST[12]. The telescope had evolved to study the ISM, including (1) interactions between its ionized, atomic, relativistic, and magnetized components, (2) the effects of star formation, stellar winds, and galactic spiral shocks, and most recently, (3) the interstellar magnetic field and magnetoionic medium.

The ST would image extended structure over a wide field of view while Earth-rotation synthesis delivered high angular resolution. Crucially, DRAO's imaging process had been expressly designed to include all structures on angular scales down to the resolution limit. Counter to practice at other observatories, the shortest-spacing visibilities not measured by the ST itself were always added from single-dish observations. Even the λ21-cm HI images, contrary to opinions of astronomers elsewhere, were expected to reveal three-dimensional structure on all scales, from large to tiny.

By 1993, a CGPS consortium of astronomers was forming, and "pilot" observations had begun in 10 overlapping 21-cm fields whose data were combined in mosaics. The area chosen? That shown in Figure 4, plus W5 to the east. In the resulting HI mosaics, "a wealth of large-scale filaments, arcs, bubbles, and shells" was revealed[14]. No one at DRAO was surprised.

The pilot project showed great scientific potential. Regardless, citing budget cuts, the National Research Council informed DRAO in March 1995 that the observatory would close in 1998. A third of the DRAO staff received layoff notices.

A barrage of letters reached NRC from astronomers protesting DRAO's closure. Defiantly, DRAO began observations for a full survey. The CGPS consortium applied to NSERC for funding to cover 73° in galactic longitude. In November 1995, this application succeeded—funding for 5 years, 190 fields.

Reversing its decision, NRC announced that DRAO would keep operating until 2001, then close. Two years later, NRC modified that decision as well: the ST could keep observing. In 2002, the DRAO personnel left the ad-hoc collection of creaking, sagging, "temporary" trailers they had endured for 20 years, and moved to a new observatory building.

DRAO and the ST survived. The CGPS would ultimately be extended in coverage, through a Phase 2 and a Phase 3. Running 12 years nearly full-time on the ST, at 21-cm it would comprise 454 fields at 21 cm by 2009. At least 9° wide in latitude (15° wide at 74 cm), it would stretch 140° in longitude—Aquila to Orion—and extend northward into the star-forming region in Cepheus[15].

Even while the CGPS was underway, however, the DRAO scientists wondered about the post-CGPS era. Would the ST be labelled obsolete, to be closed down despite its versatility and wide-field capability? To avoid that, perhaps its sensitivity and polarization imaging could be enhanced.

Antenna and Polarization Improvements

There is always room for refinement in astronomical images, and a source of unwanted ST noise remained—the 9-m antennae. In 2002, Teresia Ng, an M.Sc. student in ECE, arrived at DRAO and undertook antenna improvements, supervised on site by Tom Landecker. Like the receiver work by Angel Garcia already underway (see above), Ng's efforts would proceed even while CGPS observations continued full-throttle.

Ng's work had two components. First, in 1988, Anderson had found the main contributor to T_A was ground radiation picked up as spillover, scattered from the struts, or leaked through the mesh of the dish surface. Ng found that these components could be reduced by different means: by positioning inclined reflecting screens around each antenna, by changing the strut cross-sectional shape to tear-drop, or by replacing the mesh by solid metal over the inner 20% in area. Consequently, she could reduce the ST antennae's mean zenith T_A from 14 K to 8 K.

By 2004, combining Ng's reduction in T_A with Garcia's reduction in receiver noise, signal-to-noise in 21-cm continuum images had improved by 25%[16].

Important though ground noise might be, Ng was interested primarily in a second aspect of ST antenna performance: the polarization characteristics at 21 cm. She studied how imperfections in the antennae produced instrumental polarization across the field of view—polarization that corrupted and obscured that inherent to the object being imaged.

Using electromagnetic simulation software, Ng calculated the distribution of spurious polarization across the main beam and near sidelobes of a 9-m dish[17]. She mapped the conversion of unpolarized "I" signal into unwanted polarization across the field of view. Non-ideal feed performance was most significant, she found, followed by scattering from feed struts. Different strut arrangements, sizes, and cross-sectional shapes had different impacts.

Corrections could be applied across the ST polarization images. These went beyond those introduced by Smegal, being calculated across the field of view based on the spurious polarization expected at each position. Later holographic-mode ST observations of unpolarized sources[18] took the art a step further—after Ng's thesis had been submitted—into instrumental defect removal in the Fourier domain. This change in image processing, which Ng's work had facilitated, was implemented midway in the preparation of the ST's Galactic Plane polarization survey covering 66° to 175° in longitude[19].

Astronomical Studies

An important development had occurred in the late 1980s: DRAO's data manipulation and display programs had been made available on magnetic tape as "the DRAO export package"[20] for use on Unix workstations at other institutions. ST users' astronomical studies could then progress between visits to DRAO.

By the mid-1990s, DRAO had adapted the package for PCs running Linux.

In 1998, Tyler Foster, an M.Sc. student (Physics Department), joined the ECE group, jointly supervised by Professor Douglas Hube (Physics). Foster used the ST to study an extended object in Cygnus, NRAO 655 (G93.4 + 1.8), whose shell structure had led others to suggest it might be an SNR. Foster showed the radio spectrum was flat; hence it was likely an HII region. Assisted by John Galt, he operated the DRAO 26-m telescope remotely (the first person to do so) and detected recombination line H158α in emission, confirming NRAO 655 was not an SNR. He found an HI cavity and molecular cloud coinciding with NRAO 655, whose velocities placed it in the Perseus Arm[21].

Continuing in a Ph.D. program jointly supervised by Professor Sharon Morsink (Physics), Foster used HI observations from the CGPS of an SNR in Cygnus, 3C 434.1 (G94.0 + 1.0). He found it to be expanding inside a fragmented HI shell, which is a highly evolved stellar wind bubble[22]. λ21-cm HI absorption of an extragalactic source let him probe the shell's properties. He modelled it in three dimensions, and showed that the shell and SNR lie in the Perseus Arm.

Foster then tackled an issue of huge importance in galactic radio astronomy: assigning distances to objects. Since the 1950s, "kinematic" distances had been calculated assuming that galactic hydrogen orbited the centre with a velocity that decreased with radius. An object's line-of-sight velocity then gave its distance from the telescope by trigonometry. By 2000, however, kinematic distances were known to disagree with photometric distances when available. Foster devised a new distance method, using λ21-cm HI data to find the column density to an object. Modelling the large-scale distribution of HI, he reproduced the observed HI toward two objects near longitude 90°, then applied the new technique to 29 HII regions using line-of-sight velocities from associated CO. His new distances agreed with photometric distances[23].

The Moving Finger Writes

Vaneldik retired in 1998, Routledge retired in 2005, and the ECE radio astronomy group began to evanesce into a memory.

The ST itself, however, was another matter. Phase 3 of the CGPS came to an end in 2009, but the ST reverted smoothly to proposal-driven mode, already at work on non-CGPS projects, such as establishing the foreground in the *Planck Space Telescope*'s Deep Fields in Ursa Major. With the ST's renown in wide-field imaging—including 74-cm and 21-cm continuum, 21-cm polarization, and λ21-cm HI spectroscopy—there was no shortage of proposals. Studies included polarization in planetary nebulae, an Anti-Centre survey, a new HI chimney connecting galactic disk and halo, a wind-blown bubble in the polarized "Fan" region in Camelopardalis, off-plane SNRs, a magnetic-field reversal in the outer galaxy, the M81/M82 group of galaxies in Ursa Major, and others[15].

One surprise, just as CGPS observations were ending, illustrates the maxim that whenever technical progress produces new capabilities in instrumentation, remarkable discoveries follow. Seven degrees wide, though situated in the Perseus Arm, a huge shell structure was found—blown by a cluster of stars, several having exploded as supernovae. This superbubble, discovered as a feature imprinted by Faraday rotation on the polarized emission, hung huge but unnoticed in the Galactic Anti-Centre, invisible except in the 21-cm mosaic of polarized intensity[19]. Straddling its northern limb among a retinue of young objects—possibly initiated by the superbubble's shock front—sat VRO 42.05.01, the enigmatic SNR of Figure 3 above.

Though 6000 light-years distant, this enormous stellar-wind bubble covered more than a hundred times more "area" of sky than a full Moon. Passing overhead daily throughout all of humankind's history, it had remained unseen until wide-field polarization imaging was added to the ST as a result of Karpa's and Smegal's thesis projects.

The DRAO-ECE Liaison

The training that the DRAO-ECE collaboration opened to ECE graduate students was outstanding in two regards:

(1) Students tackled real research problems on a telescope in high demand by Canadian and international scientists. This gave incentive: student research was valued, producing prototypes of enhancements to be implemented in final and reliable form on the ST by the observatory staff.

(2) Several students (Kasper, Lo, Veidt, Anderson, Trikha, Karpa, Smegal, Belostotski, Thorsley, Davison, Reid, Ng, Garcia, and Foster) spent extended periods of time at the observatory, working directly with the DRAO wizards. The challenging environment and stimulating interactions made this experience priceless. It was the DRAO scientists' willingness—Tom Landecker's in particular—to function as

on-site supervisors that made the collaboration both possible and so valuable. DRAO reduced administrative barriers to a minimum, and made students feel part of the observatory team.

An important development occurred in 1985: Landecker became adjunct professor in the ECE Department. He could then apply for NSERC operating grants, specifically to pay students' travel costs and to offset their living expenses while at DRAO.

Conclusion

The most important work done by the ST has been the CGPS, a spectacularly successful project advancing humanity's understanding of our galaxy in ways that could not be foreseen. Such a project lay far beyond the capabilities of the two-antenna ST of the 1970s. Through continuous technical effort, nonetheless, the ST now produces wide-field 21-cm continuum images every 8 days including accurate polarization, plus 256-channel HI spectral data cubes, plus 74-cm continuum images. Signal-to-noise in 21-cm images has risen markedly. Polarization imaging in four sub-bands has opened a second window onto magnetic fields through Faraday rotation.

In the CGPS, the ST achieved panoramic arcminute-resolution images—including polarization and structure on all angular scales—along 40 percent of the entire Milky Way. In hindsight, four ECE student projects lay on the critical path to that accomplishment. These were the 74-cm front-ends and local oscillator system (Veidt), the 74-cm DSP (Lo), the 21-cm continuum correlator (Karpa), and polarization imaging (Smegal). Several other students contributed to the steady advance of the ST's capabilities over the years. All these individuals benefitted from the DRAO-ECE collaboration, and the observatory did as well.

The authors are grateful—and proud—to have been part of this journey of discovery. ✶

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The RASC podcast

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Curious about the history of The Royal Astronomical Society of Canada and all the things that tell the story of who we are and what we've done since the beginning in 1868?

In celebration of the 150th anniversary of the RASC, join the hosts of the new RASC 150 History Podcast in a series of monthly released audio episodes about 20 minutes long, available on the website (www.rasc.ca/rasc-2018-podcasts) or iTunes/SoundCloud.

Heather Laird (Director, RASC) and R.A. Rosenfeld (RASC Archivist) will delve into the fascinating (and sometimes unbelievable) stories of our Society, based on the surviving artifacts, the members who made and used them, and what we've learned (and haven't learned) about doing citizen science.

Every episode will be released on the last Monday of each month. Images of rare RASC artifacts and documents illustrating the podcasts will appear on their associated link on the website, with associated resources. We will also have transcribed versions of the episodes available.

January's episode, "Beginnings: Documentary Traces & Tatters," is already available for your listening pleasure! It is an examination of how and why the RASC happened, along with featuring our miraculously surviving draft bylaws from 1868 and the unlikely story of that document's rediscovery. We also recount the efforts to prevent the RASC from being founded and the documentary trail behind that! Alas, here we are! 150 years later!

Please join us on our journey and stay tuned online for regular updates from the team!

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Beginnings—Documentary Traces & Tatters, or lessons from doing the first RASC 150 podcast

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Abstract

The making of the first podcast exploring the history of the RASC for the Society's sesquicentennial revealed previously unseen gaps in the canonical account of our founding. The opportunities these present are discussed here, as well as some of the new material and perspectives which have resulted from work on the podcast.

Unexpected Lessons

By the time this article reaches prospective readers (should it have any), the first of the RASC 2018 podcasts delving into our history will have become available to listeners (should there be any). This paper provides further discussion of some of the material presented in the first podcast, and of some minor discoveries made in the course of its production.

We, and the rest of the production team, were looking forward to presenting the received account of the origins of the RASC, which would allow us to devote our energies to finding the best means to transmit the narrative. All that seemed necessary to convey a satisfyingly complete version of a story seemingly familiar to many of us was the marshalling of facts already known, based on sources previously uncovered. We had the map; nothing could be simpler. Anticipation of such a pleasant and easy trek over a known path with little undergrowth turned to surprised wonder at the incomplete survival of the evidence, the remaining gaps in the account, and the limits of what we know, and might ever know, of the start of the modest astronomy club which would in time become the RASC. Our map, with its unmarked *terra incognita*, was far from complete. We can now affirm that nothing reveals gaps in a received narrative like subjecting it to critical scrutiny in the light of day, under a looming deadline.[1]

What have we learned about what we didn't know?

Inviting Technologies

We know that eight people attended the organizing meeting on 1868 December 1 of what became the Toronto Astronomy Club; George Brunt, Samuel Clare, Andrew Elvins, James L. Hughes, Charles Potter, Robert Ridgeway, Mungo Turnbull, and Daniel K. Winder. We don't yet know the time of day (or night) the meeting was held.[2] For the Toronto Astronomical Club, it was probably in the evening, for none of the founders were men of leisure, and the time of the next meeting is specified as 7 p.m. (TAS Minutes, 6).

In itself, the question of when on December 1st in 1868 the founders met seems trivial. The question gains greater significance as an example of the many simple and basic facts about that first meeting which remain unknown.

We have incomplete knowledge of the technologies used to distribute the notice to residents of Toronto before the meeting in the fall of 1868. We know a circular was distributed, because Professor George Templeman Kingston (1816-1886), Director of the Magnetical and Meteorological Observatory, Toronto, referred to it in his magnificent letter of discouragement to the founders of the "Proposed Astronomical Society" (Thomas, KINGSTON; TAS Minutes, 2-3). We don't have the text of the circular, nor are we aware of the existence of any extant original or latter copies of that document. We do have a modicum of information regarding the distribution strategy:

> "…we [i.e., Andrew Elvins and colleagues] formed the first Astronomical Society in Toronto. Mr. Clare was also interested in astronomy and we prepared and sent out an address to such as might take part in forming a society, among others we sent to a Mrs. R. Ridgeway, a teacher in a High School on Jarvis St., a good mathematician. Also Prof. Kingston, a forerunner of Mr[.] Stupart, who rather discouraged us. He suggested joining the Canadian Institute as a better means of study. Yet we formed a society. Our meetings were reported in a paper "Scientific Opera"[3] [recte *Scientific Opinion*] of which I have some stray copies;" (Elvins 1904, 6).

Based on Elvins's recollection of events then thirty-six years in the past, the circulars were addressed to individuals deemed likely to be interested, rather than to a more general audience. Elvins's wording is interesting; it implies that there was a pre-existing group doing the organizing. This is indeed reflected in his further reminiscences forty-five years after the event:

> "When Winder came over [to Canada from the States], as we were both Disciples [of a religious sect] we soon met. Then it was proposed to gather a few together, to meet in my house. This we did, and then we got together a few whose names are on the sheet. These did not come all at once, Mr. Hughes did not join at the very first. He joined soon after, through. Mr. Clare. Hughes was a student at the Normal School, but teaching at the same time, and he was introduced thro' Mr. Clare. When we had been meeting in that way for a while, we began to talk about forming a club where we might come together and read, and discuss what was doing in the Astronomical world. A committee was appointed to draw a constitution and by-laws;" (Elvins 1913, 15).

According to Elvins, the group which planned the organizing meeting was composed of himself, Daniel K. Winder, James L. Hughes, and Samuel Clare. So half of the original founders were already meeting informally to discuss astronomy. It is, of course, possible that Elvins has conflated people and events, between the organizing group and those who turned up to the meeting at the beginning of December 1868, and the events preceding and following that meeting.

We hope that a copy of the circular may someday surface. At present we don't know if it was printed—and, if so, if Winder was the printer—or if it was reproduced manually for distribution by the writing master Samuel Clare, and possibly others (or if both technologies were used). Perhaps one day a copy of the original may be accessioned to our Archives.

Comparisons are always instructive. The Astronomical Society's (RAS) organizational meeting at Freemason's Tavern on 1820 January 12 appears to have been by invitation; only when the founders had decided what sort of organization they wanted did they prepare, print, and distribute a circular to drum up membership (Turner 1923, 3-6). The British Astronomical Association (BAA) appears to have done its preliminary business of organizing with a provisional committee communicating through the post, so that all was in place before the first meeting of 1890 October 24 (Evershed 2011, 7-11). So each of these—the Toronto Astronomical Club, the RAS, and the BAA—effected their beginnings a little differently.

In the course of the podcast we raised the question of whether our founders might have announced their first meeting through letters or notices in the press, and stated that it might be profitable to look through surviving newspapers of the time. Since the broadcast, one of us (Rosenfeld) has searched through editions of *The Globe* 1868–1870, and not only discovered that the founders did *not* advertise their planned meeting of 1868 December 1, but that the Toronto Astronomical Club/Society figures not at all in the pages of *The Globe*. Even when major celestial events were covered, such as the total solar eclipse of 1869 August 7, which despite the fact that Toronto was out of the path of totality, was the chief observational project of the Toronto Astronomical Society in its early existence (Anon. 1869a-d; TAS Minutes, 30-46). Perhaps they had recourse to other Toronto papers for the purpose.

In one respect the Toronto Astronomical Club/Society tried to emulate the media strategy of better established societies, but to seemingly limited effect. In the later 1860s, the meetings of the RAS were covered *in extenso* in the pages of the *Astronomical Register*¸ a publication directed at the amateur sector, and although it published a note of congratulations to the Toronto Astronomical Club on its founding, our ancestors seem not to have sent any notices of their doings to that publication, despite the fact that Elvins was a correspondent! (AR 1869, 51; 69, 172, 197, 260—year of activity to the periodical *Scientific Opinion*, which duly printed it (preserved in a clipping in TAS Minutes, 50-52; see note 3 above). Just as important, if not more so to the amateur astronomical community in the nineteenth century was *The English Mechanic and World of Science.* Letters to its pages were fundamental to the founding of the BAA in 1890 (Evershed 2011, 7; Chapman 2017, 251-252), but apparently not so to

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Pen & Pixel

Figure – 1: This image was taken at Algonquin Radio Observatory 2016 September 3 at 12:50 a.m. local time. Stu McNair used a Canon 6D, Rokinon 14-mm ƒ/2.8 lens at ISO 6400.

Figure – 2: On 2009 January 3, Journal *Production Manager James Edgar saw a bright sundog that appeared to have a line extending away off to the right. Quickly grabbing his camera, he snapped several shots to complete this panorama of about a third of a parhelic circle—it extended all the way around the sky to join the left-hand sundog. The bright spot to the right is the anti-solar point. He used a Canon 50D with an 18-55-mm stock lens at 18 mm, ƒ/5.6 for 1/8000 s at ISO 800.*

Figure – 3: Dan Meek took this stunning image of IC 405 in narrowband over 6 hours using a Tele Vue NP127is telescope and a QSI583wsg camera.

Figure – 4: This stunning image of a winter favourite, the Orion Nebula (M42), was taken by Blair MacDonald. He imaged using a Canon 60Da DSLR and a SkyWatcher Esprit 120 f/7 APO refractor, with processing done with Images Plus. He acquired 50 minutes (25 X 2 minutes) for the outer areas and 160 seconds (16 X 10 seconds) for the core.

Continued from page 73

the Toronto Astronomical Club/Society two decades earlier (and the latter organization's members were readers, and contributors; Elvins 1870; 1873)! Why the Toronto Astronomical Club/Society wasn't more successful in the exploitation of multiple press organs for publicizing their activities is hard to say. It could have been due to lack of ambition, or a want of proper connections, or an inability to meet high enough standards of quality to attract the sustained interest of the scientific media.

Is it a Club, or a Society?

It is striking, and unexpected that our Victorian ancestors could be both precise, and imprecise in naming themselves institutionally.

In the letter of "official" dissuasion from G.T. Kingston cited above, the scientific professional refers disapprovingly to the organization as "the Proposed Astronomical Society…" (TAS Minutes, 2). The earliest surviving list of members, almost certainly dating from 1868 December 1, is headed "Toronto Astronomical Club" (TAS Minutes, 4).

The notion of a "club" being a "society," and a "society" a "club" is present in the minutes of the first meeting 1868 December 1: "…a meeting…to take into consideration the propriety of forming a society for the prosecution of Astronomical Science…Moved by Mr. Elvins, seconded by Mr. Turnbull, that a society be formed under the name of "The Toronto Astronomical Club"…" (TAS Minutes, 5). And in those of the second meeting on 1869 January 5: "…that he [Turnbull] be requested to allow the original manuscript to become the property of the club, as being the first paper read before the society" (TAS Minutes, 10). Finally, at the meeting of 1869 May 4, the following was resolved: "Moved by Mr. Ridgeway, seconded by Mr. Turnbull that the name of the Association be changed from "Astronomical Club" to "Astronomical Society." Passed" (TAS Minutes, 29).

The surviving minutes offer no clue as to the reason for the change. It is possible that the line of reasoning behind the decision might be revealed in letters between the members, or in their personal diaries—should they survive. We are not left entirely in the dark without such sources, though.

Some enlightenment may be had from consulting dictionaries which were available prior to 1869, from which established usage and the social connotations of words can be discerned. Versions of Dr. Johnson's famous dictionary were still in print, and older editions still circulated: "CLUB. n. s…4. An assembly of good fellows, meeting under certain conditions" (Johnson 1785, n.p.) . And Ronald Hutton, Professor of mathematics at the Royal Military Academy, Woolwich, and friend of the Astronomer Royal, the Rev'd Dr. Nevil Maskelyne, in his monumental technical dictionary, wrote: "SOCIETY, an assemblage or union of several learned persons, for their mutual assistance, improvement, or information and for the promotion of philosophical or other

knowledge. There are various philosophical societies instituted in different parts of the world. See ROYAL Society" (Hutton 1815, 407). These definitions may tell us everything we need to know about why our predecessors changed the name of their organization. The only wonder is that it took so long.

Who *are* the Founders?

We really know very little about the eight men who arrived at the Toronto Mechanics' Institute "…to take into consideration the propriety of forming a society for the prosecution of Astronomical Science" that December a hundred and fifty years ago, particularly their individual astronomical interests and attainments (TAS Minutes, 5). For some of them, even the basic details of their lives—places and dates of birth and death, sequence of education, residence, and occupation—are presently incompletely known. Most of them are indistinctly discerned against the backdrop of Victorian Toronto; they meld all too easily into the urban background. None of them have merited independent entries in the *Dictionary of Canadian Biography* (James Hughes's brother, the notorious Sir Sam Hughes, does merit his own entry; Brown, "Hughes, Sir Samuel").

Their obscurity is such that fundamental, authoritative, and indispensible resources for the history of the RASC barely mention the majority of them. Only one has an entry in the Encyclopedia Uranica, namely Andrew Elvins ("Elvins," Encyclopedia Uranica). *Looking Up* has a biographical entry for Elvins, but not for any of the other founders (Broughton 1994, 20—it's the basis for the Encyclopedia Uranica entry). For that matter, the majority of the founders (George Brunt, Samuel Clare, James L. Hughes, Charles Potter, and Robert Ridgeway) don't even figure in the index to *Looking Up*.

Elvins, because of his longevity in the RASC, is the best documented as an amateur astronomer. Besides the surviving autobiographical accounts, he is also profiled in Albert Watson's presidential address of 1917 (Elvins 1904; 1913; Watson 1917, 51-57).

Three of the others have been the subjects of separate studies; Charles Potter (Smith 1993), Mungo Turnbull (Rosenfeld 2012; Rosenfeld & Luton 2012), and Daniel K. Winder (Broughton 2008).

Perhaps the RASC sesquicentennial will provide the impetus to document the rest of the founders better.

None of these men were members of the Toronto establishment in 1868. Hughes and Potter eventually rose to some distinction in their professional positions. None were professional scientists. None were astronomical researchers of distinction. The contrast with the founding groups of other astronomical societies of the period is striking. The fourteen members who joined John Herschel in 1820 to found the Astronomical Society (later the Royal Astronomical Society) included leading scientific researchers, university professors, members of the upper middle class, and lower gentry (Turner 1923). The group included no one from the working class. The members of the Toronto Astronomical Club/Society of the late 1860s also contrast as a group with the founders of the British Astronomical Society in 1890, among whom were several professional astronomers (including some from the Royal Greenwich Observatory), leading amateur observers, important astronomy authors, world-class instrument makers, and members of the upper-middle class (Evershed 2011). In fact, the social composition of the re-invigorated RASC of the 1890s resembled much more closely the membership of the BAA, than it did its incarnation of the 1860s. Possibly the best analogue to the Toronto Astronomical Club/Society may be the Leeds Astronomical Society of 1859—both groups share some striking parallels, as well as differences (on the early LAS, see Chapman 2017, 244-247).

In his *Cold Light of Dawn*, Rich Jarrell remarked that: "In a city of approximately 50,000 inhabitants, those seriously interested in astronomy were few: in 1868, at the founding meeting of the Toronto Astronomical Club, only eight turned out" (Jarrell 1988, 74). That is one way to look at it, but it doesn't tell the whole story. Proportionally, that 1868 turnout of eight out of 50,000 is approximately an order of magnitude greater than even the best attended meetings of our largest RASC Centres today. It was also more than an order of magnitude greater than the number of people, fourteen out of about 1,000,000, who attended the organizing meeting in London in 1820 for what would in time become the Royal Astronomical Society. Those eight RASC founders represent a strong turnout.

The Mechanics' Institute may seem from its very name to be a haunt of those far from the power elites of the cities in which they were found. The Institutes were set up to provide technical learning resources for the working classes, and they could be lasting and effective institutions (Walker 2017). Astronomy courses were frequently given at the Institutes (Jarrell 1988, 74). Inevitably, some from the middle classes were involved as lecturers, and as part of the audiences, and there were even complaints in some places of the Institutes being "colonized" by the middle class. In the Toronto of the late 1860s, as a venue it was in some ways a good match to the social standing of those who established the Toronto Astronomical Club/Society, at least for their organizational meeting. Interestingly enough, once established, the members held the meetings in each other's homes—perhaps as a measure of frugality.

Discontinuity, or Continuity?

Finally, there is the matter of the RASC's continuity from 1868. Much depends on how one reads the evidence. The chief informant (to use an anthropological term) from the early days, who continued to play an active role into the early 20th century was Andrew Elvins. He left three accounts, and they differ somewhat.

In the first version one can read:

> "The society had but a short existence as such. Mr Clare's death and Mr Winder's removal to the United States were deeply felt. But weekly meetings were held at my house by a few who felt interested in Astronomy or scientific subjects. We embraced other subjects, and found it useful as far as attendance was concerned. Natural History was a favorite study among some of the members…Natural History found more enthusiasts than

> the Astronomical part, and it was at last decided to join the Natural History Society of Toronto which had already obtained a charter. Several of our members became its members but yet kept up interest in Astronomy, and with the assistance of Mr Roberts, and Mr A.F. Miller, Astronomy was always a favorite study" (Elvins 1904, 9).

The second version offers:

> "For a time we existed in a very precarious way. Mr. Miller and I used to get together, and occasionally some others. Mr. Winder returned to the U.S.A., and business interests had so overweighted the rest of us that the work languished. Finally, Mr. Lumsden (with Mr. Ross at his back), recommended us to get incorporated [ca.1890]…" (Elvins 1913, 15-16).

and Watson in his 1917 Presidential Address remarks of Elvins that:

> "There were times when the Toronto Astronomical Society was not a very vigorous institution…Mr. Elvins assures me, however, and his accuracy is confirmed by others who have knowledge of the facts in the case, that the meetings of [the Society] have never been discontinued at any time since their inception in 1868' (Watson 1917, 58).

Make of this what you will.

Acknowledgements

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Endnotes

1 With apologies to Dr. Johnson: "Depend upon it, Sir, when a man knows he is to be hanged in a fortnight, it concentrates his mind wonderfully;" Boswell 1791, 152.

2 By way of comparison, standard accounts of the organizing meeting of the (Royal) Astronomical Society in London on 1820 January 12, and of the British Astronomical Society on 1890 October 24 similarly don't provide the time of day of their respective meetings; Turner 1923, 2-3; Evershed 2011, 9. The Astronomical Society became the Royal Astronomical Society with the grant of a charter 1831 March 7; Dreyer 1923, 51. And, for those who may wonder, the course the Astronomical Society chose to become the Royal Astronomical Society included paying the not inconsiderable sum for a Royal charter (1831 March 7), whereas the route the Astronomical Society of Canada pursued to become the Royal Astronomical Society of Canada involved the considerable saving of seeking the Royal assent alone (1903 February 27), without the expense of a Royal charter (Dreyer 1923, 51; RAS, "The Charter of the Royal Astronomical Society;" Rosenfeld, "The Society's "Royal" Charter"). We leave it to the reader to decide whether the Canadian route was a false economy. The tradition of RASC parsimony is long, if not noble.

3 Elvins has misremembered the title; it is in reality *Scientific Opinion*, a short-lived (1868-1870) weekly periodical edited by Henry Lawson in London, devoted to topical science. It was similar to Norman Lockyer's *Nature*, and Richard Proctor's *Knowledge*; Lightman 2016.

CFHT Chronicles

Welcome 2018

by Mary Beth Laychak, Outreach Program Manager, Canada-France-Hawaii Telescope

2018 at CFHT is starting off with a bang. In January alone, SPIRou arrived at CFHT and our project, the Maunakea Spectroscopic Explorer (MSE), completed its conceptual design phase and made its debut to the American astronomy community.

Maunakea Spectroscopic Explorer Update

The new year brought new opportunities and exciting project milestones for the MSE program. For those not familiar with the program, it is a project to redesign and ultimately replace the current CFHT telescope with an 11.25-metre telescope fully devoted to multi-object spectroscopy. Think of the Sloan Digital Sky Survey on an 11.25-metre telescope with 4200 fibres. MSE is the realization of a long-held ambition by the international astronomy community for a highly multiplexed, large-aperture facility dedicated to optical and near-IR spectroscopy.

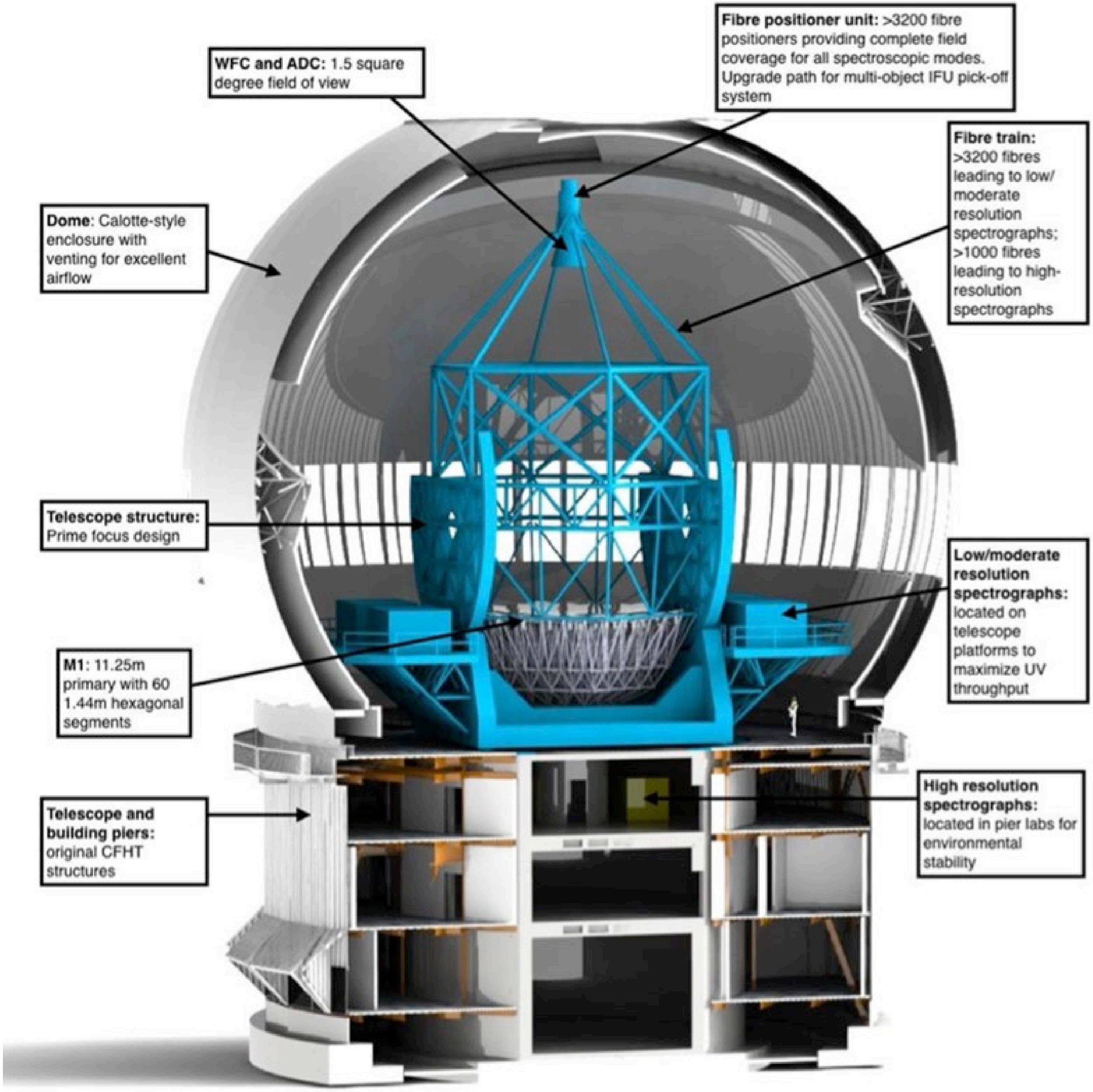


Figure 1 — The MSE facility as it is designed now.

Over the course of 2017, the MSE project team hosted ten conceptual design reviews for eight subsystems. The final design review, the system design review occurred in mid-January. The reviews went very well, and the team is ready to move on to the preliminary design phase in 2018. Let's take a look at where the system stands now.

The MSE Observatory leverages the latest technical advancements made by similar astronomical facilities, current and under development, and knowledge and experience gained from CFHT after four decades of operation. This design philosophy enables the team to establish an efficient and cohesive system design while minimizing engineering costs and technical risks.

Fundamentally, the new MSE Observatory is built on a proven site and well-established facilities by repurposing the CFHT outer building and inner pier. After a required seismic structural upgrade, the outer building will remain as well as the enclosure pier and work facility to support science and engineering operations. The bulk of the MSE work will occur on CFHT's fourth floor and above, leaving most of the original structure intact. The current outer building will be reconfigured to optimize workflow and upgraded to more modern thermal management while reusing, as much as possible, the current mechanical and electrical equipment. The inner pier remains as the support structure to accommodate the telescope, high resolution spectrographs and mirror coating laboratory.

The planned enclosure is a Calotte style structure, the same design style as the Thirty Meter Telescope. Its spherical form maximizes strength and minimizes construction and operation costs compared to the traditional dome styles. The telescope is also structurally efficient by having a high stiffness-to-mass ratio. The design has a slender open-truss telescope frame along with exterior enclosure vents to promote dome flushing and eliminate thermally induced turbulence along the light path. CFHT retrofitted dome vents several years ago. The resulting improvement in image quality was impressive. Adding dome vents from the start for MSE helps to preserve the excellent image quality found at the CFHT site (arguably the best single site in the Northern Hemisphere, if not the world).

The selected telescope configuration is a prime-focus configuration. This configuration was adopted after an extensive study comparing the pros and cons of four different optical configurations and the geometry implied by each telescope structure. Rather than simply comparing the optical performance alone, the study compared how the telescope design affected a wide range of systems such as the outer building, enclosure, access, observatory maintenance and operational safety. The team also took the cost and risk associated with each design into account for the comparison.

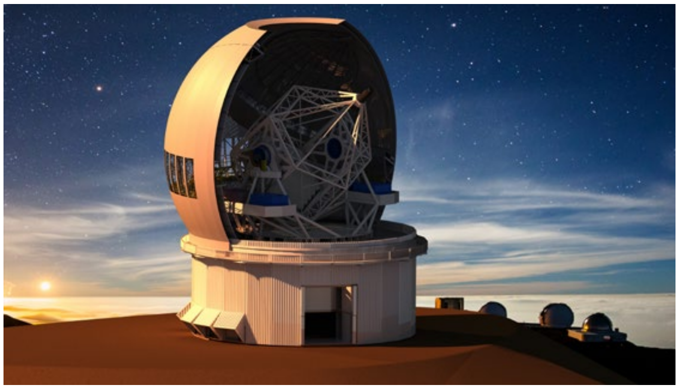


Figure 2 — MSE on the CFHT site.

Now for the more-technical details: Opto-mechanically, the adopted prime-focus configuration is an Alt-Az segmented mirror telescope, with 60 segments, and a hexapod system incorporated in the elevation structure supporting a top-end assembly. The top-end is composed of a wide-field corrector lens barrel with an integrated atmospheric dispersion corrector, field de-rotator system, positioner system, and fibre transmission system. Providing full-field coverage, the positioner system contains more than 4,000 remotely controlled tilting spine positioners across the focal surface. This is based on the Australian Astronomical Observatory Sphinx position system. Controlled by its metrology camera, the positioner system is capable of placing the input fibres to within six-micron accuracy. The fibre transmission system delivers light from the focal surface to the spectrograph slit inputs.

After their conceptual designs, the MSE team envisions two sets of spectrographs: six low/moderate and two high-resolution spectrographs. The low/moderate spectrographs will have approximately 3200 fibres and the high resolution will have 1000 fibres. This combined system is the collaborative result between scientists and engineers to determine the optimal wavelength coverage, efficient usage of detectors, and flexibility for future enhancements to maximize MSE's science productivity.

One subtle but crucial part of the planning process is the science calibration system and its corresponding control system. The MSE team is working on a plan to seamlessly perform daytime and nighttime calibrations. They are also considering the need for hardware and software infrastructure to support data reduction.

On the science side, the MSE science team has developed a list of the driving science behind the project. The power of MSE lies in the survey speed and sensitivity, the spectral performance and its dedicated operations. With a 11.25-metre mirror and a 1.5-square-degree field of view, MSE will be able to observe the faintest science targets. As mentioned above, MSE will have 4200 fibres, 3200 of which will span the optical to the H-band.

MSE will be the ultimate facility to measure the dynamics of dark-matter halos from dwarf-to-cluster scales, obtaining complete samples of millions of tracer particles over the entire extent of the halo.

MSE is the ideal follow up to the *Gaia* mission and will be the only dedicated facility to obtain detailed chemical abundances for millions of stars across the full luminosity range of *Gaia* targets. *Gaia* is a European Space Agency mission to create a three-dimensional map and catalogue of our galaxy. The *Gaia* team anticipates the catalogue containing over 1 billion astronomical objects—stars, planets, comets, asteroids, and quasars.

Figure 3 — The MSE team and CFHT's outreach manager at the AAS meeting. The rainbows are from the give away diffraction gratings.

MSE will measure the masses of thousands of supermassive black holes and trace their growth with redshift via a time-resolved reverberation-mapping program. A team using the Sloan Digital Sky Survey, CFHT, and the University of Arizona Steward Observatory Bok Telescope recently announced new measurements of the masses of a large sample of supermassive black holes using the same technique. In reverberation mapping, astronomers compare the brightness of light coming from a region close to the supermassive black hole to a region farther away. Changes occurring close to the black hole eventually move outward, but this travel or "reverberation" takes time. By measuring the time delay, astronomers can measure how far away the gas is from the black hole. The team used SDSS to observe 850 quasars simultaneously. With MSE's larger mirror and additional fibres, imagine the possibilities!

On that note, MSE will perform the equivalent of a SDSS Legacy Survey in seven redshift bins out to beyond the peak of the star-formation history of the Universe. A key science driver is to link the formation and evolution of galaxies to the large-scale structure of the Universe.

Figure 4 — One of the 13 crates that brought SPIRou to Hawaii.

Figure 5 — CFHT engineers and members of the SPIRou team work to uncrate one of the 13 boxes containing SPIRou.

Currently, astronomers are embarking on next generations of multi-wavelength imaging surveys, including LSST, the aforementioned *Gaia*, Euclid, WFIRST, the SKA and ngVLA. MSE will occupy a unique and critical role in the emerging network of astronomical facilities active in the 2020s. It will become an essential follow-up facility to these projects.

And it was that message that CFHT and the MSE team took to January's American Astronomical Society meeting. MSE's current partnership consists of Canada, France, the University of Hawaii, Australia, China, and India. With the leap into the preliminary design phase, it is an ideal time to look to expand the partnership, bringing in new institutions. The AAS meeting was MSE's coming-out party to the larger American community. The MSE team staffed a booth and explained the project to interested astronomers. The reception was fantastic, and the team was encouraged by the interest.

Stay tuned throughout 2018 for updates on MSE's progress.

And speaking of updates… The eagle has landed and SPIRou is in the building!

As frequent readers of this column may recall, SPIRou is CFHT's newest instrument.

SPIRou (SpectroPolarimètre Infra-Rouge) belongs to the next generation of astronomy instruments with the goal to find Earth-like planets in the habitable zones of nearby red-dwarf stars. It is capable of detecting the tiny wiggle in a star's position, which indicates the presence of planets.

"SPIRou is a giant leap forward for the search for planets" says Claire Moutou, astronomer and SPIRou instrument scientist at CFHT. "With its high precision and ability to look at infrared light, we will discover planets that were undiscoverable before. It's very exciting."

SPIRou looks at the rainbow or spectra of nearby red-dwarf stars. These red dwarfs are very cool, roughly the temperature of a halogen bulb. To measure the spectra of the stars, SPIRou operates in the infrared, wavelengths of light longer than the red light humans can see with their eyes. As the planet orbits its star, the gravity of the planet pulls the star ever so slightly. SPIRou will detect these wiggles in a star that is being moved at a speed of 1 m/s by its orbiting planets.

"The cameras on SPIRou are cutting-edge technology," say Greg Barrick, project engineer for SPIRou at CFHT. "No one else on Earth right now has cameras that can make these measurements."

After its arrival at the summit, SPIRou will be unpacked and reassembled, a delicate process that will take a couple of months. Once it's reassembled, the instrument will undergo testing in the lab and on the sky before being declared ready for science. CFHT anticipates SPIRou capturing its first light in summer 2018.

(Author's note: I borrowed liberally from MSE documents written by Kei Szeto, MSE project engineer/deputy project manager and Alan McConnachie, MSE project scientist. I had their permission, but wanted to be sure to acknowledge their excellent starting points.) ✶

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

Skyward

Of Meteors and Eclipses

by David Levy, Kingston & Montréal Centres

The Geminids! The Geminids is the most active, surprising, gorgeous, and wonderful meteor shower of the entire year. I recall first observing this meteor shower on 1961 December 13, from Montréal. During observing session No. 12E that night, I observed 15 meteors. Over the decades since then, I have counted thousands of Geminid meteors, all appearing to radiate from a point in the sky within the constellation of Gemini.

The Geminids is the richest meteor shower of the year, but the 2017 version was fantastic even by its own standards. Over the course of about 90 minutes on the night of 2017 December 13, I counted 62 meteors, of which some were so bright that I photographed them. The attached pictures show two versions of the brightest meteor I saw that night. One includes a view of the sky over the Jarnac Observatory, including that wondrous shooting star as it scratched the sky; the other is a detailed view of the meteor.

When we see a meteor, we are not looking at the dust-sized speck that is encountering the Earth's atmosphere. But as the speck races through the atmosphere at a velocity of 22 miles per second, it heats the surrounding air to incandescence, and that is what we see as a meteor.

All meteor showers originate from comets. At least we thought they did, until October 1983, when the Infrared Astronomy Satellite (IRAS) discovered an asteroid now known as 3200 Phaethon. This object may be an asteroid, but it travels about the Sun in a long, looping orbit that takes it closer to the Sun than Earth is, and then it swings out toward Jupiter before returning. Phaethon's orbit is more like that of a comet than an asteroid. In any event, the famous comet astronomer, Fred Whipple, after studying the orbit of Phaethon, concluded that its orbit is the same as the orbits of the Geminids. Therefore, Phaethon is the "parent object" of this meteor shower.

I was actually observing atop Kitt Peak that October, and since then I have always wanted to see Phaethon. I had that opportunity this December 17, but it wasn't easy. Twice early that evening I thought I had detected stars that did not belong, only to find then still plastered to the sky in their same stellar positions later. The third one was much fainter, but when I went out to check on it later, it had disappeared. It must have moved on, as Phaethon should have, and did. Phaethon has no evidence of a tail or even a coma of dust surrounding it. If it was a comet once, it isn't any more. But every December 13, debris from it encounters the Earth in a marvellous, unforgettable shower of shooting stars that tickle the sky.

Lunar eclipse memories

In the last two hours of darkness before dawn on the morning of 2018 January 31, the Moon waded into the shadow of the Earth. The result was a total eclipse of the Moon. Despite a forecast of high clouds during the night, the sky remained clear.

There is a profound difference between a total eclipse of the Sun and a total eclipse of the Moon. As some of us witnessed last August, a solar eclipse begins quietly and innocuously, and as the Moon crosses over the Sun, the sky begins to darken, first gradually, and later precipitously and suddenly until, for a magic minute or two, the Sun disappears and is replaced by a jewelled crown. The January 31 eclipse began gradually around 4 a.m., as the Earth's partial shadow, or penumbra, began to work its way across the face of the Moon. Instead of a sudden start, the beginning is so gradual that at least half the Moon has to be covered by the Earth's penumbral shadow before it becomes noticeable. I woke up at 4:30 and crawled out to see the penumbral phase already well advanced.

Figure 1 — The brightest Geminid meteor spotted on 2017 December 13/14, with the north side of Jarnac Observatory in the foreground. Photos by David Levy.

Then, at about 4:45, the dark edge of the umbra, the Earth's central shadow, began its onslaught. That was obvious. For the next hour, more and more

Figure 2 — A detail of the same meteor.

of the Moon became covered as the shadow crossed craters, mountain ranges, and maria. Wendee appeared shortly after 5 with an idea to watch the event through a closed window in our warm front room. That was a special treat. Even though it was not particularly cold outside, the warmth of the front room was beckoning and fun. As we watched, I noticed a classic eclipse effect: the bright blue sky around full Moon, known to offer only the brightest stars, was giving way to a progressively darker sky filled with thousands of beautiful stars.

I had planned for this eclipse to be a mostly visual event for me. But I did want to take one picture using my camera's fish-eye lens. About 20 minutes into totality, I took a 30-second exposure of the night sky, at full Moon, with the totally darkened Moon in the picture.

Figure 3 — This is a 30-second image of the dark sky toward the west on the morning of January 31. The eclipsed Moon is part of the picture, about 20 minutes into totality.

There was also a chance to check on my favourite variable star. Discovered by Clyde Tombaugh, who found Pluto in 1930, this star is known formally as TV Corvi, even though I call it Clyde's Star. It was nice to get a check on my old friend in the middle of a lunar eclipse.

It was certainly time to look back at the Moon. The eclipse was dark, but not particularly dark. On Danjon's luminosity scale for total lunar eclipses, I gave this one about a 2.5. This is also not the first time I have seen this particular eclipse. When I first saw it in the predawn hours of 1963 December 30, dust from the erupting volcano Mt. Agung darkened the shadow so much that the Moon essentially disappeared at totality. By coincidence, the volcano was erupting again in the months preceding this eclipse, but not nearly as calamitously. That distant eclipse of my youth was an L=0 on the Danjon scale.

Eclipses prove that things happen in the sky. The heavens are not static. Thomas Hardy knew that, and he even wrote of it in 1903:

> Thy shadow, Earth, from pole to Central Sea,
> Now steals along the Moon's meek shine
> In even monochrome and curving line
> Of imperturbable serenity.

* * *

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 over 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 and his wife, Wendee, also run the National Sharing the Sky Foundation, which tries to inspire people young and old to enjoy the night sky.*

Dish on the Cosmos

Lasers in Space

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

Last week, one of my students discovered a new space laser. While putting it that way is a bit hyperbolic, the essence is basically true. Laser is an acronym for "Light Amplification by Stimulated Emission of Radiation," but my student technically found a maser or "Microwave Amplification by Stimulated Emission of Radiation." Masers are relatively uncommon, so it was worth letting the community know about the new detection. Masers are extremely bright, and the new results may prove useful for future studies of how nearby galaxies are moving around each other.

Lasers and masers are understood by thinking about atoms and molecules through the lens of quantum mechanics. Quantum mechanics holds that the internal energies of atoms and molecules can only be in specific energy states, called the energy levels. To change the internal energy of an atom, it needs to absorb or emit an amount of energy that is exactly equal to a difference between the energy levels in the atom. In astronomy, we typically think about this energy exchange happening through a photon of light being emitted or absorbed by an atom. Since the spacings of the energy levels are unique to each atom and molecule, the differences between those energy levels are unique, too. Thus, the energies of light emitted and absorbed by a type of atom are also unique. This characteristic thumbprint leads to a unique spectrum that we can use to identify the composition of a distant object. This spectroscopy is essential to determining what the Universe is made of (hydrogen and helium is 98 percent of the answer!).

For the purposes of understanding lasers, it is important to note that atoms and molecules can also absorb specific amounts of energy through their collisions with other particles. If an atom gets hit by a particle (another atom or a free electron) it can absorb some of that energy of the collision directly into a change in its internal energy levels. This "collisional excitation" is usually unimportant in space, since the density of gas is so low that collisions are rare. However, the easiest laser to understand is the helium-neon (HeNe) laser, which relies on collisions.

In a HeNe laser, a pair of electrodes is used to channel electrons through a gas mixture of helium and neon. When these electrons smack into a helium atom, they excite the atom to a specific energy level. This energy level happens to be at about the same energy as a level in the neon atom, so when the helium atoms hit the neon atoms, it is very easy to swap energies from the helium atom to the neon atom. The energy levels in helium are relatively simple because the atom has only two electrons. Neon has ten electrons and this gives rises to a huge suite of different energy levels. After a while, the excited state of the neon atom will decay, giving off a photon of light as it drops into one of many different possible energy levels.

While this decay process will happen if the "ripe" neon atom is left alone, it can also be triggered by a passing photon of light emitted by the same decay happening in another atom. We typically think that the atom would not be able to interact with the passing photon because it would need to make the electron jump up in energy to a level that is not there. However, the passing photon will actually trigger the emission of the matched energy photon and the two photons will move out from the atom together, locked together in their wave oscillations. This process is called stimulated emission, i.e. the SE in the acronym LASER. As these photons pass through the neon gas that is filled with atoms that could emit the photon, a chain reaction builds up where the photon emission is triggered to go through this particular exit route from the upper energy level in neon. This chain reaction skews the expected radiation from the neon atom. Instead of the excited state decaying into a range of possible energy levels, the radiation preferentially comes out in one particular energy, leading to incredibly bright light at one particular wavelength. The intensity of the radiation is far higher than would be expected from just the random processes that would be determined by the temperature of the gas. This "light amplification" finishes explaining the meaning of the word laser.

The HeNe lasers was a product of careful engineering, leading to the characteristic red colour that early lasers typically showed. Presently, most lasers are made from diodes, which eliminates a lot of the delicate parts of HeNe system. This means that they can be packed into laser pointers and use different colours to point out constellations at star parties and other less important functions.

Lasers were actually predated by masers, which follow similar principles but operate in the microwave radiation rather than in visible light. Microwaves are relatively short-wavelength radio waves, and are usually associated with molecules, since individual atoms have relatively few energy levels that emit in the radio part of the spectrum. Masers typically arise when molecules are excited to high energy levels by a nearby source of infrared radiation. In space, this is typically the result of nearby young stars, since the combination of relatively dense gas with the source of infrared radiation will tend to generate masers.

Several molecules can be seen emitting masers including water, methanol, ammonia, and hydroxyl (OH). The maser that we discovered is a hydroxyl maser coming from the nearby Triangulum Galaxy. Masers are particularly useful because they come from tiny regions about 1 astronomical unit in size (i.e.

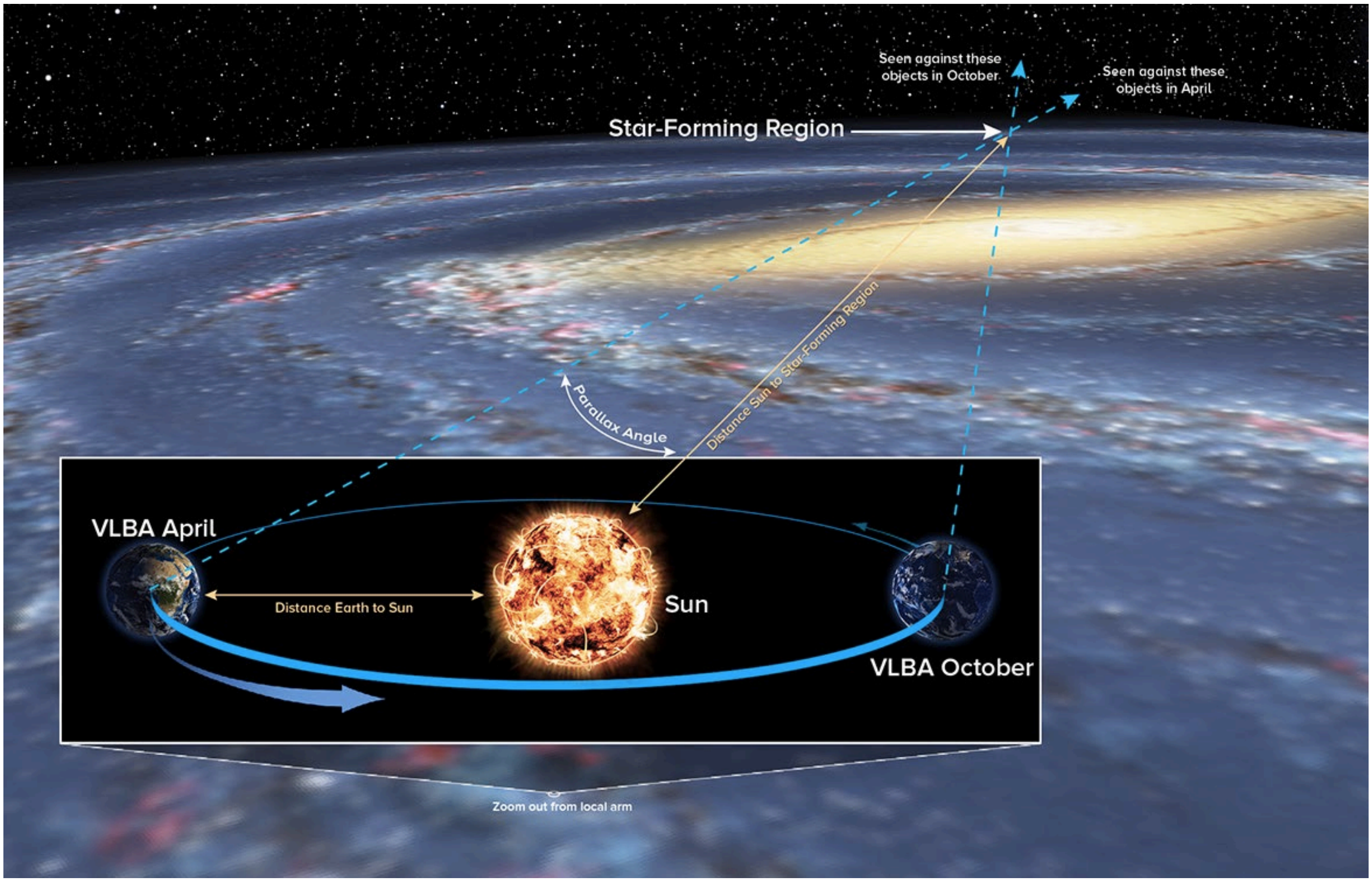


Figure 1 — Schematic diagram of how parallax is used to measure the distance to a star-forming region in our own Galaxy. Image Credit: Bill Saxton, NRAO/AUI/NSF; Robert Hurt, NASA.

the size of Earth's orbit) but they are incredibly bright. If the gas were not undergoing a maser transition, it would take gas temperatures of billions or trillions of degrees to give off that much radiation in the same spectral line. The key is that all of the relatively modest amounts of energy are channeled by the maser process to come out in the individual spectral line associated with the maser.

Since the masers are bright and tiny, they serve as excellent markers for measuring the positions of the maser spots in space. They can readily be detected by the largest radio interferometers with antennae spread across the surface of Earth. The precision in position measurements that can be achieved is amazing. Astronomers routinely use masers to measure the parallax to distant regions with the Very Long Baseline Array (see Figure 1). By measuring the apparent change in position of distant objects created by the Earth's motion around the Sun, it is possible to directly measure the distance to those objects. This is essential for measuring the size and structure of our own galaxy. In Triangulum, it is difficult to directly measure parallax, but astronomers will be able to watch the maser move around the galaxy because of the galaxy's rotation. By watching the maser slowly move, it becomes possible to map out how the galaxy is spinning and, with a few more assumptions, how far the galaxy is from us. The unique features of masers are essential to understand the size and motions of stars and galaxies, playing a key part in mapping our local space. ✶

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.

Observing Tips

Drawing Lunar Features

by Denis Fell, Edmonton Centre
(Denis_Fell@yahoo.com)

[Note from Dave Chapman, Observing Committee Chair: This is the fourth in a series of articles contributed by RASC members on observing, edited by me. In my mind, drawing at the eyepiece is the ultimate form of observing, as you need a keen eye for detail and have the patience to record it. For future columns I am looking for practical content contributed by active observers—please email me at observing@rasc.ca with your ideas.]

Introduction

I began recording my observations through the telescope in the mid-1970s, as the materials were inexpensive, I had some training in secondary school, and I was drawing figures as a pastime. Also, photography in those days was a hit-and-miss affair, requiring modification of the telescope, and there were few films suited to lunar and planetary imaging.

The aim of drawing the Moon, planets, and sunspots is primarily to record your observations in a way that conveys the visual impression made by the object under scrutiny at the time. The objective is not so much to create a faithful scientific illustration, as that is much more easily accomplished by imaging technology that is readily available to amateurs today.

Figure 1a — Materials to make the original drawing at the telescope (all photos and images by the author).

The beauty of this approach is that any telescope that can deliver a sharp image at 100x to 200x magnification will suffice. Use eyepieces or eyepiece/Barlow combinations with generous eye relief to avoid eye fatigue. It is handy to have an equatorial mount with some sort of right-1ascension drive to minimize the distraction of adjusting the instrument while you are concentrating on recording the view in the eyepiece.

Another aspect of drawing what you see at the eyepiece is that it puts you in the same league as the observers of the 18th, 19th, and early 20th centuries, who had no other method of recording their observations. I find that the historical perspective adds to the experience. As you put pencil to paper, you can imagine yourself in the place of Galileo or Huygens or Percival Lowell, patiently drawing what they saw and trying to make sense of details on the target for that night.

For this article, I have selected lunar drawing, as the Moon is often available and shows high contrast detail through any optical instrument. First views will show a bewildering amount of complex related features that at first seem to defy any attempt to record. My method is to select an individual, well-defined feature that has interesting detail, and to concentrate on that feature by using medium to high magnification to isolate it. This may be a single crater, mountain, valley, or fault line. While doing this, one gains an appreciation for the works of historical lunar cartographers and the amount of effort that it took to produce their hand-drawn maps.

Equipment and Preparation

First and foremost, you need a seat of some sort at the telescope in order to be relaxed and steady, so you can observe for a sufficient period of time without becoming fatigued. Use a red or white flashlight attached to the telescope mount with Velcro, or some other means to provide light while freeing both hands for drawing. Draw on medium-weight drawing paper in a sketchbook or on a clipboard (you might prefer to attach your light to the clipboard).

Shown in Figure 1a, to draw at the eyepiece, I generally have B, 2B, and 3B pencils, as well as a white eraser. An HB pencil is included to make marginal notes for later reference, including location, date, time, and instrument characteristics (e.g. objective aperture, focal length or *f*/ratio, eyepiece focal length, magnification, filters, etc.). A note about sky transparency and seeing conditions is helpful for later reference. Figure 1b shows additional tools used for finishing the drawing indoors.

Figure 1b — Materials for use indoors to refine the drawing.

Step 1: At the Telescope

Begin by observing the chosen area (in this example, Rupes Recta, or the Straight Wall), noting placement of features in relation to one another, and draw an outline of each feature—generally a geometric pattern will be apparent, items in a triangle or in line with others. It is important to remain aware of the solar illumination angle when outlining shadows within depressed features such as craters and rilles, compared with those of elevated features like ejecta, boulders, and wrinkles in lava plains (mare).

Figure 2 — The initial outline of Rupes Recta (the Straight Wall) at the telescope.

When you have completed this, it is time to begin shading darker areas, shadows, and small craterlets as well as crater-wall features—you can smooth the shading of larger areas using your finger or a small sponge and lighten brighter areas and sunlit portions by using your eraser. Making notes about specific items as you go helps when you finish your work indoors, later.

As we northern-latitude observers are often outside on cool autumn or winter nights, we often have to pause to warm our hands and have a drink of hot beverage. I have found that wearing silk gloves greatly helps, allowing dexterity and feeling while making handling cold equipment easier.

When you have completed shading and adding all the features, and when you are satisfied that you have recorded all the detail that you wish, it is time to pack up and go indoors.

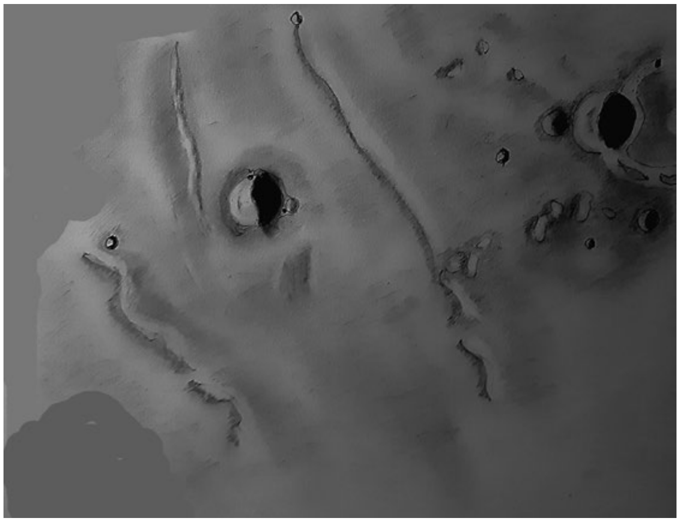


Figure 3 — Semi-finished drawing at the end of the telescope session.

Step 2: Indoor Refinements

Once comfortably ensconced indoors, finish the drawing by blending light and dark areas to form a gradual transition of shading, and by defining shadows to obtain the stark effect of lunar lighting. A technique I have found effective is to use a soft artist's brush to blend dark areas, as the 3B pencils are easily blended, and a stiff brush to blend lighter with darker areas. When this done to your satisfaction you can move on to the final step.

Step 3: Digital Treatments

Over the last five years, inspired by the work of Carlos Hernandez, I have been combining manual drawing technique with digital artistic rendering, initially on Mars, and now

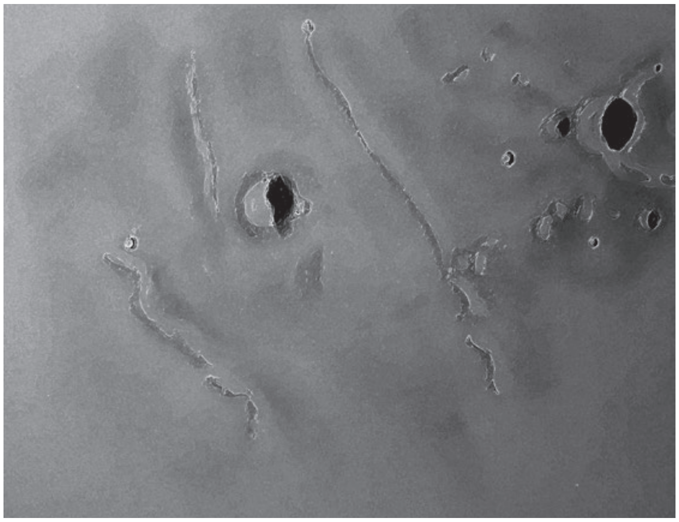


Figure 4 — The finished product after refining the drawing indoors.

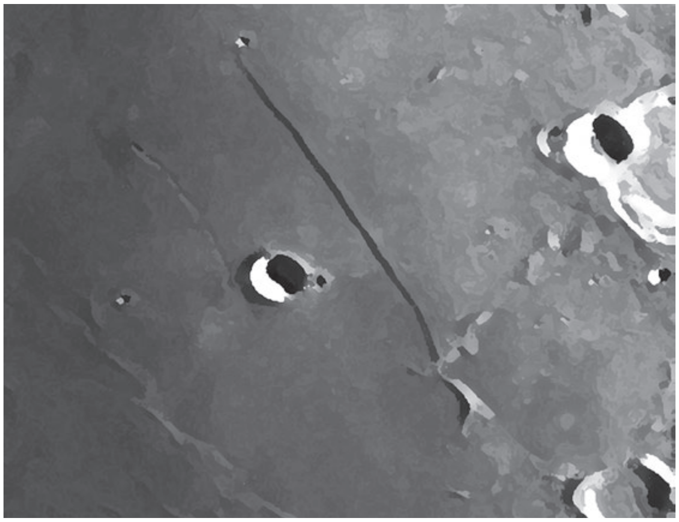


Figure 5 — After digital treatment of the scanned drawing, for artistic effect (optional).

on lunar subjects. This is where the magic of modern digital technology comes in. Either scan or digitally photograph the drawing, upload the image to your computer, launch a graphics-editing program (such as Photoshop, GIMP, or Lightroom), and load your image into the application.

All these programs have a multiplicity of filters and functions to adjust and give various finished effects to your image. Artistic finishes can be used to give the finished drawing the appearance of watercolor, oil paint, charcoal, or pastel finishes. Textures can be as subtle or bold as you wish. I tend personally to favour a watercolor look that gives a personal touch I prefer. Adjustment of feature location in the image can also be done to correct the original drawing for errors in placement. Unlike processing of camera images, which tends to follow a linear work flow to extract maximum detail, the flow with drawn images tends to wander until a satisfactory final image is obtained, and may explore filter settings that are subsequently tried and rejected until you are happy with the result.

You can then resize the image and increase the dots-per-inch (dpi) resolution, eventually saving the image for printing, emailing, or posting on social media or astronomy webpages.

Some may not want to proceed to the digital stage and that is fine, because this is a very enjoyable pastime and is as individual as the observer—it is always pleasant to sift through your sketchbooks from earlier years and bring back memories of those nights at the telescope.

I welcome questions or comments on this topic by email at Denis_Fell@yahoo.com. Happy sketching! ✶

Denis Fell has been observing and drawing at the eyepiece since 1971. He joined the RASC in 1974. Denis is well known for his Mars drawings over the years, some of which have been published in the ALPO Journal and the RASC Observer's Handbook. Denis is retired and observes and draws through 80-mm and 102-mm refractors from Wetaskiwin, Alberta.

Binary Universe

The Sky for the Next 580 Months

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

For years—correction, decades—I have wanted to have a concise list of upcoming astronomical events at my finger tips. In other words, on my computer screen. Over time, I have tried many things like RSS feeds into desktop applets and widgets, and programming alerts in the Clear Sky Alarm Clock website. I want this information for personal reasons, but I also rely heavily on this for content when asked to deliver The Sky This Month (TSTM) presentations.

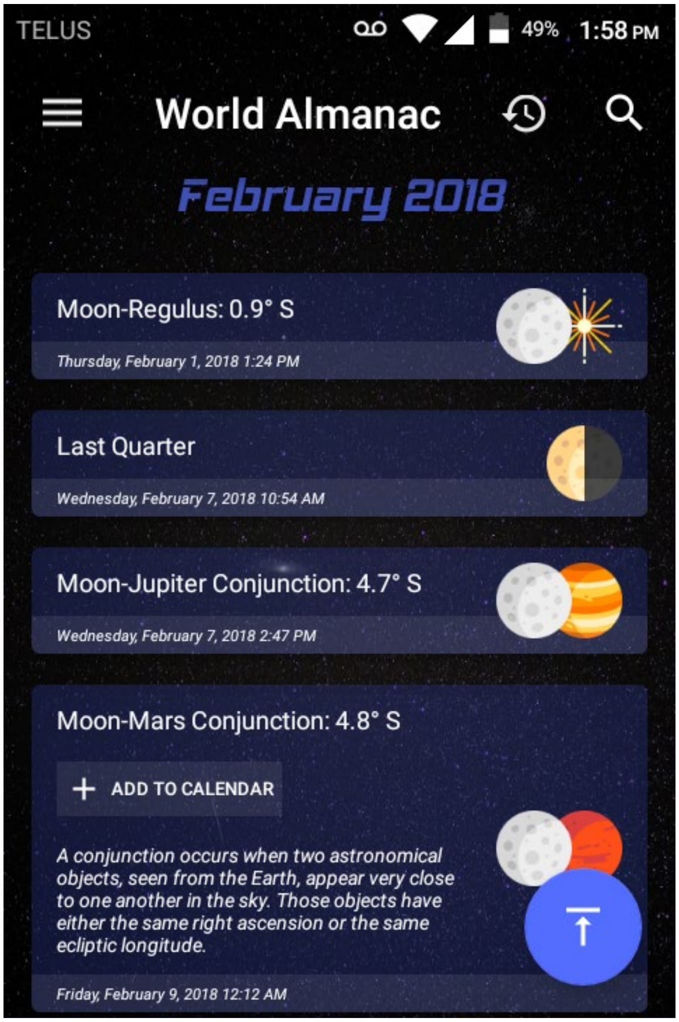
For personal use, ultimately, I want a list of things I'm rather interested in, like new-Moon phases, planetary appulses and conjunctions, meteor showers, major comets, gas-giant shadow transits, apparitions of Mars, and other planetary oppositions, etc. For TSTM presentations, I also like to report on notable variable stars, ISS flyovers, asteroid occultations, near-Earth objects, and so on. The content needs to be location sensitive.

There are many sources that I refer to, including periodicals like *SkyNews* and the amazing JPL space calendar managed by Ron Baalke. Of course, I regularly consult the *Observer's Handbook* and the *Observer's Calendar*.

Dissatisfied with a lack of delivery mechanisms, I started to simply collate information myself. For many years, every month or so I manually transcribed things from my preferred sources into one of the "layers" of my personal Google calendar. This astronomy-specific content I normally leave visible, so I can monitor things. Now that I use Google's planner tool for personal and work purposes, I see all my calendars on all my devices. Many Moons ago, I made the astronomy calendar public and it appears on my astronomy website. Before a TSTM presentation, I do a thorough update.

Still, I want for a highly customisable tool that is location-aware, that shows me upcoming events and ideally alerts me of them. In previous *Journals* I've talked about specialized apps, like *ISS Detector* and *Meteor Shower Calendar*, but I continue to look for an all-inclusive solution. I actually found something a while ago but forgot that I had installed it to my Android phone. The *Sky Events* app looks to be fairly good.

On launching the *Sky Events* tool from Axl Softs, you are usually presented with the World Almanac view. This is a list of upcoming astronomical events (Figure 1) with the next items immediately showing.



Moon-Regulus: 0.9° S
Thursday, February 1, 2018 1:24 PM

Last Quarter
Wednesday, February 7, 2018 10:54 AM

Moon-Jupiter Conjunction: 4.7° S
Wednesday, February 7, 2018 2:47 PM

Moon-Mars Conjunction: 4.8° S
A conjunction occurs when two astronomical objects, seen from the Earth, appear very close to one another in the sky. Those objects have either the same right ascension or the same ecliptic longitude.
Friday, February 9, 2018 12:12 AM

Figure 1 — Main screen with World Almanac list of upcoming astronomical events.

In February 2018, we have an appulse of the Moon and Regulus on the 1st and a Mars–Jupiter conjunction about a week later. Between is the last (or third) quarter phase of the Moon.

Swiping or scrolling will reveal a very long list of events, each with a brief description, the local date and time, and an appropriate icon. Unfortunately, the date/time info is displayed at a terribly small font size, which is a little challenging for these old eyes on my small phone. Many months into the future are shown with all manner of event types. I noted conjunctions, all the main Moon phases, the notable positions of Venus (e.g. superior conjunction), the lunar nodes (e.g. descending), lunar and solar eclipses, planetary elongations, the Earth's significant orbital events (e.g. equinox), and meteor showers. Oh yes! So, to keep track of all those Super Moon events, our natural satellite's positions are noted too (e.g. perigee).

A handy button appears at the bottom-right of the screen to help one zip back to the top. (I wish a clever button like that was in other apps).


TELUS 37% 2:25 PM

mars

June 2018

Moon-Mars Conjunction: 3.5° S

Sunday, June 3, 2018 7:58 AM

July 2018

Mars at Opposition

Friday, July 27, 2018 1:31 AM

October 2018

Moon-Mars Conjunction: 2.2° S

Thursday, October 18, 2018 9:01 AM

November 2018

Figure 2 — Short list search results from the extensive main display.


TELUS 25% 2:55 PM

Solar Eclipses

Saturday, October 14, 2023 11:22 AM

April 2024

Sun in Total Eclipse

1:09:11 PM	Eclipse Begins
2:26:21 PM	Totality Begins
2:28:35 PM	Maximum Eclipse
2:30:51 PM	Totality Ends
3:50:19 PM	Eclipse Ends

Duration: 2h 41m 07.4s

Duration of totality: 4m 29.3s

Magnitude: 1.028

Obscuration: 100.0%

ADD TO CALENDAR

Monday, April 8, 2024 1:09 PM

Figure 3 — Solar Eclipses list with tile expanded for a specific occultation.

Happily, this main list is searchable. For example, when I tapped the magnifying glass icon and searched for "Mars," I was rewarded with a short list (Figure 2). I'm looking forward to seeing Mars up close this summer.

This view is one of four in the helpful application. The second mode is the Lunar Phases, which obviously invokes a preset filter to focus on the Moon. Useful when planning your dark-sky site excursions for the season.

Similarly, the Solar Eclipses mode restricts the listing to partial or full occultations of the Sun by the Moon, for when you're planning your excursions around planet Earth.

This brings up the matter of location. Some astronomical events are impacted by your topographic position. By default, *Sky Events* uses your current location, but this can be easily changed. I tested this for the April 2024 eclipse by tapping on the map icon, panning to Mexico, performing a long-press on Zaragoza, and applying the change. After a moment the list updated using the new latitude and longitude and informed me that the April 8 event would be a total solar eclipse.

The bull's eye icon allows the user to reset the location to their current position.

Tapping on any event item expands its tile and allows for various details to be shown. For example, for a meteor shower, the panel explains what the ZHR acronym means. Conjunctions are noted as events when two celestial bodies share the same right ascension values. In the case of the eclipse at Zaragoza (Figure 3), the circumstances indicate that totality will be around four and a half minutes with a magnitude of 1.03, and it will end around 2:30 p.m.

Another worthwhile feature of the expanded tile is the ADD TO CALENDAR button. When I use this, the details of the astronomical event are copied to my Google calendar, of course, using the correct date and time with details transferred to the notes or long-description field. I can see using this for future events that I missed or overlooked.

The last mode to be mentioned is the Daily Data view. This includes Sun and Moon information like the sunrise and civil twilight times. For the Moon, the lunar phase and illumina-

Great Images

Road 22 Bridge by Merv Graf (Unattached). In his entry for the Astrophotographer Wide Field category, he wrote: I was seeking a Milky Way panorama with an interesting foreground. I am learning to judge and make a 30% overlap in the dark. The Milky Way was low in sky so lens distortion was low in portrait orientation. It was suggested I clone out the bridge sign as a huge distraction but I think it is part of the scene.

Detail: 2016 June 4 at 11:48:40 pm PDT, over Okanagan River north of Osoyoos, B.C., Nikon D750 14–24 zoom lens at 14 mm, 20 sec, f/3.3, ISO 2200 (9 images)

Crescent Moon and Earthshine Luca Vanzella (Edmonton) submitted this image for his Astrophotography Wide Field certificate entry. He wrote: This is one the first times I photographed the Moon with Earthshine. The dark clouds separated the sunset glow from the blue twilight sky in an interesting way. The image is straight out of the camera.

Details: 2008 March 8 at 18:31 MST, Strathearn Drive, Edmonton, Alberta, Canon EOS REBEL XTi, 1 sec @ f/5.6, 90 mm, ISO 800

tion percentage are noted (Figure 4). By default, again this uses your current date; you can easily select any future or past period.

Speaking of which, if you missed an event and wanted to look it up for whatever reason, you may do so. You can easily show past astronomical events from the main screen by tapping the clock icon or while using the search function.

The app draws data prepared by staff at the NASA Goddard Space Flight Center. You will need an active internet connection for some of its features, such as Solar Eclipses. Also note the app does not account for sightlines, that is, an event listed may not be above your horizon at a specific time. You will need to double check things for your geographic location.

Sky Events is a pretty basic Android app, but it does provide a number of things that I like. Often, I want to know when the Sun will disappear below the horizon or when that photogenic conjunction is coming up.

I tested free advertisement-supported version 1.5 and it worked well. That said, I do wish the events would pop up in notifications, like other planning or predictive apps do. Neither does it offer an Android home-screen widget with a dynamic display. The planning tool works in portrait or landscape mode, and it displayed fine on my small touchscreen. It does not appear to have a red-light mode, which I think all astro apps should have.

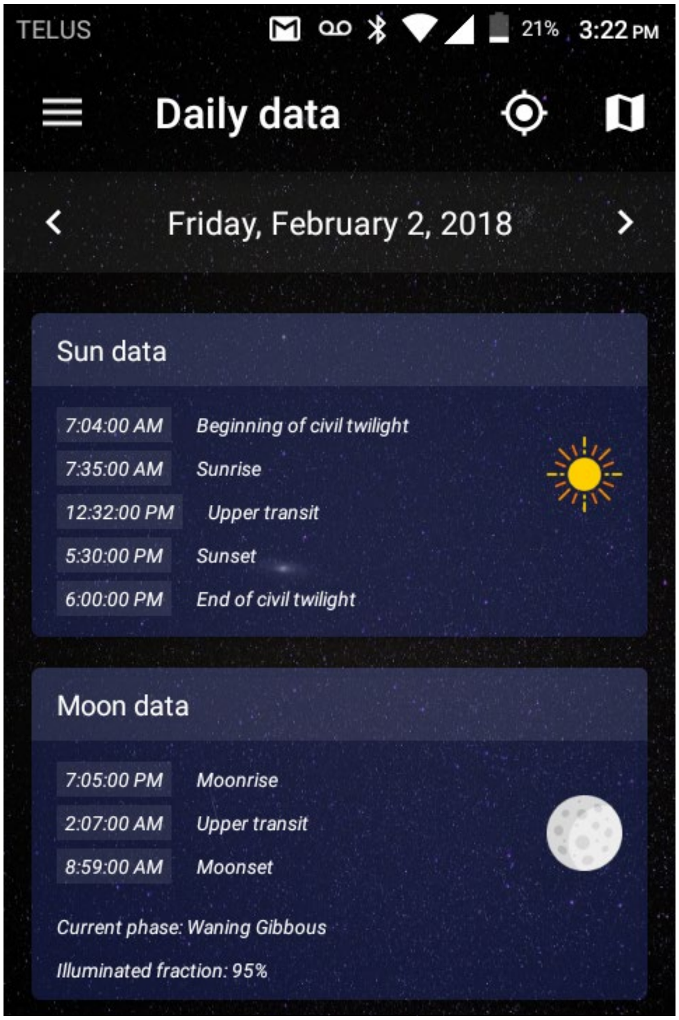
I checked the developer's website for more information, but oddly I could not find anything about the *Sky Events* app! The Twitter feed has not been updated for about a year (when *Sky Events* appears to have been last updated).

I put some questions to the developer, such as, "What does one receive with the Premium edition?" It's inexpensive to upgrade with an in-app purchase, at less than $3, but I don't see any documentation about this. I suspect it simply stops the sliver banner ads. I'd like to know if there plans for a night mode. It'd be great if additional data feeds could be used to monitor for other significant events such as bright comets. Not heard back yet.

I rather like the idea of this app and I have tried to find an equivalent product for iOS users, but regrettably the search continues. I know Sky & Telescope has a tool called SkyWeek and I plan to take a look at that one (again) and report to you shortly.

So, while *Sky Events* does not cover all astronomical events you may be interested in, I do think for some it might allow for one-stop shopping. It is certainly a light-weight, fast, and simple Android program. Visit the developer's page in the Google Play Store to download the app.

https://play.google.com/store/apps/developer?id=Axl+Softs



Daily data

Friday, February 2, 2018

Sun data

7:04:00 AM	*Beginning of civil twilight*
7:35:00 AM	*Sunrise*
12:32:00 PM	*Upper transit*
5:30:00 PM	*Sunset*
6:00:00 PM	*End of civil twilight*

Moon data

7:05:00 PM	*Moonrise*
2:07:00 AM	*Upper transit*
8:59:00 AM	*Moonset*

Current phase: Waning Gibbous

Illuminated fraction: 95%

Figure 4 — Daily Data view with information on the Sun and Moon.

With *Sky Events* you can easily plan ahead.

Update Bits

Beta testing for the SkyTools 4 planning software has begun! ✶

Blake's interest in astronomy waxed and waned for a number of years, but joining the RASC in 2007 changed all that. He volunteers in education and public outreach, supervises at the Carr Astronomical Observatory, and is a councillor for the Toronto Centre. In daylight, Blake works in the IT industry.

The June *Journal* deadline for submissions is 2018 April 1.

See the published schedule at www.rasc.ca/sites/default/files/jrascschedule2018.pdf

John Percy's Universe

Careers in Astronomy. Or Not.

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

In an earlier column (Percy 2015), I described how the education of Canadian astronomers had changed over the last 150 years. The column devoted a few paragraphs to a description of a modern astronomy curriculum, and different strategies for giving graduates the necessary knowledge and skills to be a front-line astronomer. The focus was on Canada's professional astronomers.

In this column, the focus is different: I will emphasize *the wide range of careers that astronomical education prepares graduates for, and the wide range of careers in which astronomy graduates are found.* Whether graduates stay in academia and in astronomy depends on many factors, including the job market, their commitment to astronomy, and their personal circumstances. In a separate column (Percy 2017), I discussed the special career challenges faced by women, such as the "two-body problem"— the difficulty faced by two partners, in specialized research fields, in finding jobs in the same place.

Among other things, this kind of career information is important for schools. The Ontario school science curriculum requires students to "identify and describe a variety of careers related to the fields of science under study"—astronomy, for example. These careers may be closely related to astronomy, or more distantly so. Students should also realize that most post-secondary STEM (science, technology, engineering, mathematics) programs give them *generic* skills, which prepare them for a very wide range of STEM careers, including ones that are currently in high demand. The University of Toronto Mississauga's Career Centre has an excellent webpage(1) about careers related to undergraduate programs in astronomy. It lists almost a hundred sample career titles, sample job listings, sample areas of employment, plus program-related skills, and much more. It was updated in September 2017.

Students should also realize that careers *within* astronomy can be quite varied. Astronomy researchers make observations at a wide range of wavelengths, with telescopes on the ground or in space. They build novel instruments, ranging from tiny detectors, to radio telescope arrays covering half a continent. They do pure astrophysical back-of-an-envelope theory, or use high-end computers to do complex simulations or data analysis. Their observations, instruments, software, and results may be used by astronomers around the world. If they are in a university, they may teach, supervise, and mentor students ranging from non-science students to Ph.D. students and postdocs. They may write: Ray Jayawardhana, Professor of Astronomy and Dean of Science at York University, is an award-winning science writer. They may develop an interest in history and heritage, as I have. If they have an interest and talent for administration, they may become a department chair, or dean, as Jayawardhana at York and Doug Welch at McMaster have done. They may be active in professional organizations such as the International Astronomical Union (iau.org) or the Canadian Astronomical Society (casca.ca). They may attend conferences around the world. Astronomers tend to travel a lot!

Some astronomers may combine careers. My colleague Bill Clarke divided his time between astronomy and the family publishing business, Clarke Irwin. Christopher Corbally, with a Ph.D. from Toronto, is a Jesuit astronomer and priest. Robin Kingsburgh, Ph.D. astronomer and artist, teaches astronomy (at York) and art (at OCADU). CITA postdoc and musician Matt Russo recently achieved media fame by "sonifying" the orbits of the exoplanet system Trappist-1. He has now developed a very popular planetarium show on "Our Musical Universe," and another for the visually impaired.

Astronomy lends itself especially to outreach and communication, and astronomy students may "catch the bug" early and make a career of it. In the Toronto area: Maurice Bitran, Director-General of the world-famous Ontario Science Centre, has a Ph.D. in radio astronomy. Ivan Semeniuk, award-winning science reporter for the *Globe and Mail*, and Kirsten Vanstone, Executive Director of the Royal Canadian Institute for Science (RCIS), each combined an undergraduate degree in astronomy with a graduate degree in science communication. Pierre Chastenay (Figure 1), 2017 winner of the RCIS Sandford Fleming Medal for excellence in science communication, has an M.Sc. in Astronomy and a Ph.D. in Education, and has hosted hundreds of episodes of award-winning TV science programs—among many other things. Pierre is one of many astronomy graduates who work in planetaria and museums. The powerful visualization capabilities of modern planetaria, by the way, can be used not only to communicate astronomy, but also as a "big data" research tool.

I know many astronomy graduates who have become schoolteachers. They can play an especially important role: astronomy is a compulsory part of the school science curriculum, but very few teachers have any background in the subject. Those who have can develop resources, give workshops, co-author textbooks, and generally provide leadership in astronomy education in their school or board or science teacher's organization.

Some graduates' careers lie much further from astronomy. Charles Lumsden went from a B.Sc. in astronomy at Toronto to an M.D., and became an eminent medical scientist. Dr. Hugh Ross became a minister. Blake Kinahan, RASC Gold Medallist in 1971, obtained a Ph.D. in astrophysics at Princeton, then became a lawyer and Toronto municipal politician. The late Barry Sherman had a Ph.D. in astrophysics from

Figure 1 — Pierre Chastenay, the 2017 recipient of the Royal Canadian Institute for Science's Sandford Medal for outstanding contributions to science communication in Canada. An astronomy graduate, he has been a planetarium presenter and administrator, an author, a professor of education at UQAM, and charismatic host of literally hundreds of science programs on TV.

MIT before he became the founder of Apotex, and a philanthropist. Queen guitarist Brian May has a Ph.D. in astronomy, though I doubt that his astronomical education had anything to do with his success in his present career!

My department keeps track of its Ph.D. graduates and their current employment. Those graduating in the last decade are mostly in astronomy postdoc positions, or astronomer positions in university or government. But others are data scientists or machine-learning research scientists, software engineers, a manager of capital markets stress testing, a load-forecasting analyst, a model risk and vetting manager, and a high school teacher. Previous graduates have transferred their skills to remote sensing (imaging that looks downward, rather than upward!) and to medical imaging and related topics.

It is sometimes possible for graduates to create their own career. Jeff Crelinsten, after an M.Sc. in astronomy and a Ph.D. in the history of science, and a few years as a science writer, founded The Impact Group, which provides expertise in science policy, communication, and education to a variety of clients. Glen Rutledge, with a Ph.D. from UVic, founded a successful company that develops music and signal-processing technology for vocal and instrumental music effects.

In almost every university department, a significant fraction of graduates go into non-academic careers. The University of Toronto has just released the results of the "Ten Thousand PhDs Project," in which they have tracked down the employment status of 88 percent of the 10,886 Ph.D.s who graduated from the university between 2000 and 2015 in all disciplines. Overall, 41 percent found work outside of academia, and 22 percent entered the private sector, including 40 percent of the graduates in the Physical Sciences.

My university (and others) have reacted to these developments by developing Graduate Professional Development(2). This may include short courses and workshops to help graduate students develop professional skills, especially "soft skills" that are not necessarily learned in graduate programs—oral and written communication; teamwork; how to mentor, supervise, and lead (and be mentored, supervised, and led); conflict resolution; time and project management; networking; advocating; and "branding". My former student Nana Lee (who almost became an astrobiologist but ended up as a biochemistry professor) has given lectures and workshops on graduate professional development across the country and, with a colleague, written a "textbook" for such workshops (Lee and Reithmeier 2016). These workshops supplement the regular graduate curriculum of coursework and research.

The American Association for the Advancement of Science maintains an excellent non-commercial website on science careers(3), including an interesting and very useful Individual Development Plan site(4) that enables students to complete an on-line survey to explore career possibilities, broadly defined. Although intended for graduate students and postdocs, the site would be useful to any STEM student.

Some astronomy departments may feel that graduates who go on to non-academic or non-astronomy careers are "lost." But look on the good side. There are advantages to getting astronomers into high-level positions in fields such as government, business, and education, because it's increasingly important to bring an understanding and appreciation of STEM into the public sphere. This point was eloquently made, many years ago, by Tobias, Chubin, and Aylesworth (1995). These graduates can then be brought back to the university as mentors for present-day students. In fact, they can continue to do astronomy outreach, or even astronomy research as "citizen scientists" if they want. At the very least, they can join and support the RASC!

It would be nice to think that "once an astronomer, always an astronomer"! ✶

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Notes

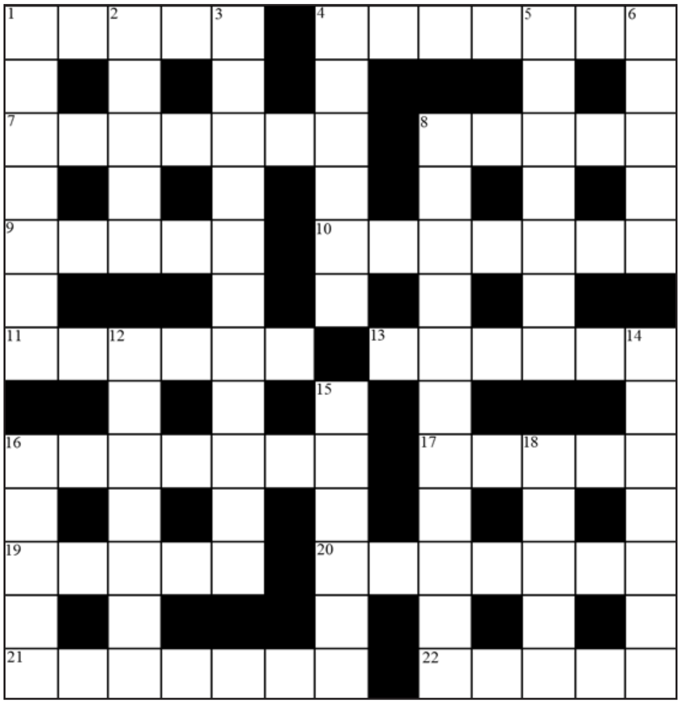
1 www.utm.utoronto.ca/careers/careers-by-major-astronomy
2 www.sgs.utoronto.ca/Documents/Report_on_GPD_at_UofT_Reinhart_Reithmeier_July.16.pdf
3 www.sciencemag.org/careers
4 myidp.sciencecareers.org

References

Lee, N. and Reithmeier, R. (2016). *Success after Graduate School: A Guide for Professional Development for Graduate Students in the Biomedical Sciences*. NR Publishing: Toronto.
Percy, J.R. (2015). Educating Astronomers in Canada—Then and Now. *JRASC, 109*, 225.
Percy, J.R. (2017). Women in Astronomy (or Not). *JRASC, 111*, 85.
Tobias, S., Chubin, D.E., and Aylesworth, K. (1995). *Rethinking Science as a Career*, Research Corporation: Tucson AZ.

Astrocryptic

by Curt Nason



ACROSS

1. Rider commonly included in legal correspondence (5)
4. Scrambled message about a thorium terminal to attract positive types (7)
7. It goes around Neptune in a Polaris satellite (7)
8. Nice solar system one on a catwalk (5)
9. Overtime put in at Russian telescope factory for an eclipse (5)
10. Narrowband filter devices sale not organized (7)
11. Our financial ministrant will tear an errant invoice (6)
13. Sounding board for a quantum physicist (6)
16. Copernicus started on tour following lines of a relief map (7)
17. President's first lesson in a quarter, for example (5)
19. Guam's extraordinary star follower (5)
20. On-line program about a spacecraft component thrown away (7)
21. Calculating conjunction periods comes across as easy—no dice! (7)
22. Waves soundly scatter charged particles up to the speed of light (5)

DOWN

1. Sponsor and dealer of top athlete telescopes (3-4)
2. Company decay led to demise of an exoplanet discoverer (5)
3. Observing Committee decisions regarding double stars (11)
4. Carved depression on a snake's back (6)
5. Not quite new, but soon will be (3,4)
6. Hall support for Queen's Observatory (5)
8. Suicidal Pam gets strung out in the keel (11)
12. Active galactic nucleus rotates in midday plane figure (7)
14. Refer back to relative type of energy (7)
15. Pictor hides an extreme solar position (6)
16. Dimmer of pair with me in a brief costume (5)
18. Study renal failure (5)

Answers to February's puzzle

ACROSS

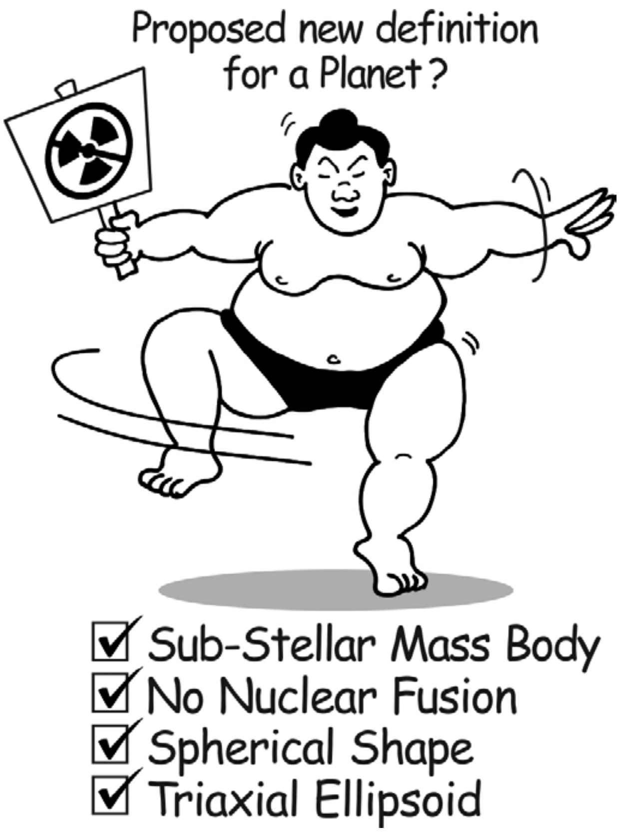
1 DOPPLER EFFECT (anag); **8** BRAGG (garbage-ea; anag); **9** CORONAL (co(ron)al); **10** AVERTED (an(rte)ag); **11** APSIS (anag); **12** PASCAL (2 def); 14 NAKANO (na(KA)no); **17** EPACT (2 def); **19** HOGG-TIE (hog(g)-tie) sorry, I was desperate; **21** ALMANAC (ALMA+NAC); **22** DELOS (2 def); **24** ZODIACAL LIGHT (2-def)

DOWN

1 DOB (2 def); **2** PLANETS (an(N)ag); **3** LIGHT (2 def); **4** RECEDE (2 def); **5** FORNAX A (2 def); **6** ENNIS (Dennis-D); **7** TELESCOPE (anag+cope); **10** ALPHERATZ (anag+p); **13** ANTENNA (anag+); **15** ANTILOG (2 def); **16** PHECDA (anag+d); **18** AIMED (anag); **20** GODEL (anag); **23** SET (2 def)

It's Not All Sirius

by Ted Dunphy

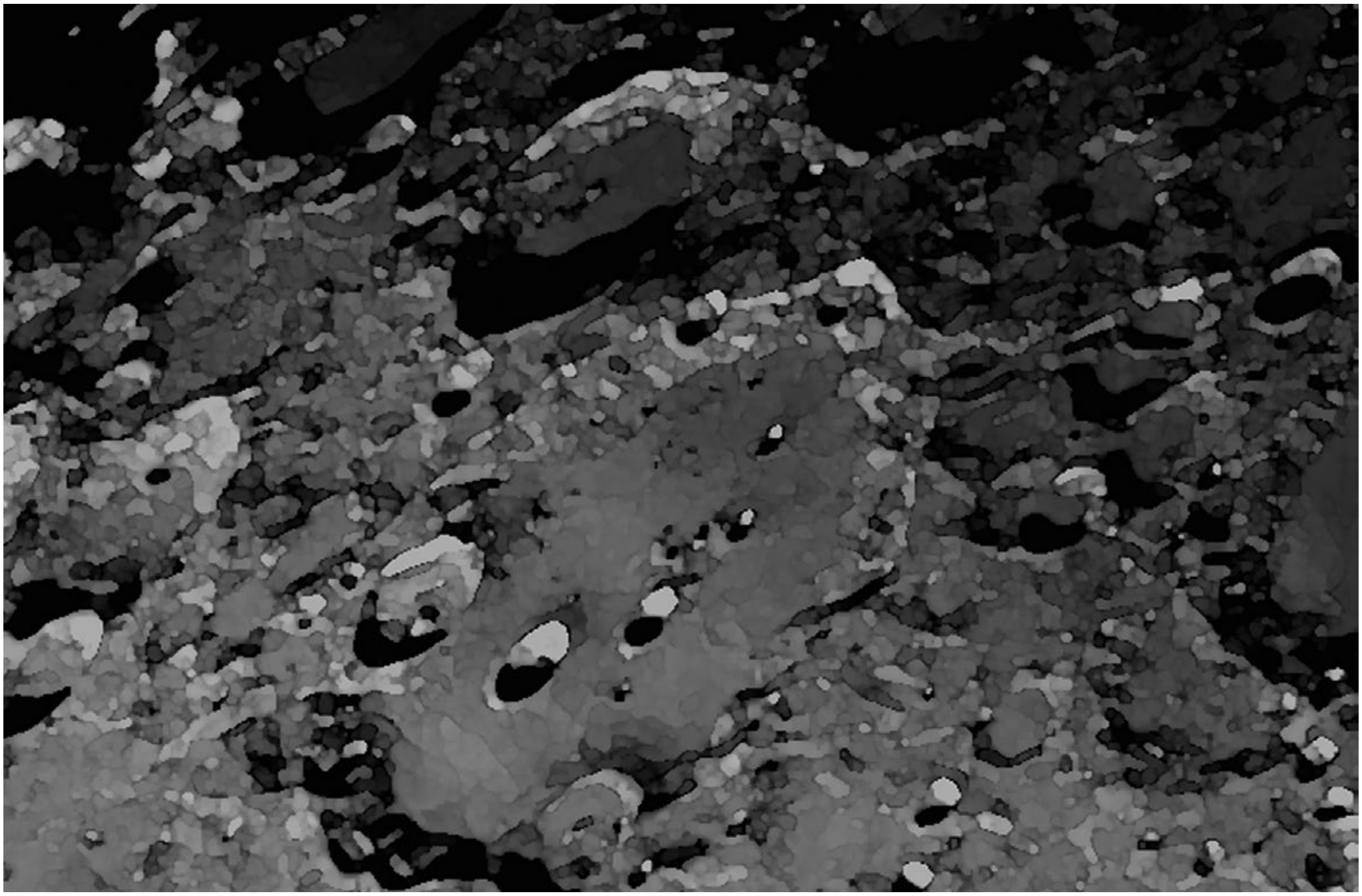


THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

Board of Directors and appointed officers for 2017/2018 | Conseil d'administration et membres attitrés pour 2017/2018

Great Images

by Denis Fell



Denis Fell did this amazing sketch using a bino viewer and two 20mm Plossl eyepieces with a 2x Barlow. He used various techniques, including various pencils, finger and moist sponge smudging, blending, and a dry stiff oil brush for light blending. He also used a stipple technique with different pens and a coarse sponge in India ink, as well as Photoshop.

Journal

Great Images

The dusty Pleiades along with C/2016 R2 (PANSTARRS) are seen here in this image taken by Sheila Wiwchar from Kaleida, Manitoba. She used a Canon 6d and a William Optics Star 71 on an HEQ5 mount taking 5x3min subs at ISO 5000.