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Journal

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PROMOTING ASTRONOMY IN CANADA

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Amateur Astronomers and the *Hubble Space Telescope*

Canadian Guidelines for Outdoor Lighting (CGOL)

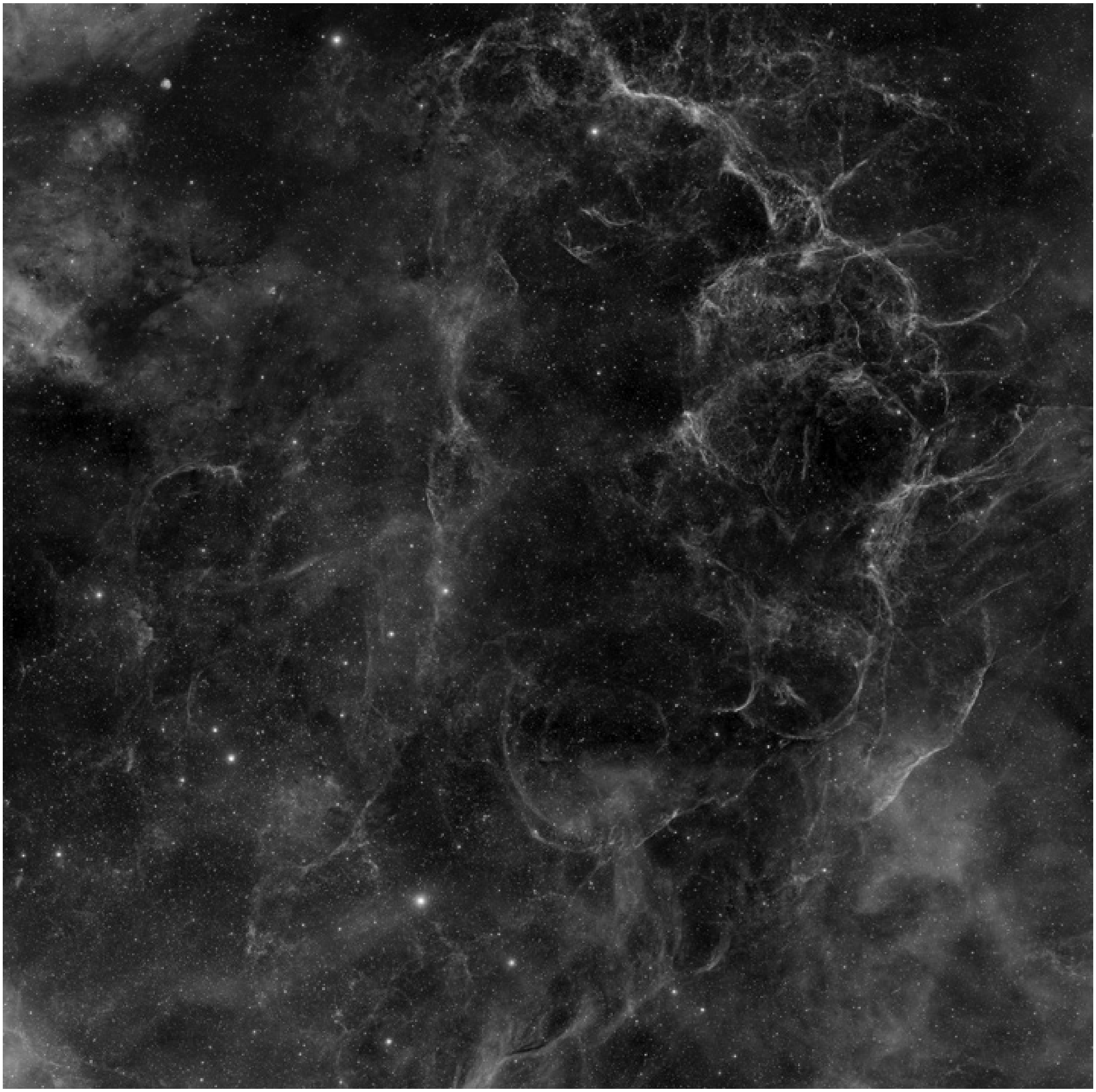
The Planetarium: Linked to War

Caroline Lucretia Herschel, 1750–1848

Gee, Wiz!

The Best of Monochrome.

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



This stunning nine-panel Hα mosaic of the Vela supernova remnant was taken by Malcolm Park from his remote observatory in San Pedro de Atacama, Chile. "The field of view of the camera/scope is about two degrees for a single shot. So, the resulting field of view of the 3 × 3 panel mosaic after processing, with overlap and cropping ends up being 5.1 × 5.1 degrees," Malcolm says. "[There are] 20 × 30-minute subframes per panel, for a total of 10 hours per panel equalling a total of 90 hours imaging time for the whole mosaic." Malcolm used a TEC140 APD with TEC Field Flattener that has a 1,024-mm focal length at f/7 on a 10Micron G2000 mount, and a Moravian G4 16803 CCD.

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Société Royale d'Astronomie du Canada

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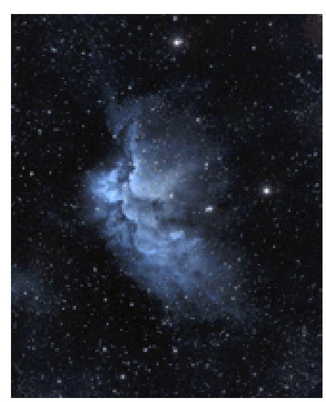

The Wizard Nebula is a popular photographic target for amateur astronomers. Jeff Booth imaged this magical nebula from the North Frontenac Dark Sky site, north of Kingston, Ontario, using OIII, Hα(bi-colour OHH). He used a Sky-Watcher 80 ED on a Celestron CGEM mount, and a ZWO 1600 cooled camera. Each filter was 90 minutes for a total of roughly 3 hours. The final image was processed in PixInsight.

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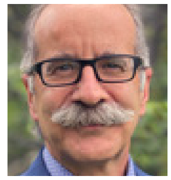
President's Corner



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

Mars. What a fascinating world; one that's been capturing our attention for thousands of years.

Known as *Nergal*, the great hero, the king of conflicts by the Babylonians; *Har Decher*, the Red One by the Egyptians; *Ares* to the Greeks, and *Mars* to the Romans, the God of War to both.

In the 1600s, Galileo, Huygens and Cassini observed Mars telescopically and in 1877 a misinterpretation of Schiaparelli's term *canali* started the canals on Mars/life on Mars speculation. Also, in 1877, Asaph Hall discovered Mars's moons and he named them after the horses of Ares: Phobos (fear) and Deimos (fright), harbingers of things to come perhaps?

Fast forward past Percival Lowell and Orson Welles to the dawn of the Space Age in the 1960s where we saw several failed attempts to get to Mars: five Russian and one American. Finally, there was success with *Mariner 4* in 1965 and *Mariners 6* and *7* in 1969.

This young enthusiast sent a letter along with $1.00 CDN some time in 1970 and received a package in the mail from NASA with information "now available at the Manned Spacecraft Center," including my very own copy of the eight-page Mission Report of *Mariners 6* and *7*, a fascinating report.

With more failures than successes logged—that's 36 failures of 49—Mars continues to be a challenging target for spacecraft. However, the successes have been spectacular. NASA has been at the forefront since 1997, with *Sojourner*, *Spirit*, *Opportunity*, *Curiosity*, and *Perseverance* bringing Mars right into our homes.

The goals of all these missions? To determine if Mars was once habitable, if it could have supported life, as well as trying to better understand the geological history and evolution of Mars. And it's all about the ultimate goal: Preparation for human exploration.

Contrary to its moniker, the God of War is becoming a bastion of international cooperation, too. NASA, ESA, Roscosmos, ISRO, and JAXA have all collaborated in various ways on missions to Mars. And SpaceX, a private company, is also focused on Mars. In fact, CEO Elon Musk is all about getting humans to Mars.

"You want to wake up in the morning and think the future is going to be great—and that's what being a spacefaring civilization is all about," he said. "It's about believing in the future and thinking that the future will be better than the past. And I can't think of anything more exciting than going out there and being among the stars."

How do we get to Mars? It requires technological innovation akin to *Apollo* in 1962, when Kennedy announced that Americans would get to the Moon before the decade was out. All of the aforementioned agencies have launch vehicles that can get to Mars, but when it comes to innovation and disrupting the old-school players, SpaceX redefines expectations. A visit to their website offers the *Falcon Heavy*, a vehicle with 3 launches, 7 landings, and 4 reflown rockets, and an advertised payload capacity of 16,800 kg to Mars. Under the Human Spaceflight tab, SpaceX highlights missions to and from the ISS and offers commercial flights to Earth and Lunar orbit. The road to Mars as SpaceX sees it, will take place aboard Starship. Starship is an innovative spacecraft—that's had some successful launches and not-so-successful landings—that plans to get an Earth-orbit refuel and an on-Mars refuel for the return. It also requires a lot of money to get to Mars, but Musk certainly knows how to do that. Success with PayPal, Tesla, and others finds Musk with an estimated net worth of $209B USD. It all reminds me of Robert Heinlein's *Future History* in a good way, although I may re-read *The Man Who Sold the Moon* sometime soon.

Canadian scientists are actively engaged in numerous projects too, and at the upcoming General Assembly of The Royal Astronomical Society of Canada, you can join in a panel discussion on Mars, moderated by our very own Emilie Lafleche. Emilie is the chair of RASC's Next Generation Committee, and by the time you read this, she will have completed her undergraduate studies at McGill University. We are very proud to announce that Emilie has been accepted as a Ph.D. student at Purdue University where her work will be centred on modelling biologically modulated seasonality in planetary atmospheres, which has important implications for detecting biosignatures and assessing habitability of exoplanets with next-generation space telescopes.

I hope to virtually see you all at the General Assembly where we can continue to discuss Mars and other interesting things. ✶

News Notes / En manchette

Compiled by Jay Anderson

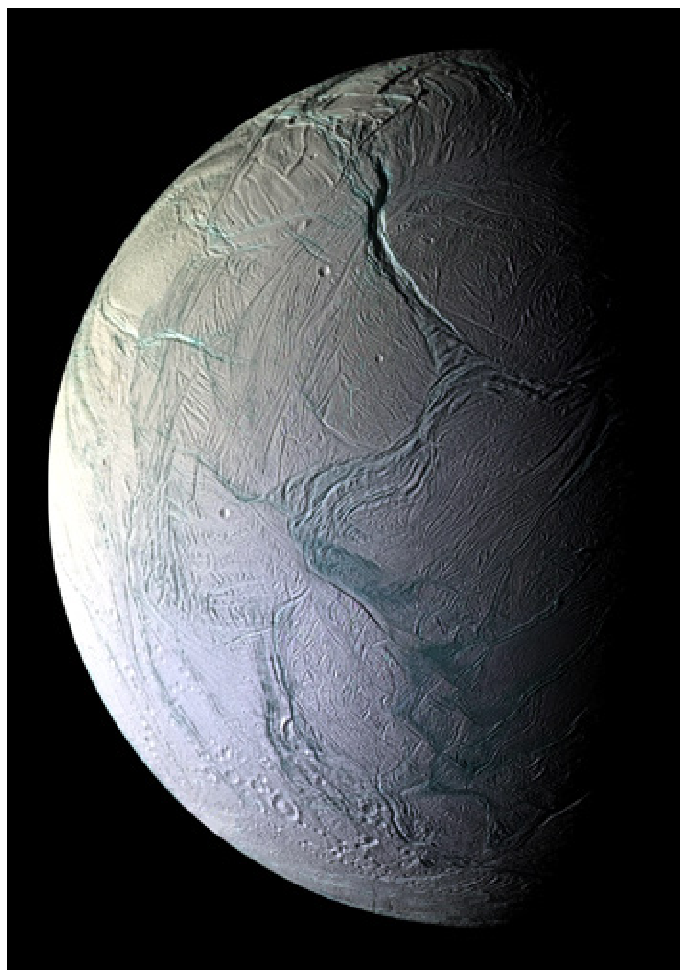
Ocean currents on Enceladus

Buried beneath 20 kilometres of ice, the subsurface ocean of Enceladus—Saturn's sixth-largest moon—appears to be churning with currents akin to those on Earth. The moon is covered in fresh, clear ice, turning it into a bright, reflective body with a surface temperature that lingers around –200 °C.

The new theory, derived from the shape of Enceladus's ice shell, challenges the current thinking that the moon's global ocean is homogenous, apart from some vertical mixing driven by the warmth of the moon's core.

Despite its small size, Enceladus attracted the attention of scientists in 2014 when a flyby of the Cassini spacecraft discovered evidence of its large subsurface ocean and sampled water from geyser-like eruptions that occur through fissures in the ice at the south pole. It is one of the few locations in the Solar System with liquid water (another is Jupiter's moon Europa), making it a target of interest for astrobiologists searching for signs of life.

The ocean on Enceladus is almost entirely unlike Earth's. Earth's ocean is relatively shallow (an average of 3.6 km deep), covers three-quarters of the planet's surface, is warmer at the top from the sun's rays and colder in the depths near the seafloor, and has currents that are affected by wind. Enceladus appears to have a globe-spanning and completely subsur-



In 2008, NASA's Cassini *captured this stunning mosaic as the spacecraft sped away from this geologically active moon of Saturn. Image: NASA/JPL/Space Science Institute* face ocean that is at least 30 km deep and is cooled at the top near the ice shell and warmed at the bottom by heat from the moon's core.

Ice volcanoes near the south pole shoot geyser-like jets of water vapor, molecular hydrogen, other volatiles, and solid material, including sodium chloride crystals and ice particles, into space, at a rate of about 200 kg per second. Over 100 geysers have been identified. Some of the water vapour falls back as "snow"; the rest escapes, and supplies most of the material making up Saturn's E ring.

Despite thermal differences between Earth's oceans and that on Enceladus, Caltech graduate student Ana Lobo suggests that oceans on Enceladus have currents akin to those on our planet. The work builds on measurements by Cassini as well as the research of Andrew Thompson, professor of environmental science and engineering, who has been studying the way that ice and water interact to drive ocean mixing around Antarctica. Lobo and Thompson collaborated on the work with Steven Vance and Saikiran Tharimena of the Jet Propulsion Laboratory, which Caltech manages for NASA.

The oceans of Enceladus and Earth share one important characteristic: they are salty. And as shown by findings published in Nature Geoscience on March 25, variations in salinity could serve as drivers of the ocean circulation on Enceladus, much as they do in Earth's Southern Ocean, which surrounds Antarctica.

Gravitational measurements and heat calculations from Cassini had already revealed that the ice shell is thinner at the poles than at the equator. These regions of thin ice are likely associated with melting and regions of thick ice at the equator with freezing, Thompson said. This affects the ocean currents because when salty water freezes, it releases the salts and makes the surrounding water heavier, causing it to sink. The opposite happens in regions of melt, giving rise to a circulation between the two regimes.

"Knowing the distribution of ice allows us to place constraints on circulation patterns," Lobo explained.

An idealized computer model, based on Thompson's studies of Antarctica, suggests that the regions of freezing and melting, identified by the ice structure, would be connected by the ocean currents. This would create a pole-to-equator circulation that influences the distribution of heat and nutrients.

"Understanding which regions of the subsurface ocean might be the most hospitable to life as we know it could one day inform efforts to search for signs of life," Thompson said.

Compiled with material provided by Caltech.

Space isn't as dark anymore

Scientists reported new research results suggesting that artificial objects in orbit around the Earth are brightening night skies on our planet significantly more than previously understood.

The research, accepted for publication in Monthly Notices of the Royal Astronomical Society: Letters, finds that the number of objects orbiting Earth could elevate the overall brightness of the night sky by more than 10 percent above natural light levels across a large part of the planet. This would exceed a threshold that astronomers set over 40 years ago for considering a location "light polluted."

"Our primary motivation was to estimate the potential contribution to night sky brightness from external sources, such as space objects in Earth's orbit," said Miroslav Kocifaj of the Slovak Academy of Sciences and Comenius University in Slovakia, who led the study. "We expected the sky brightness increase would be marginal, if any, but our first theoretical estimates have proved extremely surprising and thus encouraged us to report our results promptly."

The work is the first to consider the overall impact of space objects on the night sky rather than the effect of individual satellites and space debris affecting astronomers' images of the night sky. The team of researchers, based at institutions in Slovakia, Spain, and the U.S., modelled the space objects' contribution to the overall brightness of the night sky, using the known distributions of the sizes and brightnesses of the objects as inputs to the model.

The study includes both functioning satellites as well as assorted debris such as spent rocket stages. While telescopes and sensitive cameras often resolve space objects as discrete points of light, low-resolution detectors of light such as the human eye see only the combined effect of many such objects. The effect is an overall increase in the diffuse brightness of the night sky, potentially obscuring sights such as the glowing clouds of stars in the Milky Way, as seen away from the light pollution of cities.

"Unlike ground-based light pollution, this kind of artificial light in the night sky can be seen across a large part of the Earth's surface," explained John Barentine, Director of Public Policy for the International Dark-Sky Association and a study co-author. "Astronomers build observatories far from city lights to seek dark skies, but this form of light pollution has a much larger geographical reach."

Astronomers have expressed unease in recent years about the growing number of objects orbiting the planet, particularly large fleets of communications satellites known informally as "mega-constellations." At the beginning or the end of the astronomical night, when the Sun is at a declination of

–18° with respect to the horizon, the Earth's shadow reaches 328 km above the observer, a height that has relatively few satellites. The authors estimate that the current suite of satellites contribute 24.5 magnitudes per square arcsecond to the zenith sky brightness at the end or beginning of astronomical twilight, about a 10 percent increase in the natural sky background illumination; the contribution is expected to increase to 24 magnitudes per square arcsecond by 2030.

In addition to crowding the night sky with more moving sources of artificial light, the arrival of this technology increases the probability of collisions among satellites or between satellites and other objects, generating further debris. Recent reports sponsored by the U.S. National Science Foundation and the United Nations Office for Outer Space Affairs identified mega-constellations as a threat to the continued utility of astronomy facilities on the ground and in low-Earth orbit. In the U.K., the Royal Astronomical Society has established several working groups to understand the impact of mega-constellations on optical and radio astronomical facilities used by scientists.

The results published imply a further brightening of the night sky proportional to the number of new satellites launched and their optical characteristics in orbit. Satellite operators like SpaceX have recently worked to lower the brightness of their spacecraft through design changes. Despite these mitigating efforts though, the collective effect of a sharp increase in the number of orbiting objects stands to change the experience of the night sky for many across the globe.

The researchers hope that their work will change the nature of the ongoing dialogue between satellite operators and astronomers concerning how best to manage the orbital space around the Earth.

"Our results imply that many more people than just astronomers stand to lose access to pristine night skies," Barentine said. "This paper may really change the nature of that conversation."

Compiled with material provided by the Royal Astronomical Society.

Interstellar Comet Borisov carries relic of birthplace

New observations with the European Southern Observatory's Very Large Telescope (ESO's VLT) indicate that the rogue comet 2I/Borisov, which is only the second detected interstellar visitor to our Solar System, is one of the most pristine ever observed. Astronomers suspect that the comet,

Figure 2 — A platoon of Elon Musk's Starlink satellites crosses Manitoba's dawn sky on March 14. Image: Jay Anderson

which flew by the Sun in 2019, most likely never passed close to a star, making it an undisturbed relic of the cloud of gas and dust it formed from.

2I/Borisov was discovered by amateur astronomer Gennady Borisov in August 2019 and was confirmed to have come from beyond the Solar System a few weeks later.

"2I/Borisov could represent the first truly pristine comet ever observed," said Stefano Bagnulo of the Armagh Observatory and Planetarium, Northern Ireland, UK, who led the new study published in *Nature Communications*.

Bagnulo and his colleagues used ESO's VLT to study 2I/Borisov in detail by measuring the extent to which the light reflected from the comet is polarized (that is, the extent to which its light waves oscillate along a particular angle). Polarization in comets is related to the amount of dust in their coma, particularly the dust-to-gas ratio. Since this technique is regularly used to study comets and other small bodies of our Solar System, it allowed the team to compare the interstellar visitor with local comets. More information can be wrung from polarization measures by watching how it changes as the comet moves through its orbit, since the emission of material from a comet body is related to its heating and thus the distance from the Sun.

The team found that 2I/Borisov has polarimetric properties distinct from those of Solar System comets with the exception of Comet Hale–Bopp. Comet Hale–Bopp received much public interest in the late 1990s as a result of being easily visible to the naked eye, and also because it was one of the most pristine comets astronomers had ever seen. Prior to its last passage, Hale–Bopp is thought to have passed by our Sun only once and had therefore barely been affected by solar wind and radiation. This means it was pristine, having a composition very similar to that of the cloud of gas and dust it—and the rest of the Solar System—formed from some 4.5 billion years ago.

By analyzing the polarization together with the colour of the comet to gather clues on its composition, the team concluded that 2I/Borisov is in fact even more pristine than Hale–Bopp. This means it carries untarnished signatures of the cloud of gas and dust from which it formed.

"The fact that the two comets are remarkably similar suggests that the environment in which 2I/Borisov originated is not so different in composition from the environment in the early Solar System," said Alberto Cellino, a co-author of the study, from the Astrophysical Observatory of Torino, National Institute for Astrophysics (INAF), Italy.

"The arrival of 2I/Borisov from interstellar space represented the first opportunity to study the composition of a comet from another planetary system and check if the material that comes from this comet is somehow different from our native variety," explained Ludmilla Kolokolova of the University of Maryland in the U.S., who was involved in the research.

Even without a space mission, astronomers can use Earth's many telescopes to gain insight into the different properties of rogue comets like 2I/Borisov.

"Imagine how lucky we were that a comet from a system light-years away simply took a trip to our doorstep by chance," said Bin Yang, an astronomer at ESO in Chile, who also took advantage of 2I/Borisov's passage through our Solar System to study this mysterious comet.

In a different study, Bin Yang, an astronomer at ESO in Chile, and her team used data from the Atacama Large Millimetre/submillimetre Array (ALMA), as well as from ESO's VLT, to study 2I/Borisov's dust grains to gather clues about the comet's birth and conditions in its home system. They discovered that 2I/Borisov's coma contains compact pebbles: grains about one millimetre in size or larger. In addition, they noted that the relative amounts of carbon monoxide and water in the comet changed drastically as it neared the Sun. The team said this indicates that the comet is made up of materials that formed in different places in its planetary system, from near its star to further out, perhaps because of the existence of giant planets, whose strong gravity stirs material in the system. Astronomers believe that a similar process occurred early in the life of our Solar System.

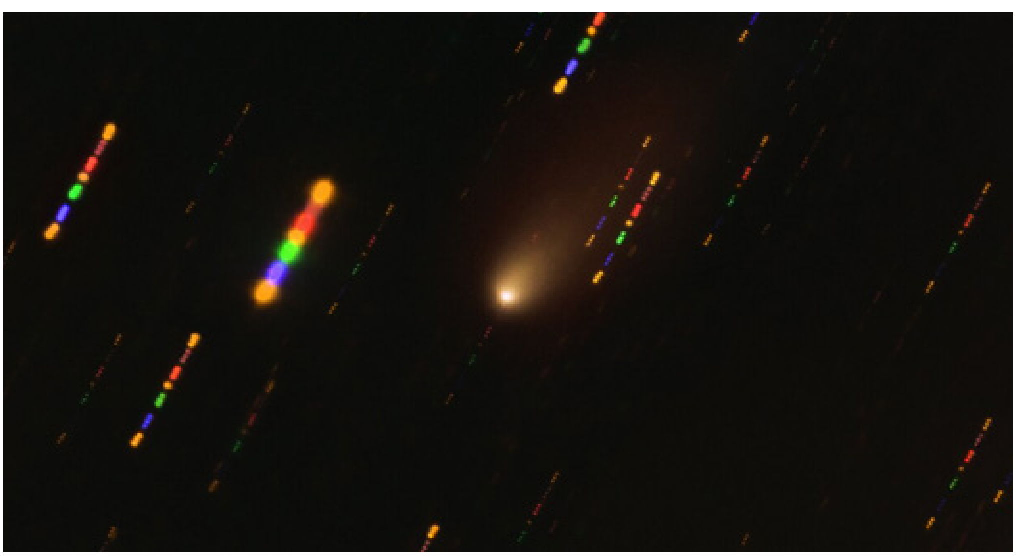


Figure 3 — Image of Comet 2I/Borisov captured by the VLT. Image: ESO.

Compiled with material supplied by the ESO. ✷

Feature Articles / Articles de fond

Amateur Astronomers and the *Hubble Space Telescope*

by Christopher Gainor, Victoria Centre
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Abstract

While the history of space telescopes goes back to the early days of the space age, it entered a new phase in 1990 with the launch of the *Hubble Space Telescope*. Like their professional counterparts, amateur astronomers have been interested in observing from space, and they got their first chance when the director of the Space Telescope Science Institute, Riccardo Giacconi, offered observing time on HST to amateurs in 1986. Twelve observing projects from amateurs got time on HST from 1992 to 1997. This article examines the history of this unique initiative and the reasons it came to an end. Amateur astronomers have since been able to access HST observations online from the archive of *Hubble* observations, part of a growing trend to astronomical research using archival resources.

Introduction

The *Hubble Space Telescope*, which is still operating more than three decades after it was launched into Earth orbit on 1990 April 24, remains the best known of the many space telescopes put into orbit starting in the 1960s. HST marked an advance from its predecessors with its 2.4-m Ritchey- Chrétien reflector that operates in visible, ultraviolet, and near infrared wavelengths, making it a far bigger and more sophisticated observatory than any space telescope that had come before it. The key to HST's longevity was a series of five servicing missions flown by astronauts on the U.S. Space Shuttle between 1993 and 2009 that replaced, updated, and repaired instruments and systems on HST. The large amount of data and many images produced by HST in its lifetime have vastly increased our knowledge of the universe.[1]

Figure 1 — An IMAX camera in the rear of Discovery*'s payload bay obtained this image of the* Hubble Space Telescope *moments after its release into space by the* Space Shuttle *Remote Manipulator System on 1990 April 25 during the STS-31 mission. (NASA)*

Astronomers from anywhere can apply for observing time on HST, but requests for observations have always far exceeded available observing time, so this time is allocated only after a rigorous selection process. Amateur astronomers, like professionals, have dreamed of the day when they could make observations from above the Earth's atmosphere. For a few years in the 1990s, that dream became a reality when observing time on *Hubble* was specifically set aside for amateur astronomers. This article tells the story of that observing program and why it came to an end after only a few years.

Background

The idea of putting telescopes into space and above the effects of the Earth's atmosphere, which blocks many wavelengths of light, and distorts visible light, goes back to the 1920s. U.S. astronomer Lyman Spitzer wrote the first detailed proposal for space telescopes in 1946, and small specialized space telescopes began to fly in the 1960s. Years of lobbying by professional astronomers paid off in 1977, when the National Aeronautics and Space Administration (NASA) obtained formal approval from the U.S. Congress to begin building a large space telescope that would operate in various wavelengths, including visible light. The European Space Agency (ESA) signed on as a partner in the program the same year, and the telescope was named in 1983 after famed American astronomer Edwin P. Hubble. HST was designed to carry five instruments at a time, all of which could be changed out by shuttle astronauts. HST's fine guidance sensors act as a sixth instrument based on astrometric measurements they make. While NASA's Marshall Space Flight Center in Huntsville, Alabama, was responsible for building HST, responsibility for *Hubble*'s operations passed after launch to the NASA Goddard Space Flight Center in Greenbelt, Maryland. NASA contracted HST's science operations to the Space Telescope Science Institute (STScI) in Baltimore, Maryland, which was created in 1981 by the Association of Universities for Research in Astronomy (AURA) to carry out that job.[2]

Before HST flew, amateur astronomers also were dreaming of using a space telescope. In 1979, a group of students at Rensselaer Polytechnic Institute in Troy, New York, began work on the *Amateur Space Telescope*, which would be made from off-the-shelf equipment and launched from the *Space Shuttle*. Their plan, which was publicized in *Astronomy* and *Sky & Telescope* magazines, contemplated an 80-kg satellite built around a 45-cm Ritchey-Chrétien telescope. While work soon began on building the satellite, it apparently did not continue beyond the middle of the decade.[3]

The HST Amateur Program

HST was being built at that time, and a number of people at NASA, Congress, and STScI discussed giving HST observing time to amateur astronomers. STScI's founding director Riccardo Giacconi, whose earlier scientific work on the Einstein X-ray Observatory had benefitted from observations made in visible wavelengths by amateurs of bright X-ray objects, became a driving force behind the idea. In December 1985, Giacconi invited leaders from seven U.S. amateur astronomy organizations to meet with him at the Institute. They were Janet A. Mattei, director of the American Association of Variable Star Observers; John E. Westfall, acting director of the Association of Lunar and Planetary Observers; George Ellis, president of the Astronomical League; Jesse E. Eichenlaub, president of the Independent Space Research Group; Gerald Persha of International Amateur-Professional Photoelectric Photometry; David W. Dunham, president of the International Occultation Timing Association; and Stephen J. Edberg, president of the Western Amateur Astronomers.

The seven leaders had already formed the *Hubble Space Telescope* Amateur Astronomers Working Group (AAWG) with Edberg as chair, and they created a plan for a peer-review system using amateur astronomers in the participating organizations that they presented to Giacconi at the meeting. At the time, HST was slated to be launched aboard a *Space Shuttle* in 1986, but the loss of the *Space Shuttle Challenger* in January 1986 led to a series of postponements to HST's launch that extended into 1990.

In spite of this setback, Giacconi soon went public with the idea of *Hubble* observations by amateur astronomers. On 1986 August 7, at the Astronomical League meeting in Baltimore, he announced that the plan would go ahead, with up to 20 hours of observing time in HST's first observing cycle. The director of STScI has direct control of up to 10 percent of HST's observing time, and Giacconi set aside time for the amateur astronomers from his director's discretionary time. "I expect that amateur astronomers will use the *Hubble Space Telescope* to ask refreshingly new questions and that your findings will, as they always have, make a real contribution to the advancement of astronomy. Rather than emphasize the differences between professionals and amateurs in a field such as astronomy where the distinction is so thin, let us emphasize instead our common thirst for knowledge, our love of nature, and our appreciation of the beauty and mystery of the universe," Giacconi told the meeting.[4]

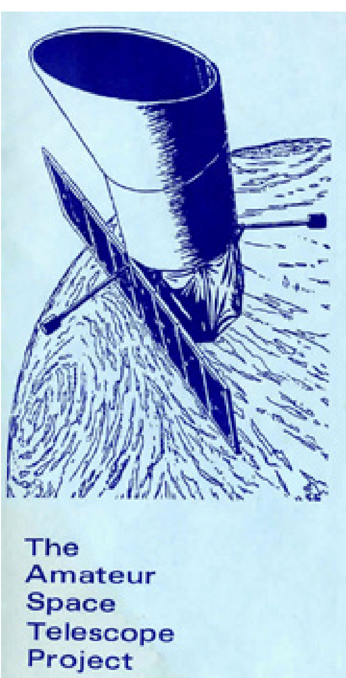

Figure 2 — Cover of leaflet from the Independent Space Research Group, Troy, New York, circa 1980 (Drew Ex Machina blog).

Figure 3 — Riccardo Giacconi, the first director of the Space Telescope Science Institute. (STScI)

STScI issued a *Hubble Space Telescope* Handbook for Amateurs in October that provided an overview of HST and the arrangements for amateur access to telescope time. The Handbook went out to interested amateurs starting in December with application forms for time on HST. While the original application deadline was set for 1987 March 31 to permit observations to take place during HST's first observing cycle after its launch, the application deadline was soon pushed back three months. In spite of a report that the deadline had been pushed back further as HST's launch date was further delayed, 1987 June 30 became the effective deadline for initial applications.[5]

While most observation proposals on HST were open to residents of any country, proposals for the amateur time were open only to U.S. citizens. All proposals had to spell out what the observations involved, including the targets being observed and time required for the observations, and the specific instrument on HST and instrument mode that were required for the observations. Proposals had to come with a bibliography, and explain the scientific rationale for the observations, along with an explanation of why HST with its unique capabilities was required to make those observations. Applications had to include plans for data analysis and publication of the findings. Anyone applying for the amateur time on HST had to have a thorough knowledge of their research topic and also of HST and its instruments. Applicants whose proposals were approved for further consideration then had to prepare a more detailed proposal that one astronomer compared in detail and length to a university grant proposal.[6]

HST Observations

The working group evaluated the amateurs' proposals based on scientific and educational merit, technical feasibility, the need

Figure 4 — Amateur astronomers chosen for HST observations in the second amateur cycle in 1993. Front Row: James Secosky, Rukmini Sichitiu, George Lewycky, and Nancy Cox. Middle Row: Lewis Thomas and STScI Director Riccardo Giacconi. Back Row: Benjamin Weiss, Winslow Burleson, Karl Hricko, Harald Schenk, and Joseph Mitterando. (STScI)

for the unique capabilities of HST, and time demands on HST, and then passed them to Giacconi for final time allocation. Each successful principal investigator was funded to visit STScI and were entitled to assistance from institute scientists. They were granted proprietary rights to their data for one year and were expected to write a paper on their results for a peer-reviewed journal in a similar manner to professional astronomers.[7]

In 1989, Giacconi announced that five amateur programs would be given time on HST. The five selected amateur astronomers were due to obtain their observations during HST's first observing cycle approximately a year following its launch, which took place on 1990 April 24 on board the Space Shuttle *Discovery*.[8]

Eric J. Chaisson, who, as head of the institute's Public Affairs Office, promoted the program, reported that many of the 200 amateur applications from 500 people for the first round showed original thinking, while a few were best described as "ludicrous." The program met resistance from some professional astronomers who were concerned about limited time availability on HST, he said, and NASA took some time to warm to it. "In return, the chosen amateur astronomers became among the best ambassadors for the *Hubble* project."[9]

A few weeks after HST was launched and deployed, its first observations showed the effects of spherical aberration on HST's main mirror. This unexpected problem and HST's lengthy commissioning process caused the first round of amateur observations to be postponed until 1992, and one of the five planned observing proposals was cancelled because spherical aberration would make a successful observation unlikely.

Finally at 4:45 a.m. EDT on 1992 April 20, 45-year-old high-school science teacher James J. Secosky of Bloomfield, New York, became the first amateur astronomer to make an observation using HST. After having proposed a number of Solar System observations, his proposal to observe the Jovian moon Io was selected. Secosky was present at STScI when his initial observation was made, and it was repeated on two later dates. While they did not turn up the possible evaporation of frost on Io that he sought, his observations added to others that suggested that the volcanic moon's surface was made up mainly of sulphur and sulphur dioxide.[10] His observations were followed by those of computer scientist Raymond E. Sterner II of Woodbine, Maryland, who was studying luminous arcs in a galactic cluster; Theodore Hewitt, a museum technician from Berkeley, California, who sought images of a nova outburst, and electrical engineer Peter J. Kandefer of New Hartford, Connecticut, who was seeking spectral evidence of a magnetic field at the variable star Epsilon Ursae Majoris.[11]

Ana M. Larson of Seattle won time on HST on Amateur Cycle 1 for an ambitious proposal to search for evidence of planets around other stars. Since her observations would be at the edge of HST's capabilities, HST's spherical aberration problem caused her observations to be cancelled. Larson had previously taken astronomy courses after having worked in business and then raising her children, and she was so inspired by her *Hubble* experience, including a visit to STScI, that it served as a "kickstarter" for a career in astronomy. Larson earned a Ph.D. in Astronomy from the University of Victoria and became a lecturer in astronomy at the University of Washington. She has carried out research on exoplanets in major observatories including the Canada-France-Hawaii Telescope.[12]

In September 1992, STScI announced that another five amateur proposals would get telescope time. The investigators included civil engineer Harald Schenk of Sheboygan, Wisconsin, who worked together with James Secosky to make observations of asteroids, looking for outgassing similar to that seen for comets; 19-year-old student Benjamin P. Weiss of Amherst College, Massachusetts, who was exploring the dynamics of binary asteroids; computer programmer/analyst George Lewycky of Milltown, New Jersey, making observations of the atmosphere of Titan; high school teacher Karl J. Hricko of Edison, New Jersey, observing quasars, with co-investigators high school teacher Lewis Thomas and high school student Joseph Mitterando; and nurse Nancy K. Cox of San Francisco, California, who was making spectroscopic observations of star formation in the Lagoon Nebula, M8. These investigations got telescope time in 1993 in HST Amateur Cycle 2.[13]

George Lewycky, who was looking for evidence of formaldehyde on Titan as a possible precursor to DNA formation, called his experience with HST "amazing," and something that involved a huge amount of work. During his extensive research supporting his observations, he communicated with many scientists, including Carl Sagan and Nobel laureate

Gerhard Herzberg. “All were very cooperating, inspirational and generous of their time and resources,” Lewycky recalled. Although most investigators are not present at STScI when their observations were made, Lewycky was there when they took place, after many postponements, on 1993 September 21. He became something of a celebrity, with appearances on local television and national astronomy publications, and with his experience on *Hubble*, Lewycky found himself in the surprising position of assisting professional astronomers with their own observations. His observations, made by HST’s Wide Field/Planetary Camera, were not affected by HST’s spherical aberration, but trying to distinguish between spectral lines originating from the Sun and Titan itself made it difficult to complete the measurements he hoped to make.[14]

These second-cycle observations took place against the background of several changes at STScI. At the end of 1992, Giacconi stepped down as Institute Director to take another post. Chaisson had left earlier that year, and Ray Villard, who generated a great deal of publicity for the program, was transferred to a different job. In December 1993, the first *Space Shuttle* servicing mission flew to *Hubble*, replaced HST’s main camera, and installed a new instrument, changes that effectively overcame HST’s spherical aberration problem but vastly increased demand from professional astronomers for observing time on the telescope. Despite the success of the servicing mission, the Institute’s new director, Robert Williams, had to deal with major budget cuts at the Institute that included staff reductions.[15]

After the interruption for the servicing mission, three more amateur proposals were selected in 1994. William R. Alexander, a chemist from Huntington, West Virginia, asked to conduct a spectroscopic search for deuterium in the interstellar medium; computer programmer R. Dennis Tye from San Francisco sought to search for absorption lines in a galaxy associated with a quasar; and chemist James P. Flood of Scotch Plains, New Jersey, whose proposal involved imaging of a Seyfert galaxy. Alexander’s observations were made in 1994 and 1995, and Tye’s in 1996. Flood’s observation, which was carried out on 1997 August 14, after the second shuttle servicing mission to HST, was the last under the amateur program. The amateur program saw a total of 12 observing proposals from amateurs carried out on HST.[16]

Figure 5 — George Lewycky (right) looks on as Space Telescope Science Institute staff conduct his observations of Titan with HST, 1993 September 21. (George Lewycky)

Two completed observing programs in the first two cycles were affected by spherical aberration, and others resulted in ambiguous results for varying reasons, some but not all involving the quality of data obtained by HST. As recounted by *Sky & Telescope*’s Stephen James O’Meara in 1997, William Alexander’s observations with HST’s Goddard High Resolution Spectrograph successfully measured the abundance of deuterium and also found “hydrogen walls” around the stars Epsilon Indi and Lambda Andromedae similar to a wall found around the Sun.[17]

The End of the Program

By the time HST began making observations in 1996 and 1997 for the last two of the three amateur observing projects selected in the third round, the program was winding down. On 1995 November 6, the Institute’s second director, Robert Williams, cancelled the program, effective with the completion of the final approved amateur proposal in 1997. The cancellation of the program kept its total cost at $31,000, and by the time the program was cancelled, the final amateur observers were working with volunteer professionals. Another promising amateur proposal was not given HST time due to scheduling issues after astronomer Anne Kinney, who had responsibility for STScI’s education and public outreach programs at the time, warned that the Institute “is not able to support the amateurs at the level which they require.” Williams agreed that staff cuts at the Institute in 1995 and additional work needed to support the upcoming second shuttle servicing mission meant “that we no longer have the staff” to be able to support amateurs “both before and after the observations.”[18]

The reasoning behind the cancellation may have had more to do with the falling interest among amateurs in using HST. In his comprehensive 1997 article on the end of the program, Stephen James O’Meara of *Sky & Telescope* noted that, out of the estimated 300,000 amateur astronomers in the United States at the time, the 200 proposals from 500 amateur astronomers for the first round was not a large number. The final round saw only 30 proposals. Stephen J. Edberg, chair of the Amateur Astronomers Working Group, blamed a lack of publicity for these low numbers, along with the large amount of work required for each proposal. Despite their good ideas, Edberg asked: “was it realistic to expect that amateurs could use a professional instrument without outside help? The answer is no!” For his part, O’Meara noted that only 3 of the 13 selected amateur programs were able to use HST with its corrected optics, a factor that limited its success.[19]

All astronomers who seek and obtain HST observing time have had to deal with a gigantic amount of paperwork and other demands that journalist Stephen Cole described as "a major culture shock," even for professional astronomers who had previously worked at ground-based observatories. This was related to the great expense of HST and the fact that demand for observing time vastly exceeded available time. The paper burden for professional astronomers was especially great in the first decade of HST operations until online tools that streamlined the application process for HST became available starting in 2003. Cole estimated that an average observing proposal for HST in the early 1990s involved four scientists and two person-years of effort.[20] While the amount of work required of the amateur astronomers was not as great, it was comparable. George Lewycky estimated that his research for his proposal took seven months, and involved referring to 500 books and using 15 government and university libraries around the United States, a daunting task in those days before the internet. "I would look around for other amateurs also to spread out the workload," he said in answer to a question about whether he would make those observations again. He also noted that he had to do this research while holding down his computer job.[21] There is little doubt that the amount of work required to win observing time on HST limited the number of serious applications from amateur astronomers.

The *Hubble* Archive

When the *Hubble* amateur program came to an end in 1997, Williams expressed the hope that amateur astronomers might be able to make use of HST in different ways in the future since most HST data were starting to become available to the public on the internet.[22] Although the Institute never reinstituted a program aimed at amateur astronomers, Williams's hope has become a reality, since the Institute's archive of HST archive has reopened HST to amateur astronomers.

HST was launched at a time when observatories were shifting from photographic film to digital imaging, and large numbers of amateur astronomers followed, starting at the end of the century. In 1990, many people were using email and some basic data-transfer protocols on the primitive personal computers available. Applications for HST time were made on paper, and the data were generally shared on tape or discs that had to be mailed to users. The internet as we came to know it, complete with websites and graphic interfaces, wasn't available to large numbers of users until the second half of the 1990s, just as the HST amateur astronomy program was winding up. STScI did a great deal of work to create the first archive of HST data, and starting in 1996, work got underway to make the data available online. By 1998, all the data were thus available, and the archive grew to encompass observations from other space telescopes and observatories. Since 2012, the archive has been known as the Barbara A. Milkuski Archive for Space Telescopes or MAST. By then, the number of academic articles using archived *Hubble* data exceeded articles related to those written by investigators who had made their own observations with HST. Widespread use of archived *Hubble* data is enhanced since STScI performs an important service by calibrating and processing all HST data so that it can be immediately put to use. HST data in MAST are available to astronomers and the public in the FITS (Flexible Image Transport System) format that is widely used by astronomers.[23]

The author, in his study of HST operations, has argued that MAST "in effect became an observatory of its own that will continue to be used long after HST itself has ceased to function." In recent years, more HST observing time has been given over to large observing programs designed to place certain types of observations in the archive for future reference. For example, observations in certain ultraviolet frequencies will no longer be made once HST stops operating, so *Hubble* is making observations of this type from various parts of the sky to be placed in the archive for future reference.[24]

For many years, STScI has worked to inform amateur astronomers and other interested members of the public about the work of HST. For example, Ray Villard and Zoltan Levay of STScI wrote an article for *Sky & Telescope* in 2002, when large numbers of amateur astronomers were moving to digital imaging, explaining how the Institute processes images for public release. The STScI's Hubblesite.org website includes a section to assist amateur image processors making use of HST image data.[25]

In recent years, growing numbers of the public have taken to processing raw data from NASA spacecraft, notably those exploring our Solar System, and others, including HST. [26] Press releases from STScI and NASA on *Hubble*'s scientific accomplishments have sometimes spoken of amateur contributions. For example, in 2013, astroimager Robert Gendler, a physician by profession, took HST imagery of the M106 spiral galaxy from the archive and combined it with images he and fellow astroimager Jay GaBany obtained of the galaxy to create an image with help from Institute personnel.[27] A 2020 news release highlighted the contribution made by amateur astronomer and artist Judy Schmidt of Modesto, California, to our knowledge of black holes through her own reprocessing of HST images from the archive.[28]

Private citizens who are not skilled in imagery are also getting involved in helping HST with its scientific work through what are known as citizen science programs on the internet. For example, large numbers of astronomy enthusiasts helped astronomers involved in the Panchromatic Hubble Andromeda Treasury (PHAT) search for star clusters in a series of images that resolved more than 100 million stars in the Andromeda Galaxy. The PHAT images were obtained during two months of observations using HST's Advanced Camera for Surveys and Wide Field Camera 3. Julianne Dalcanton of the University of Washington, who led the PHAT program, said her group had mixed results using students to search for and classify star clusters in the PHAT images. Chris Lintott, the

Oxford astrophysicist and host of the BBC television show *Sky at Night*, suggested that the PHAT team crowdsource this work through Zooniverse, an organization he had founded to promote citizen science. More than 10,000 volunteers helped out in the first round of image classifications and 5,000 in the second round. "People did such an amazing job," Dalcanton said.[29] Other Zooniverse citizen science projects related to HST have included the Galaxy Zoo project and the *Hubble* Hot Stars project, which both involved members of the public in classifying objects from HST and other observatories.[30]

Conclusion

The growing availability of astronomical data through digital archives, not only at STScI, but from astronomical observatories and surveys around the world, will allow many professionals and growing numbers of amateur astronomers to carry out research from their laptop computers linked to these data banks. New generations of telescopes on the ground and in space will have the capability to image much vaster areas of the sky than HST and other present-day observatories.[31]

Some amateur astronomers hope to equip their instruments in the future like some major observatories do today with adaptive optics, which compensate for the turbulence in Earth's atmosphere. These new enhancements for optics, which are highly complex and expensive, are still restricted to visible wavelengths, and they have other shortcomings relative to telescopes observing from space.[32] So that leaves amateurs with an incentive to build and operate their own space telescopes, as was considered in the early 1980s. It can be argued that Canadians have helped blaze the trail toward this possibility. The Canadian MOST (*Microvariability and Oscillations of STars*) space telescope, which was not much bigger than a suitcase, carried a 15-cm Maksutov telescope, weighed 53 kg and cost only about C$10 million. MOST delivered quality science starting with its launch in 2003. After government funding was cut in 2014, the microsatellite, which was nicknamed the *Humble Space Telescope*, was purchased by a private company and continued operating for another five years.[33] Amateur radio satellites have become almost commonplace, and MOST may point the way to the first amateur space telescope.

Thanks to the vision of Riccardo Giacconi, first director of the Space Telescope Science Institute, a small number of amateur astronomers got their chance to try their hand at space astronomy with the *Hubble Space Telescope* in its early years from 1992 to 1997. The program didn't last for a number of reasons, including the spherical aberration that affected HST's early observations, government cutbacks that affected HST budgets, and lower than expected interest among America's amateur astronomers. For understandable reasons, the application process for making observations on HST is extremely difficult. It could be argued that the amateur program might have done better with more publicity and the streamlined application process and improved imaging processing technologies that came with wide adoption of home computers with graphic capabilities and the internet starting in the late 1990s. The HST amateur observations did showcase the capabilities of amateur astronomers, and made small contributions to our knowledge of the Universe. Through various means, amateur astronomers will be able to advance our knowledge of the Universe again in the future. ✷

Hubble Space Telescope Amateur Observers, 1992-1997

Investigator, State	Title	Observation
James J. Secosky, NY	Sulfur Dioxide Concentration & Brightening Following Eclipses of Io	1992
Raymond E. Sterner, MD	Imaging the Arc in the Galaxy Cluster 2244-78	1992
Peter J. Kandefer, CT	Magnetic Field of a Peculiar Type-A Variable Star	1992
John Hewitt, CA	Search for the Oort Comet Cloud UV Emission, Suitable Nova of Opportunity	1992
Ana M. Larson, WA	Detection of Collapsing Extrasolar Protoplanets	Cancelled
Harald Schenk, WI James J. Secosky, NY	Transition Comets: UV Search for OH	1993
Benjamin P. Weiss, MA	Investigation of the Dynamics of Binary Asteroids	1993
George R. Lewycky, NJ	Titan's Atmosphere and Evolution Through Disk-Resolved Spectroscopy	1993
Karl J. Hricko, Lewis Thomas, Joseph Miterrando, NJ	WFC Observations of NGG-4319-Markarian 205; High-Resolution Morphology of a Galaxy-Quasar Association Displaying an Anomalous Redshift	1993
Nancy K. Cox, CA	The Ultraviolet Emission Spectrum of an HII Region	1993
William R. Alexander, WV	UV Spectroscopic Determination of the Deuterium-to-Hydrogen Ratio Along the Line of Sight Toward Epsilon Indi and Lambda Andromedae	1994-5
R. Dennis Tye, CA	Lyman-Alpha Spectra of Discordant Redshift Systems	1996
James P. Flood, NJ	Morphology of the Active Nucleus and Radial Filaments of NGC 1808	1997

Table 1 — Stephen James O'Meara, "The Demise of the HST Amateur Program," Sky & Telescope*, June 1997, 97–104.*

Endnotes

1 The story of HST operations is told in Christopher Gainor, *Not Yet Imagined: A Study of Hubble Space Telescope Operations* (Washington, D.C.: National Aeronautics and Space Administration, 2020). This paper is based on the author's research for that book, where a shorter discussion of the participation of amateur astronomers in HST is contained on pp. 300–303. The last of the five shuttle servicing missions to HST took place in 2009, two years before the *Space Shuttle* program ended in 2011.

2 The story of HST's creation is told in Robert W. Smith, *The Space Telescope: A study of NASA, science, technology and politics* (Cambridge: Cambridge University Press, 1993).

3 Andrew LePage, "Vintage Micro: The Amateur Space Telescope," *Drew ex machina*, 2014 April 16. www.drewexmachina.com/2014/04/16/vintage-micro-the-amateur-space-telescope/?fbclid=IwAR0ujoVh158qHLCY8cs8uuXdW8eLT7cGPABIUBfUtA00TsWw4H5A5Z7WrjY Accessed 2021 January 9.

4 STScI, "History of the Project to Allocate Hubble Space Telescope Observing Time to Amateur Astronomers," undated but probably 1986, in STScI Archive, Box 2.8, file "Press Releases/Fact Sheets, n.d., 1984–1991," Johns Hopkins University Library Special Collections; STScI News Release, "Amateur Astronomers to Have Observing Time on Hubble Space Telescope," 1986 August 7, STScI Release 86–03; Riccardo Giacconi, *Annual Report to AURA Board of Directors: Space Telescope Science Institute,* STScI, Baltimore, MD, March 1987, 42; Wallace Tucker, "The Space Telescope Science Institute," *Sky & Telescope*, April 1985, 295–299. Hubble observing cycles usually lasted a year each, although they sometimes varied in length as instruments were changed out on HST.

5 Space Telescope Science Institute, *Hubble Space Telescope Handbook for Amateur Astronomers,* October 1986, STScI, Baltimore MD, JHU Library Special Collections; John Pazmino, "*Amateur Astronomers and the Hubble Space Telescope*," articles from AAVSO publications 1986–1988, collected by George R. Lewycky.

6 Pazmino, "Amateur Astronomers;" Space Telescope Science Institute, "*Proposal Instructions and Application Form for Amateur Astronomer Use of the Hubble Space Telescope*," undated, supplied by George R. Lewycky.

7 *Handbook for Amateur Astronomers*, 14.

8 STScI draft news release, "*Amateur Astronomers Selected for Observing Time on NASA's Hubble Space Telescope*," undated, Release 89–05, in STScI Archive, Box 2.8, file "Press Releases/Fact Sheets, n.d., 1984–1991," JHU Library Special Collections.

9 Eric J. Chaisson, *The Hubble Wars* (New York: HarperCollins Publishers, 1994), 82–85.

10 Stephen James O'Meara, "Hubble's Amateur Hour," *Sky & Telescope,* August 1992, 154–55; STScI News Release, "*NASA's Hubble Space Telescope Explorers the Volcanic Moon Io*," 1992 October 2, STScI Release 1992–24.

11 Draft release, "Amateur Astronomers Selected for Observing Time;" O'Meara, "Hubble's Amateur Hour," Rob Stein, "*Amateur astronomers get to use telescope*," United Press International, 1990 April 9, supplied by George R. Lewycky.

12 Ana Larson, Oral History Interview by Chris Gainor, 2017 November 28, quote on 5.

13 STScI News Release, "*Amateur Astronomers Will Use NASA's Hubble Space Telescope*," 1992 September 10, STScI Release 1992–23.

14 George Lewycky, "How Voyager 1, Formaldehyde and Titan changed my life," unknown date, http://georgenet.net/hubble/files/PosterLewyckyExperience%204.pdf Accessed 2021 February 3. Lewycky has posted information relating to his experience with HST at www.georgenet.net/hubble/.

15 Stephen James O'Meara, "The Demise of the HST Amateur Program," *Sky & Telescope,* June 1997, 97–104. See also Gainor, *Not Yet Imagined*, 266–270.

16 O'Meara, "The Demise of the HST Amateur Program;" STScI Memorandum from A. Kinney to R. Williams, "*Recommendation for the final cycle of observations for Amateur Astronomers*," 1995 September 29, and STScI Memorandum from Peg Stanley and Anne Kinney, "*HST Amateur Astronomer Program Recommendations*," 1995 November 3, in STScI Archive, Box 1.3, file "*DO Office Public Outreach, 1994–1996*," JHU Library Special Collections; Max Mutchler and Harald Schenk, "*Amateur Astronomers and the Hubble Space Telescope*," 188th Meeting of the American Astronomical Society (AAS) in Madison, Wisconsin, 1996 June 13, and the 190th AAS Meeting in Winston-Salem, North Carolina, 1997 June 10, http://georgenet.net/hubble/bio/amateur.html Accessed 2021 February 3.

17 O'Meara, "*The Demise of the HST Amateur Program*."

18 Robert Williams email to Stephen J. Edberg, "Amateur Program," 1996 January 5, in reply to letter; Stephen J. Edberg, Hubble Space Telescope Amateur Astronomers Working Group, to Robert Williams, 1995 December 30; Anne Kinney, letter to HST Amateur Astronomers Working Group, 1996 January 4; all three in in STScI Archive, Box 1.3, file "*DO Office Public Outreach, 1994–1996*," JHU Library Special Collections; Kinney, "*Recommendation for the final cycle*" Stanley and Kinney, "*Amateur Astronomer Program Recommendations*" and Mutchler and Schenk, "*Amateur Astronomers and HST*."

19 O'Meara, "*The Demise of the HST Amateur Program*," 102; Kinney to Williams memo, "Recommendation for the final cycle…"

20 Stephen Cole, "Astronomy on the Edge: Using the Hubble Space Telescope," *Sky & Telescope,* October 1992, 386–394. See also Gainor, *Not Yet Imagined,* 298–300.

21 Lewycky, "*How Voyager 1, Formaldehyde and Titan changed my life*;" and FAQs from www.georgenet.net/hubble/ website. Accessed 2021 February 3.

22 O'Meara, "*The Demise of the HST Amateur Program*," 102.

23 Gainor, in *Not Yet Imagined,* discusses the history of HST imaging in Chapter 4, and the HST archive and MAST in Chapter 9. MAST is named after Barbara A. Mikulski, a longtime U.S. senator from Maryland who strongly supported HST and STScI. MAST is located at https://archive.stsci.edu/hst/.

24 Gainor, *Not Yet Imagined,* 315–316.

25 Ray Villard and Zoltan Levay, "Creating Hubble's Technicolor Universe," *Sky & Telescope,* September 2002, 28–34; STScI, "Illuminated Universe: Translating Cosmic Light," https://illuminateduniverse.org Accessed 2021 February 3.

26 Organizations such as The Planetary Society have promoted this activity. See Emily Lakdawalla, "In which I dip my toes into an ocean of Hubble data," 2010 March 25. www.planetary.org/articles/2408 . Accessed 2021 February 5.

27 STScI News Release, "Amateur and Professional Astronomers Team Up to Create a Cosmological Masterpiece," 2013 February 5, STScI Release 2013–06; John Wenz, "How Stargazing Became a Numbers Game," *The Atlantic*, 2015 May 21.

28 STScI News Release, "*Black Hole's Dust Ring May Be Casting Shadows From Heart of a Galaxy*," 2020 November 19, STScI News Release 2020–58.

29 Dalcanton, OHI, 18; Elizabeth Howell, "*Your Help Needed to Study Andromeda Galaxy*," 2012 December 10, Space.com, www.space.com/18818-andromeda-galaxy-crowdsource-study.html Accessed 2021 February 3; The Andromeda Project, "*Round 2 is Complete!*" 2013 October 30, and "*Round 2: Welcome Back*," 2013 October 13, https://blog.andromedaproject.org Accessed 2021 February 11.

30 Zooniverse Projects, www.zooniverse.org/projects?discipline=astronomy&page=1&status=live Accessed, 2021 February 3.

31 For more on the growing use of astronomical data, see Space Telescope Science Institute, *Big Data @ STScI: Enhancing STScI's Astronomical Data Science Capabilities over the Next Five Years,* STScI, Baltimore MD, 2016 March 15; and Peter Tyson, "Astronomy & Big Data," *Sky & Telescope,* September 2016, 14–21.

32 See Association of Universities for Research in Astronomy, *Space-based vs. Ground-based telescopes with Adaptive Optics (AO)*, summary prepared by staff at STScI, 2010.

33 See Maura Forrest, "*MOST Space Telescope eyes crowdfunding to stay in orbit*," *CBC News,* 2014 May 2. www.cbc.ca/news/technology/most-space-telescope-eyes-crowdfunding-to-stay-in-orbit-1.2629994 Accessed 2021 February 11; Chuck Black, "After a Long and Productive Life, the Iconic Canadian MOST Space Telescope was Finally Decommissioned in 2019," *The Commercial Space Blog*, 2019 April 11, http://acuriousguy.blogspot.com/2019/04/after-long-and-productive-life-iconic.html, Accessed 2021 February 11. For more on MOST, see Randy Attwood, "MOST: Canada's First Space Telescope, Part I." *JRASC. Vol. 96, No. 6* (December 2002), pp. 232–235; and Randy Attwood, "MOST: Canada's First Space Telescope, Part 2." *JRASC. Vol. 97, No. 1* (February 2003) pp. 7–10.

The Biological Basis for the Canadian Guideline for Outdoor Lighting 6.

Canadian Guidelines for Outdoor Lighting (CGOL)

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Abstract

Lighting technologies have reduced the cost of outdoor lighting, so it is becoming less expensive to use brighter lights in more remote locations. Currently, industry lighting guidelines only place "lower limits" on illumination and luminance, which leads to the current exponential growth in brightness and extent of outdoor lighting (Kyba 2020).

During the last two decades a century of research on light at night has been re-focused from its impact on astronomy to its wider ecological impact and how it affects human health. Using animal sensitivity to artificial light, and modern work on human vision, there is sufficient information to support a lighting guideline that can provide light for human activity after dark, while minimizing its impact on animals and the ecological balance. This paper distills the generally available information in the research literature, including the preceding five papers in this series, into a coherent and practical guideline and specification for outdoor lighting with low ecological impact.

The effectiveness of these guidelines on human vision has been tested. Although these guidelines are based on extensive study of the research on biology and behaviour, their biological effectiveness on reducing the impact on the ecosystem requires long-term observations.

Critical Attributes Of Light

Scotobiology provides a new set of rules that define "upper limits" on the attributes of outdoor luminance and illuminance (Dick 2012, Dick 2013). These Canadian Guidelines for Outdoor Lighting (CGOL) do not recommend specific luminaires or lighting technologies. Lighting products continually enter the market, and are retired, as technologies evolve with surprising rapidity. To list hardware specifications or specific lighting products would soon render these guidelines obsolete. Consequently, these guidelines provide limits on the resulting luminance and illuminance. Lighting professionals can then work back from these requirements to select compatible luminaires.

In the previous set of five papers (Dick 2020a, Dick 2020b, Dick 2020c, Dick 2021a, Dick 2021b) we have presented the four critical attributes of Artificial Light At Night (ALAN): brightness (luminance and illuminance), extent (shielding), spectrum (colour) and timing (scheduling). Table 1 shows the interdependence of these attributes. This paper integrates this information and proposes a balance between them for use in areas where the ecology is a priority in-and-around illuminated areas (target areas).

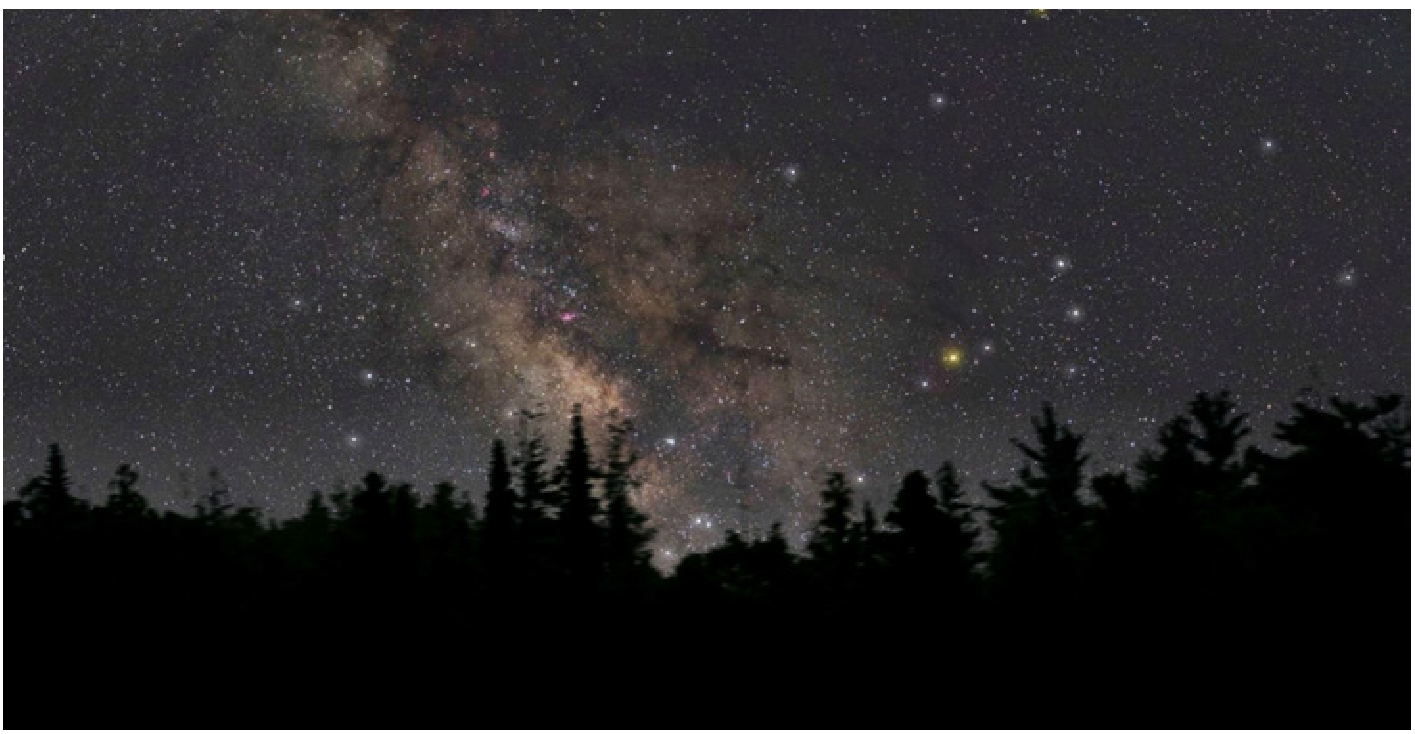


Figure 1 — Sky over Bruce Peninsula Dark-Sky Preserve. Under only starlight, the trees form a dark silhouette against the horizon.

Table 1 – Relationship between light attributes and perceived light pollution.

Attribute	Glare	Light Trespass	Sky Glow	Circadian Rhythm
Brightness (Dick 2020b)	X	X	X	X
Shielding (Dick 2020c)	X	X	X	
Spectrum (Dick 2020d)	X	X	X	X
Schedule (Dick 2021)		X		X

Glare

The most obvious impact of light pollution is glare that comes from the luminance of the light fixture, and even the light emitted by the illuminated surface. These are affected by brightness, shielding, and the spectrum of the light.

Some glare is necessary if the lamp is to be seen (marker lighting) or a surface is to be illuminated. But excessive luminance can create so much glare that it can compromise or cripple vision (Dick 2020b). We can reduce glare using several techniques.

Scattered light in our eyes, eyeglasses, and windows will be perceived as a veiling glow across the field of view, reducing the contrast of the scene. In extreme cases, "excessive" glare will contract our iris to let less light into our eyes and will bleach our rod cells, blinding us from seeing into the periphery of the illuminated area. All these can be reduced through reduced brightness, shielding, and colour of the light.

If reducing the amount of emitted light will reduce these effects, how much light do we need? The brightness required for visibility was discussed in the first and second papers of the series (Dick 2020a, Dick 2020b) and the uniformity, to reduce the concentrated luminance of a surface near the lamp, was discussed in the third paper (Dick 2020c).

Figure 2 — Sky glow of town from 15 km away. A town with only 5,000 people can appear brighter than a city of a million if its lighting is not shielded and commercial lighting is not curfewed.

Figure 3 shows that there is still significant glare beyond the illuminated area with FCO and to a lesser extent with ShCO shielding. To augment the fixture shield, trees and bushes around the target area can provide additional containment. However, for this to be practical, the luminaire must not be mounted above the surrounding trees.

The perception of glare is a function of wavelength (Dick 2020d). We unconsciously perceive blue spectral components as being 5× to 10× brighter than yellow-orange, or amber light. Therefore to reduce the visual impact of glare, the blue-light components must be filtered and removed.

Removing the blue-spectral components has a second benefit. Dust and aerosols in the low atmosphere scatter the glaring light and uplight, contributing to artificial sky glow. This brightens the urban sky and appears as a glow over distant urban centres. The process is wavelength dependent (Rayleigh scattering or 1/ wavelength), so sky glow can be reduced with longer-wavelength amber light that will scatter less.

This has a third effect. Short-wavelength light scatters close to the source, reducing its impact at greater distances. Thus the

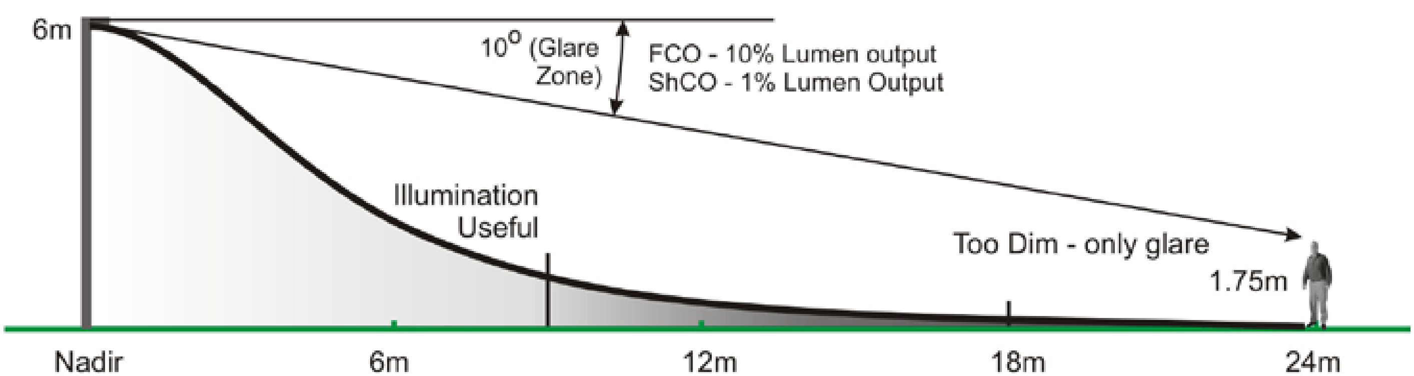


Figure 3 — Illumination and glare with distance. The range of useful illumination is quite limited, and beyond that range the luminaire creates only glare. The only ways to reduce glare is to reduce the lumen output of the luminaire, mount it on a short pole or use more aggressive shielding—ShCO instead of FCO. Since the illumination at distance is so low, the shielding will not reduce visibility in the periphery.

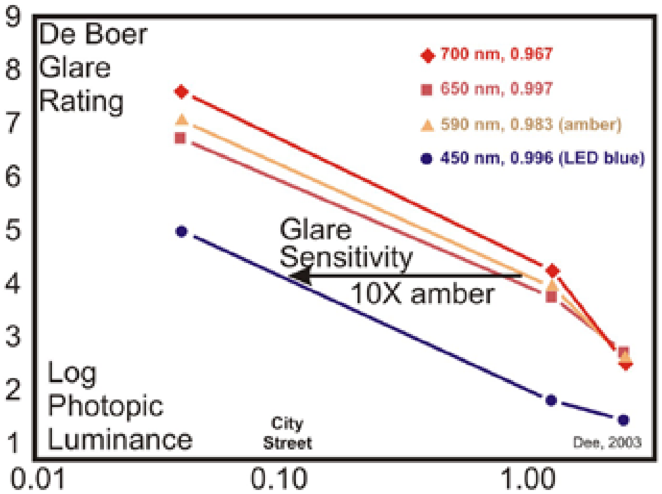


Figure 4 — Subjective assessment of glare of different colours of light. Using the de Boer scale for glare, blue light must be about 1/5 to 1/10 the brightness of amber for it to be perceived with the same degree of glare. (From Van Derlofske and Bullough 2004.)

scattered light will "redden" with distance. Although amber light will be scattered to a lesser degree and will therefore shine farther (Luginbuhl 2013), less amber light scatters back to the ground. Also, our scotopic vision is less sensitive to these long wavelengths than to blue wavelengths—so we will perceive less sky glow.

Marker Lights

The luminance of a lamp can be used to mark a course to help in navigation and situation awareness (a curve in a road). Illuminating the ground may not be sufficient for this purpose because of the poor visibility of a horizontal surface along hilly terrain viewed at a low angle at a distance, so an unshielded marker light may be preferred. However since they are not meant to illuminate the ground, much lower luminance lamps can be used.

The planet Venus (1 cd/m^2) appears quite prominent in the bright twilight sky, and appears "brilliant" in a dark sky, so the luminance of a marker light should be less than 1 cd/m^2. Since a fainter lamp will still be prominent against a dark line of trees, we prefer a lamp with about 0.1 cd/m^2. This corresponds to about a 50 mw[1] directional LED that can be powered by two AA batteries for about 1000 hours!

Bug Rating

Selecting a commercial luminaire that will reduce glare has become much easier with the "BUG Rating". The name stands for Backlight (illuminates the mounting wall behind the luminaire), Up-light (shines directly into the sky) and Glare (light that shines directly into our eyes and creates light trespass) so luminaires should have B=U=G=0. This may not eliminate all of the glare, but it will be much better than lights B, U or G ≠ 0.

Backlight can help identify a building, but if the fixture is properly shielded (no glare) there is sufficient light scattered from the ground to illuminate a nearby wall.

Light Trespass

The impact of glare and light trespass is subjective. Some people may tolerate light trespass but others may be very sensitive to it. So to simplify—these Guidelines focused on the biological and behavioural limits discussed in previous papers in order to remove "personal preferences."

Light trespass refers to light that shines where it is not wanted. It has a relatively local impact, which differentiates it from glare. It is affected by all four attributes of light: brightness, shielding, spectrum, and scheduling.

Illumination may be desirable in the early evening, but not late at night, when it could shine into bedrooms or may impact wildlife activity or biology (circadian rhythm). Shielding is an obvious solution but it can be made less objectionable later at night if the light is dimmed or the colour shifted to longer wavelengths (filtered).

Light trespass can be characterized by the luminance of the lamp and the surrounding illuminated surface (vertical wall or horizontal ground) as viewed from beyond the edge of the target area, or property. These are subject to the albedo of the illuminated surfaces.

Non-uniform illumination will exacerbate light trespass by producing over-bright patches—above the ecological threshold, that makes it difficult to see into the periphery. A small bright patch can have a greater impact than a larger area of lower illumination - below the threshold. For example, the mounting surface of a wall pack light fixture can be over 200× brighter than the threshold due to its close proximity to the mounting wall. A reflecting wall's high albedo and height will cause it to impact a wide area—"as far as the eye can see."

The illuminance at property boundaries should be below the ecological thresholds (0.02 lux or the illuminance produced by the crescent moon (Dick 2020b)) irrespective of the limits for human activity, since we should not encourage human activity beyond the activity area if it makes hazards accessible and will impact the natural landscape.

The luminance of the lamp or illuminated surface, as viewed from the edge of the target area, should be less than that the bright star Sirius (0.1 cd/m^2). Sirius is a "white" light source. However using an amber light source allows a brighter limit (up to 2.5× — Dick 2020d) that will still be less than this threshold. Alternatively, the luminaire may be mounted away from the wall, to reduce the illumination from the backlight.

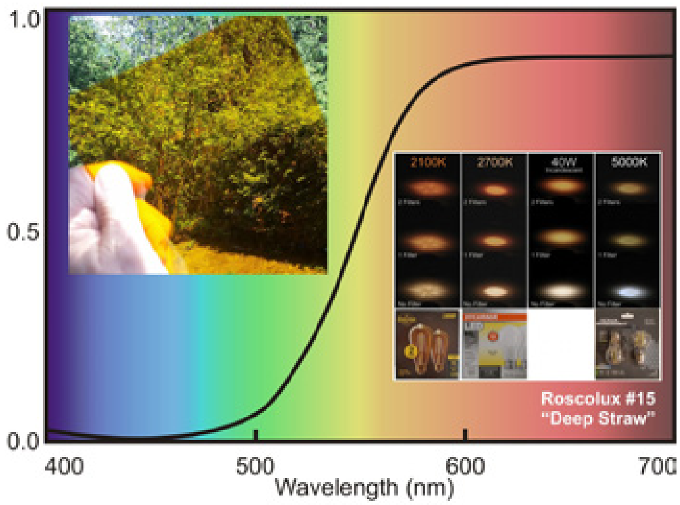


Figure 5 — Filtering offending lights may be the least expensive solution for some applications. Roscolux "Deep Straw" #15 photographic film is a very inexpensive way to render some white lamps amber-compliant. (Available from www.bhphotovideo.com, and from www.csbg.ca/BLOG.HTM, accessed 2020 June 5).

In addition to shielding the luminaire (Dick 2020c), trees and bushes bordering the area should be used to block the light scattered from the ground. This requires the luminaire to be mounted below the height of surrounding trees and bushes (typically 6 meters). Vegetation has a typical broadband albedo of 10-20%, so plants will help absorb scattered light – preventing it from shining beyond the target area.

Where possible, surfaces that are illuminated for safety (railings, steps, etc.) should have a high albedo (painted yellow or white). This will reduce the amount of light that is used for visibility to less than 20% compared to a dark brown surface.

This shows that there are a range of options for reducing light trespass that involve luminaire shielding, natural vegetative shielding, light spectrum and surface albedo control (paint). These can be balanced off to suit local circumstances.

Sky Glow

Sky glow is the symbol of distant light pollution—forming a dome of light above brightly lit areas. It is the combined effect of glare and light trespass, so by properly managing these sky glow will be minimized. However the benefits of careful shielding can be undermined if excessively bright lights are used, even if shielded because of the light that reflects off illuminated surfaces, or if some bright and unshielded lights are allowed to remain.

Circadian Rhythm

Unlike glare, light trespass and sky glow, which can be cut immediately with a light switch, the disruption of our circadian rhythm has more lasting effects that may not become evident for years or decades when we have grown into our senior years. The circadian rhythm schedules our many biological processes that retain our health and vitality; and is affected by the spectrum of the light, the light brightness, and timing the light.

ALAN will provide mis-cues and will alter our natural circadian rhythm. However we can take advantage of the natural biological and behavioural plasticity of animals to extend the early twilight later into the evening (Dick 2021b). However, this plasticity must not be used as an excuse to over-extend twilight for aesthetics or perceived safety when there is minimal human activity.

The circadian rhythm of most animals and plants is very sensitive to the perceived end of twilight, so ALAN should be dimmed below the biological threshold of 0.02lux during times of limited human activity. If more light is deemed necessary, then ALAN should be restricted with shields so as to minimize the extent of the contaminated area and limited to an amber spectrum to reduce its biological impact.

Facility managers should not assume light is required at night without records of when people are mobile. Typically most people do not drive or walk about after the late evening or during the night (Dick 2021b), and this has also been observed in rural areas and parks.

General records indicate that pedestrian and vehicle traffic are low two hours after sunset between mid-spring to mid-autumn and about 22:30 in winter—subject to the local schedule of activities. Readily available sunset and sunrise detectors and timers are available to turn lights on and off at the appropriate times. And, some luminaires have built-in and programmable timers that control the luminaires to reduce electricity use and their ecological impact.

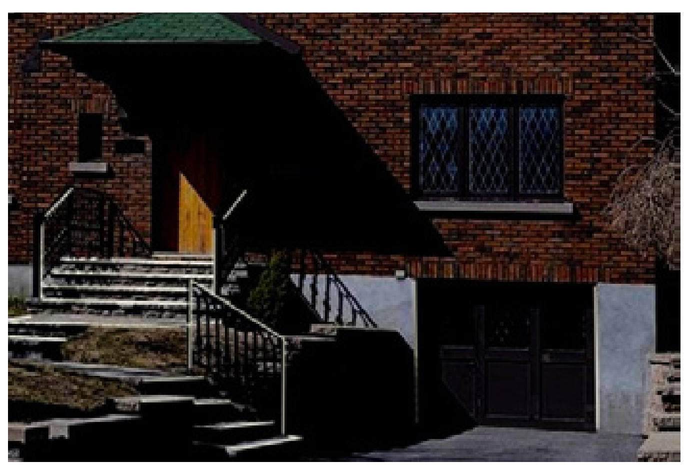


Figure 6 — Reflective paint to highlight hazards and features. Some hazards are identified by the irregular shadows they cast. However at night these shadows can be indistinct—even with flashlights. Highlighting these features with reflective pain (white or yellow) will make them more visible with less artificial light—even under moonlight. (Simulated image)

Most species are sensitive to short wavelength light at night, so the spectrum of ALAN should avoid blue-light components (<500 nm). This spectral limit is typical of consumer "bug lights" available from retail stores. If changing lamps or light fixtures is not convenient, then inexpensive filter sheets can be mounted inside the luminaire to absorb the blue light before it leaves the fixture (www.bhphotovideo.com—Roscolux #15 Deep Straw film, or equivalent).

Figure 7 — Glare from unshielded lighting. This example shows across-channel glare from light fixtures that remain on throughout the night—even when owners are not home.

Guidelines And Specifications

Guidelines provide general principles that support a vision of the future, and reflect the values that are important to society. Currently, our society aspires to protect the natural environment as much as possible given our predilection for late-night outdoor activity. As society evolves, these values may change, however, the ephemeral nature of a value system should not prevent us from trying to improve our current situation.

Some gidelines are a "narrative" and may be too general to be used to design a lighting system and select hardware, which requires more specific information. Specifications are "specific" and are used to engineer the ALAN. Scotobiology provides the limits for these specifications that are unequivocal and measurable. Specifications define the lighting requirements—not the technology. Therefore they do not include a list of compliant hardware. To do so would soon render the document obsolete.

The tables in the next section define the brightness for a range of typical applications of outdoor lighting. Urban areas have considerable co-lateral lighting that undermines the visibility that would be provided by these Guidelines. Therefore they may not be practical for some urban locations. However where practical and permissible, urban officials will benefit from adopting these guidelines to replace older lighting that conformed to earlier and disruptive urban "Best Practice." Application of these Guidelines can be used to help work toward a more sustainable future.

Canadian Guidelines For Outdoor Lighting (CGOL)

Human activity is generally centred near built structures and activity centres (referred to here as buildings) and transportation routes (pathways, roadways, and parking lots). We differentiate roads from parking areas and pathways because parking areas have greater potential for conflict between vehicles and pedestrians.

In the following tables, N/A = not applicable, and curfew refers to when the lights are turned off, or dimmed to produce less than 1-lux illumination. It defaults to about two hours after sunset when buildings or services are closed.

Lamp power is not given because it depends on the lamp efficacy, which depends on the technology used. The required fixture-brightness (lumens) is approximately the illumination level (lux) multiplied by the area to be illuminated (m^2). This assumes uniform illumination. As a point of reference, 2-lux is approximately the illumination of twilight under a clear sky 20 minutes after sunset.

Buildings

These guidelines refer to different building types and uses in park settings: administration and offices, kiosks, services, and retail outlets. Offices are generally closed and not available to the public after office hours, which usually end before sunset, except in winter. Public buildings (information kiosks, showers, toilets) will be needed throughout the night and may require both marker lighting and illumination to safely guide visitors to and from the building.

Indoor illumination (200-1000-lux) bleaches (blinds) our night vision, so upon exit, a period of approximately 10-20 seconds is needed to initially adjust to the night. Therefore a period (distance) of transition back into the night is needed for pedestrians to reach pathways, parking lots, or other facilities. Illumination levels need to be about 2-lux—high enough for the use of our cone vision but not so high as to prevent the recovery of our rod vision.

Pedestrians walk between buildings. Observation and anecdotal reports indicate that pedestrian activity (persons / minute) is typically much less than 1 person / minute after dark—when artificial light is used. This is significantly less than the urban traffic on which the industry guidelines are based (IES RP-08). Therefore only the lowest illumination levels should be used.

Retail outlets may be stores or vending machines. Stores are generally closed in the late evening so their internal lighting should be turned off or significantly dimmed. However, vending machines will likely be visited throughout the night. These machines should be enclosed to prevent their internal lighting from affecting the area around them. This will also protect the machine from the weather.

Shielding and mounting-height limits ensure the light and glare is contained within the target area. In all cases, FCO or ShCO shielding and amber light shall be used. Where no visitors are allowed after dark, outdoor lighting should be turned off or dimmed so as not to attract and encourage visitors. The dimmed brightness will protect our scotopic vision and permit our ability to read posted information (about 1-lux).

*Table 2 – Building Illumination Guidelines (Maximum Values)**

Area	Type	Light/Lamp	Level (lux)	Height	Curfew
Office Buildings	FCO ShCO	Amber Incandescent, LED or Filtered	~2 lux	2.5 m	Yes
Public Bldgs.	Marker, FCO ShCO	Amber Incandescent, LED or Filtered	~2 lux	2.5 m	No
Retail Outlets	FCO, ShCO	Amber Incandescent, LED or Filtered	~2 lux	2.5 m	Yes

** Curtains should block indoor lighting within 30-minutes of sunset.*

Parking Lots

Parking lots have both pedestrians and vehicles. Due to potential inattention of motorists and the vulnerability of pedestrians, it is necessary to augment the relatively directional car headlights with more isotropic illumination.

The illumination shall be in the low mesopic region so pedestrians can use both their sensitive scotopic vision and photopic vision when around vehicles. The lighting for these lots should be turned off after the associated office buildings have closed or other night activities have ended and traffic is minimal.

Although Table 2 refers to buildings that are accessible to pedestrians, Table 3 refers to areas where the pedestrians may have parked their cars. No extra lighting may be needed in small lots because there will be fewer pedestrians and fewer cars than in large lots. And in small lots, cars will typically be parked around the perimeter reducing the need for pedestrians to cross the open lanes.

In larger parking lots, light fixtures should be mounted on poles near the perimeter and shine light in toward the centre with shielding against backlight beyond the lot perimeter. The mounting height must be limited to that of adjacent trees (typically 6 metres) to help contain scattered light to the parking area.

Table 3 – Parking Lot Illumination Guidelines (Maximum Values)

Parking Area	Type	Light/Lamp	Level (lux)	Height	Curfew
For < 10 cars	N/A	None	N/A	N/A	N/A
For > 10 cars	FCO, ShCO	LPS, HPS or Amber CFL, LED, or Filtered	~3	6 m	Yes

Roadways

In the second paper of this series (Dick 2020b) we presented various aspects of roadway illumination and luminance. The IESNA Handbook and RP-08 provide guidance for urban illumination but are based on higher traffic densities than are typical of rural areas and parks. However, users can significantly reduce their ecological impact by taking advantage of shielding, spectrum and dimming, described here, when adapting these documents to rural and semi-rural areas.

Roadway illumination provides three functions: visibility of the road surface, situation awareness (for navigation) and to avoid unexpected hazards (visibility of pedestrians and animals). Rural roads may be illuminated in built-up areas (hamlets, villages and towns). These guidelines refer only to the rural communities and park facilities. However, roadway lighting should comply with the City Right-of-Way Lighting Policies where they exist and may be adopted for urban residential areas.

Typical park settings can have much lower traffic densities than urban areas, but during twilight when people are returning to their vehicles and tents, dark adaptation is inhibited by a relatively bright sky, yet the low albedo of trees and bushes is too low to help silhouette pedestrians against the background. Therefore some additional illumination may be needed.

Most rural and semi-rural roads only have marker lighting at intersections. However, glare from these unshielded lights along a dark road will significantly reduce visibility of roadside hazards, so it is recommended that they be shielded, or removed and replaced with roadside equipment, retro reflective signs, and turnoffs designed with car headlights in mind. For example, bushes and trees may be planted near intersections, with suitable setbacks, to provide visual cues for approaching motorists. Car headlights can illuminate this vegetation to improve situation awareness without the added glare from a streetlight; they will also shield against light that shines beyond the roadway.

In Table 4 we refer to roadways with low traffic speeds and vehicle densities. These would be typical of towns, villages, hamlets, parks, and in low-rise urban residential areas.

Table 4 – Rural Roadway Illumination Guidelines (Maximum Values)

Roadways	Type	Light	Level (lux)	Height	Curfew
Rural Local	None	N/A	N/A	N/A	N/A
Rural Collectors	Marker	LPS, HPS or Amber CFL, LED, or Filtered	~3	6 m	No
Rural Highways	Signs, Marker	LPS, HPS or Amber CFL, LED, or Filtered	~3	6 m	No

Pathways

Pathways are for pedestrians with speeds at a walking pace, however if the pathway has been graded and smoothed, human powered aids can be expected (wheel chairs, skate boards, bicycles, etc.). If these are permitted then landscaping should ensure good sight lines. IESNA recommends illumination levels of about 2 lux for walkways and bikeways, in residential areas with low traffic volumes and speeds.

Less travelled pathways do not require illumination throughout the night. However, main pathways may provide navigation cues at night, so they may be exempt from a lighting curfew.

Pathways are typically narrower than roads and the optics of overhead luminaires will be unable to limit the extent of the illumination to the path. Therefore the mounting height should be closer to the ground. To avoid glare as the pedestrians pass by, the lamps should be FCO and mounted on approximately 1-metre-high bollards.

The illuminations in Table 5 are based on the need to follow the path and see obstacles on the ground. Although 1-lux is the ground illumination, a pedestrian with printed instructions will be able to hold his or her map closer to the light source, so it will appear easy to read.

This illumination assumes an asphalt (dark) surface, so a more reflective surface will require lower illumination. For example, white crushed stone is easily followed with only a full Moon (0.1 lux)—assuming the path is not under a tree canopy.

Table 5 presents the illumination of three types of pathways. Most paths are rarely used, or the public may not be encouraged to use them at night. (There may be limited navigation cues or hazards that should be avoided.) Paths may also remain un-lit due to the cost and risk of running high voltage power along the path. To help delineate these paths, a (passive) reflective surface or light-coloured edging should be used.

Table 5 – Pathway Illumination Guidelines (Maximum Values)

Pathways	Type	Light	Level (lux)	Height	Curfew*
Minor Paths	None	None	N/A	N/A	N/A
Illuminated Paths	FCO ShCO	Amber Incandescent, LED or Filtered	~1 lux	1 m	Yes
Main Pathways	FCO ShCO	Amber Incandescent, LED or Filtered	~1 lux	1 m	No

Shorelines

Built facilities and light fixtures should be set well back from the water to protect the sensitive aquatic and shoreline ecology. Shoreline lighting will also shine out across the water, scattering off the surface—creating glare and confusing waterway navigation.

There are three general applications for these guidelines: shoreline property, private dock and large dock or lock facilities.

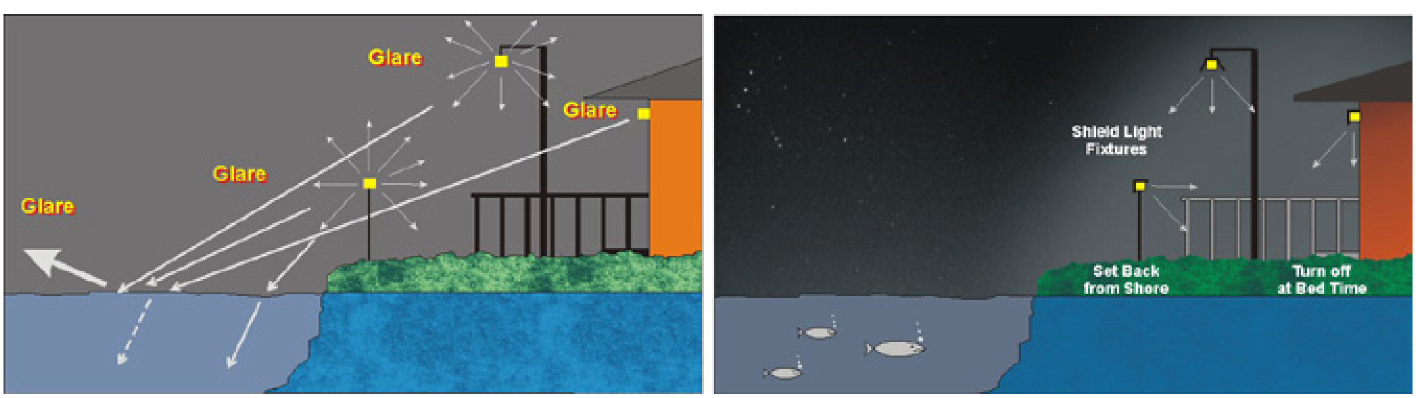


Figure 8 — Guidelines for shoreline lighting. Placement, shielding, brightness, and colour are critical for minimizing the impact of the ALAN on navigation of the waterway and on the biology of the ecosystem.

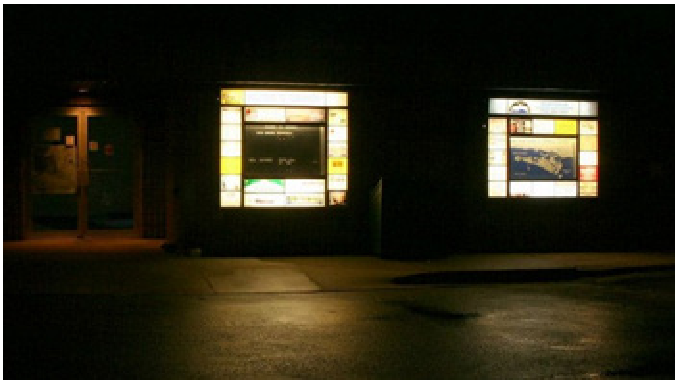


Figure 9 — Glare from backlit signs reduces visibility along roadway and makes doorway lighting ineffective. Notice that the non-white signs are more readable.

Some light may be needed at dock facilities where people will be entering or leaving boats at night. Significant glare undermines this visibility. This activity requires only enough light to see the boat gunwale, edge of the dock and the gap. White paint will help delineate these areas with minimal light and glare. Since it is inevitable that light will shine into the water, the illumination level must be as low as practical, shielded and curfewed.

In general, there should be no light fixtures within 10 metres of the shore. This setback will lower the angle the light will shine on the water and will reduce the light that penetrates the surface.

Where machinery is present, more light may be needed for safety and situation awareness. Luminaires should be mounted above the area so as not to interfere with this activity but flood lighting from the side shall not be used. Since dock activities do not generally extend throughout the night, a curfew should be in place when there is no activity. If there are boat departures and arrivals throughout the night motion detectors should be used. Otherwise these light fixtures may be exempt from the curfew.

Table 6 - Shoreline Illumination Guidelines (Maximum Values)

Waterways	Type	Light	Level (lux)	Height	Curfew
General Areas	N/A	None	N/A	N/A	N/A
Dock Bollards	FCO ShCO	Amber Incandescent, LED or Filtered	~1 lux	1m	Limited
Lock Facilities	FCO ShCO	Amber Incandescent, CFL, LED or Filtered	~3 lux	6 m	Limited

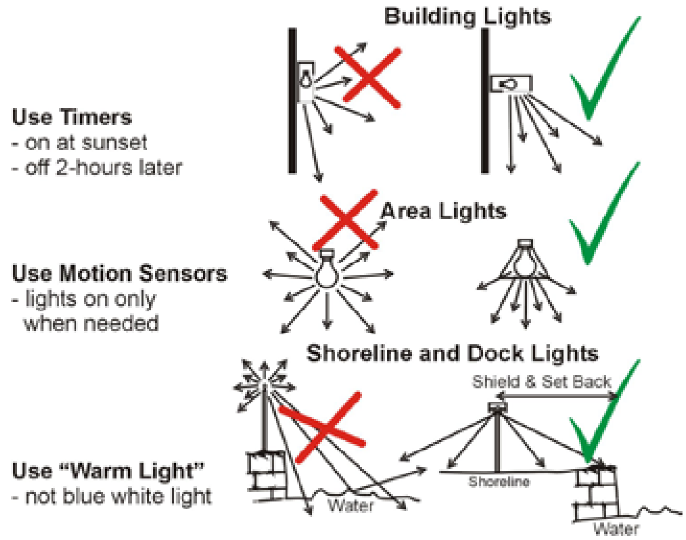


Figure 10 — Simple summary of techniques to reduce the impact of ALAN

Signage

Signs are used to augment situation awareness for navigation and provide information. There are three general types of signs. Those visible by reflecting incident light, those lit internally and signs illuminated with exterior lights. Retro reflecting signs are preferred since they are passive (scatter light when flashlights are present) and efficiently reflect dim incident light.

If signs are to be illuminated, the shielding, colour, brightness and scheduling of the light fixtures shall comply with the earlier sections of this guideline.

Managers should not use signs with white backgrounds and dark text or graphics because the expansive bright surface will cause glare. Signs should use high albedo (reflective) text and graphics on a dark background. They should also use contrasting colours instead of white and black.

Summary

In all cases the default lighting is for no illumination. However when deemed necessary by the manager, these guidelines and specifications should be used. In some cases lighting levels may need to be increased but with the knowledge that this will undermine the ecological integrity of the area, it will reduce visibility for people beyond the target area and will increase the cost of the project.

Additional and more detailed information is provided in the RASC-CGOL, and its Appendices. These are freely available from the RASC, CSbG Inc. and other sources.

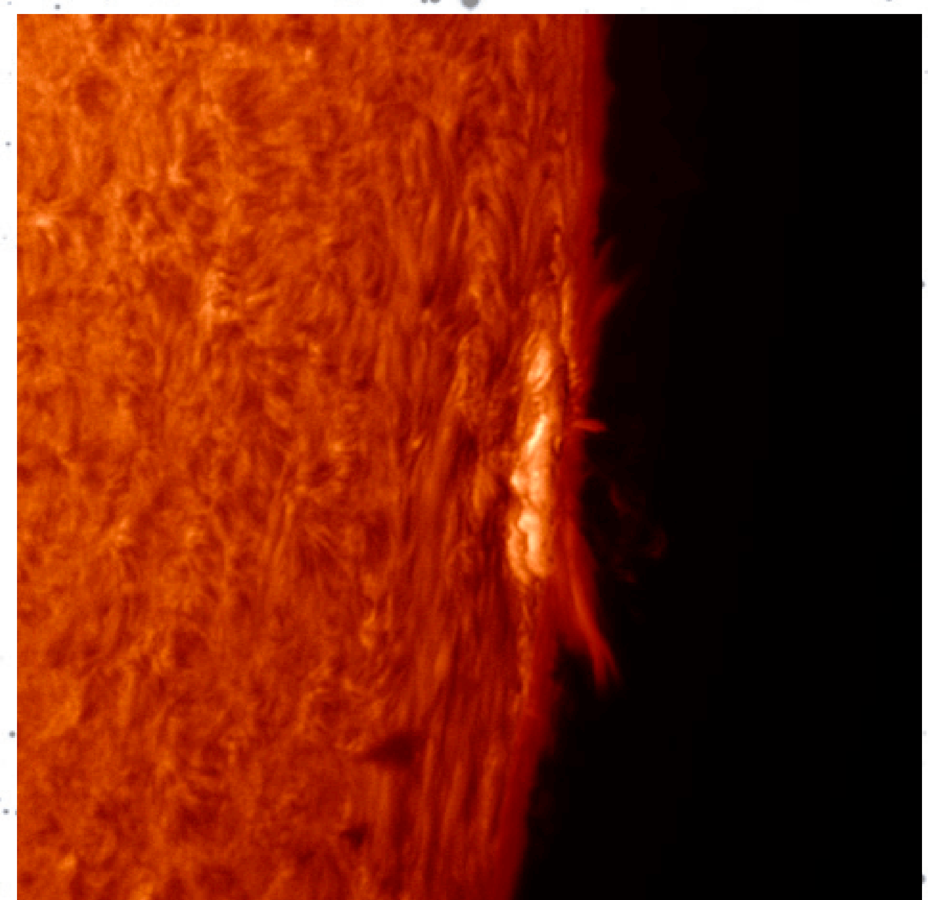
Continues on page 124

Pen & Pixel

Shelly Jackson imaged Messier 81 and Messier 82 from her backyard in Sarnia, Ontario, under a Bortle 6/7 sky. She used an 81-mm WO GT apo triplet with a field flattener/.8 reducer and a ZWO ASI294MC pro one-shot colour CMOS cooled to −10 °C, together with a 50-mm guide scope, a 120 mono-guide camera on a Sky-Watcher AZ EQ5 pro mount. The image is a stack of 93 × 180-second lights processed with PixInsight.

Our wonderful Moon peeks out of a cloudy daytime sky in this beautiful single image by Stefanie Harron, who used a Canon EOS 5D Mark IV with a 560-mm lens from her home in Castlegar, British Columbia.

Klaus Brasch imaged what he calls one of his favourite celestial objects, NGC 2024, the Flame Nebula. He says that it's a tricky one to capture due to its proximity to Alnitak, one of Orion's belt stars. He combined older images taken with a Celestron 11 with more recent ones taken with a CDK 12.5-inch. All were shot using a Canon 6D camera using an IDAS LPS-V4 filter for a total exposure time of 30 minutes at ISO 1600–3200.



Activity on the Sun is starting to pick up again as Solar Cycle 25 has begun. Gary Palmer captured an active region of the Sun rotating away on April 24. He used a SharpStar 140PH telescope with a Daystar Quantum PE 0.2A, a Player One Neptune-M camera and a SharpCap 4 Pro.

Continued from page 121

The six tables in this paper summarize most applications for ALAN in public areas based on pedestrian level activity (walking) and vehicle traffic. These limits minimize the impact on the ecosystem and they will help preserve our enjoyment and the aesthetics of the night environment. ✷

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

See the published schedule at
rasc.ca/sites/default/files/jrascschedule2021.pdf

Endnotes

1 0.1 cd/m^2 = 0.1 x 4π lumens ~ 12 lumens or 0.012W. At 3V, this is 0.004A. 2 x AA = 4Ah, so a set of 2 AA batteries (for 3V) will operate for 1,000 hours.

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www.csbg.ca

www.rasc.ca/dark-sky-site-guidelines

The Planetarium: Linked to War

by Phil Mozel, Mississauga Centre
(dunnfore@gmail.com)

As a youngster, I learned my way around the stars in a way I thought at the time was a little unusual. I learned the major stars and planets from someone who had no astronomy books, no telescope, and no apparent interest in the subject other than getting me oriented. And yet my father knew his way around the sky—and with good reason. As a pilot with the Royal Canadian Air Force in World War II, he was also tasked with learning the basics of navigation so that in an emergency, he would still be able to find his way. So, just how did one learn this skill during the war?

Finding One's Way

At the outbreak of the Second World War, flying was still in its infancy: aircraft flew low, slow and with only the most rudimentary of instruments, including those for navigation. Following roads and rivers was one sure way to find one's way around but traversing long distances, especially over trackless desert, forest, or ocean, was a problem. All this on top of the danger of putting an unskilled pilot at the unfamiliar controls of an aircraft. The seriousness of the situation was demonstrated when, in a 78–day period in 1934, a dozen pilots of the U.S. Army Air Corps were killed (1). Enter Edwin Link.

Link was fascinated by aviation and, in 1929, was prompted to build a flight simulator using knowledge and material gained from his father's Link Organ and Piano Company (2). The device looked like a small airplane and was fully equipped with the same type of instrumentation (Figure 1). Activating the flight controls caused the simulator to move in the same three axes as a real aircraft. Closing the opaque hood cut the trainee off from all external references forcing him to fly on instruments alone. This was helpful preparation for flying in conditions where visibility, in fog or low light for example, was poor. His course could be monitored by a trainer watching a "crab," a wheeled device connected to the simulator that crawled across a map thereby denoting the trainee's cross-

Figure 1 — Link Trainer at the Canadian Warplane Heritage Museum. Photo by the author.

Figure 2 — The crab of the Link trainer at the Canadian Warplane Heritage Museum. It would have been connected to the aircraft portion by a cable. Photo by the author.

country course. (Figure 2). The simulator really "took off" when, in 1934, Edwin Link travelled to a meeting with Army Air Corps officials in weather conditions that they deemed "unflyable." He flew in anyway, having gained the necessary piloting skills in one of his simulators (1).

With the outbreak of war likely, the allies found themselves in dire need of trained aircrew, a situation that the Link trainer could help remedy. The United States was neutral and therefore unable to directly satisfy this need, so in 1938, Link opened a Canadian branch plant in Gananoque, Ontario, where the first of 5,000 trainers were built (3). A number are currently on display in aviation museums across the country (4) including the Canadian Warplane Heritage Museum at the Hamilton International Airport.

Besides pilots, there was an urgent need for other skills, including navigation, whether aboard ship or an aircraft. Getting lost on a trans-Atlantic voyage was not acceptable. Bombing accuracy early in the war (something like five percent of bombs fell within five miles of the target) needed improving. Such training for airmen was sometimes accomplished by taking a version of the Link trainer and combining it with a "planetarium." Edwin Link developed this device and filed for a patent in December 1942 (Figure 3) (5).

The layout of the celestial navigation trainer is well displayed in the April 1944 issue of *Popular Science* (Figure 4), (6). A silo was constructed (Figure 5), (7) with a hemispherical dome inside on the surface of which stars and constellations were represented. Below this was the actual flight simulator, this time large enough to hold a "crew" of several people including pilot and navigator. The ground over which they were to "fly" lay below with the instructor's table and its crab at the lowest level. Much of the training of aircrews was conducted by women who had themselves learned to operate the trainer (Figure 6), (7). By war's end, finding one's way was much aided

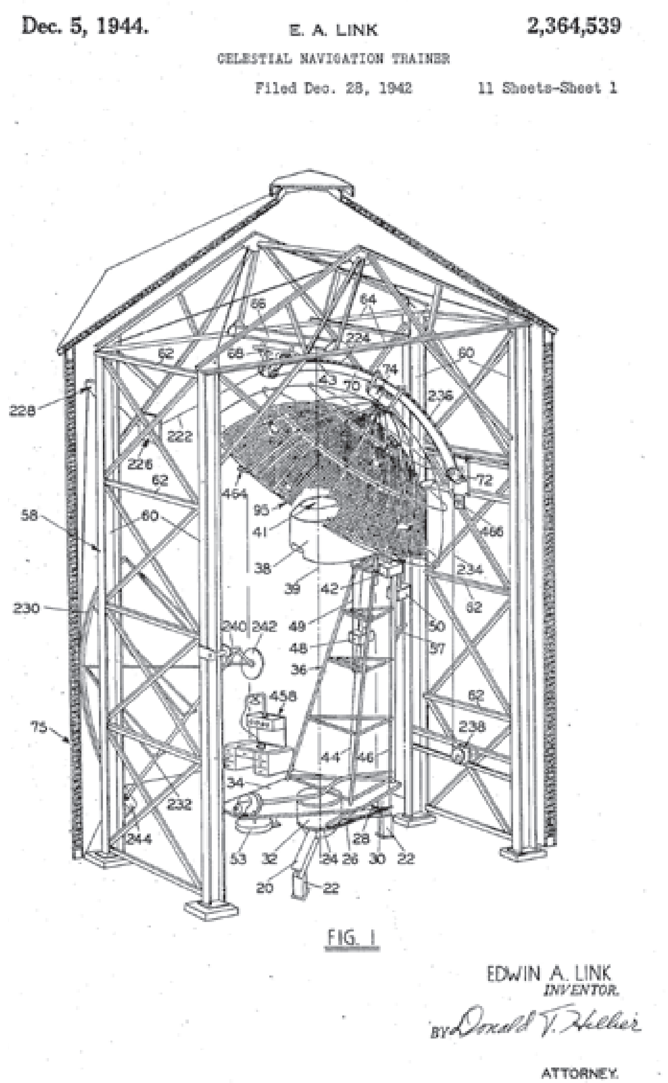

Figure 3 — Part of Edwin Link's Patent Application for a Celestial Navigation Trainer. From **Popular Science**. *https://patents.google.com/patent/US2364539*

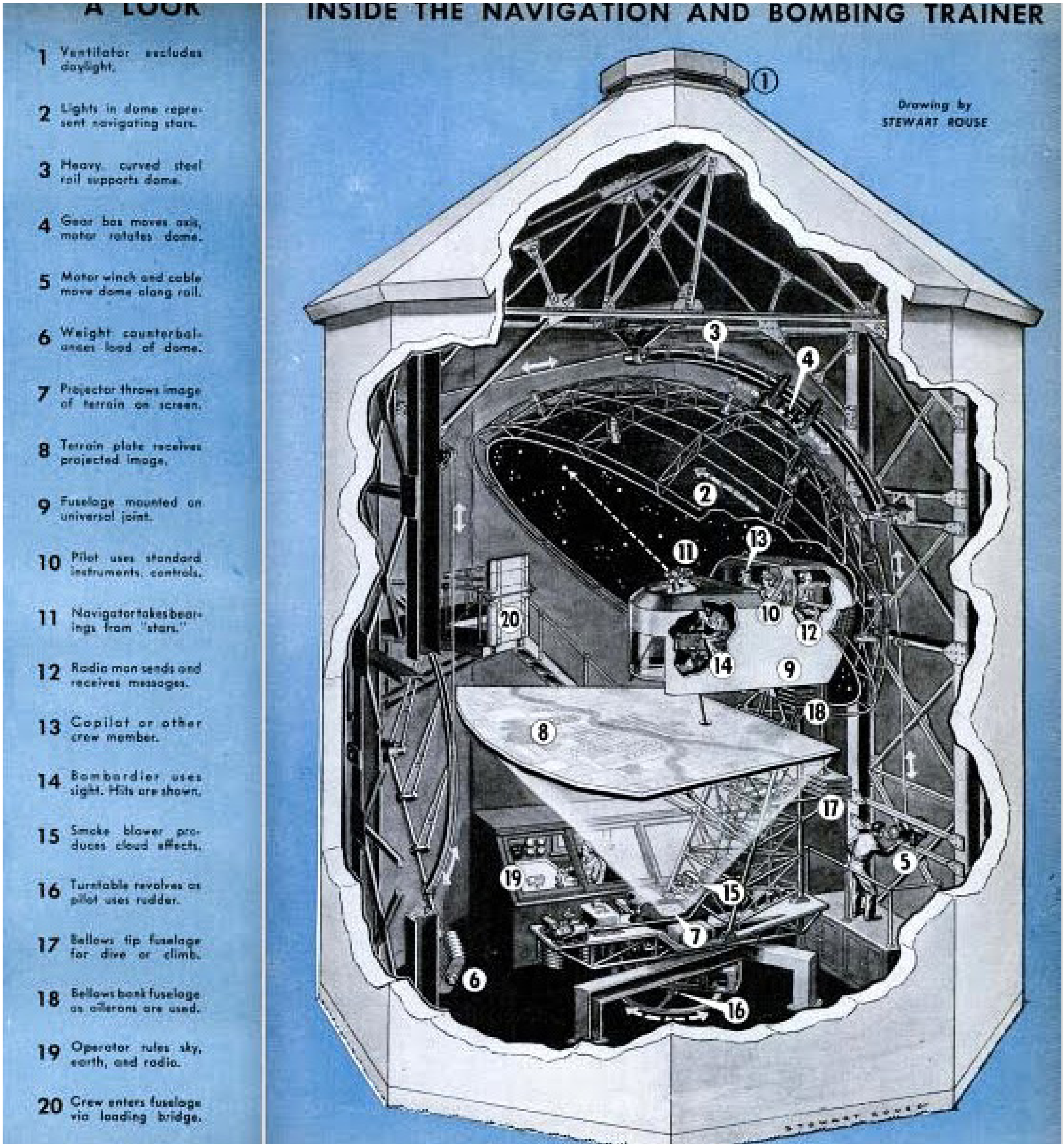

Figure 4 — Cutaway View of Celestial Navigation Trainer Silo (accessed 2020 March 20)
https://i.pinimg.com/originals/cb/24/1c/cb241c32268edc18e986339cebe0cdba.jpg

Figure 5 — Celestial Navigation Trainer Building at Lakehurst, New Jersey, Naval A ir Station, July 1945. Image: National Archives photo, 80-G325735. Sourced from Smithsonian National Air and Space Museum (accessed 2020 March 20) https://airandspace.si.edu/stories/editorial/women-guided-way-simulated-sky-during-wwii

Figure 6 — Training of instructors in the Celestial Navigation Trainer at Navigation Trainer Operators and Maintenance School, Naval Air Station Seattle. Image: National Archives and Records Administration photo, 80-G-46116. Sourced from Smithsonian National Air and Space Museum (accessed 2020 March 20) https://airandspace.si.edu/stories/editorial/women-guided-way-simulated-sky-during-wwii

Figure 7 — Royal Air Force navigation instructor Pilot Officer A.G. Fox gives a lecture on the constellations somewhere in Britain. Imperial War Museum, www.iwm.org.uk/collections/item/object/2143

by the development of radio-based navigational devices, and reliance on the stars therefore lessened.

Research for this article was prompted by the question of whether any of these devices are extant and whether anyone who trained on them survives. Many stand-alone Link trainers remain, but of the more than 100 celestial navigation trainers built for the allies, not one seems to have survived (7). Apparently, none were used in Canada despite this country's training of over 130,000 allied aircrew, including navigators, in the British Commonwealth Air Training Plan. It would seem that in this case, along with classroom work (Figure 7), the standard Link machine was the go-to trainer followed by actual aerial navigation. In some aircraft, such as the B-24 Liberator, an astrodome was provided above the navigator's position (Figure 8) from which navigational fixes on the heavens could be made.

The author's father recorded his aerial progress in both flight and navigational logbooks (Figure 9), ultimately passing down his knowledge of the night sky. Thus it was that the author became linked to the stars. ✷

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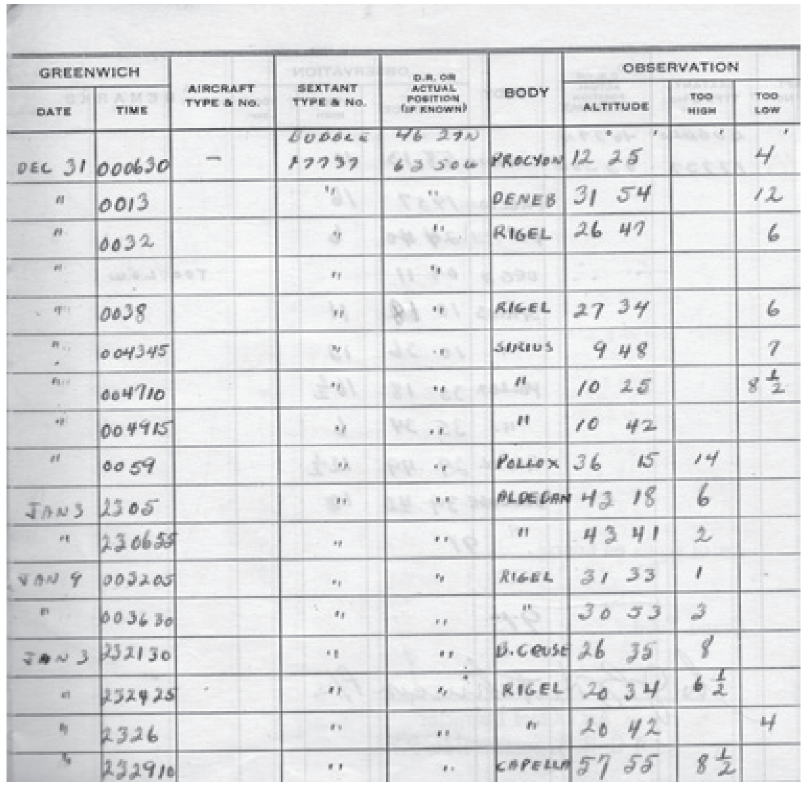
Phil Mozel is a life member of the Society and past National Librarian. As a Contributing Editor to the Journal, *he wrote the* A Moment With.... *column for several years. He is the recipient of the Toronto Centre's Ostrander-Ramsay Award and the National Society's Simon Newcomb Award. He was, for a number of years, the Producer/Educator at the McLaughlin Planetarium in Toronto and is a longtime volunteer at the Canadian Warplane Heritage Museum. He is shocked at how long ago his first article appeared in these pages (1982) when the* Journal *was small, green, and available solely in paper.*



GREENWICH DATE	GREENWICH TIME	AIRCRAFT TYPE & No.	SEXTANT TYPE & No.	D.R. OR ACTUAL POSITION (IF KNOWN)	BODY	OBSERVATION ALTITUDE	TOO HIGH	TOO LOW
DEC 31	000630	—	BUBBLE F7737	46 27N 63 50W	PROCYON	12 25		4
"	0013		"	"	DENEB	31 54		12
"	0032		"	"	RIGEL	26 47		6
"			"	"				
"	0038		"	"	RIGEL	27 34		6
"	004345		"	"	SIRIUS	9 48		7
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"	0059		"	"	POLLOX	36 15	14	
JAN 3	2305		"	"	ALDEBAN	43 18	6	
"	230655		"	"	"	43 41	2	
JAN 4	003205		"	"	RIGEL	31 33	1	
"	003630		"	"	"	30 53	3	
JAN 3	232130		"	"	B.GEUSE	26 35	8	
"	232425		"	"	RIGEL	20 34	6 1/2	
"	2326		"	"	"	20 42		4
"	232910		"	"	CAPELLA	57 55	8 1/2	

Figure 9 — A page from the navigation logbook of the author's father. Many star names will be familiar to the reader.

Figure 8 — A rendering of the B-24 flown by the author's Father. The astrodome may be seen behind the nose turret. Artwork by John Cowan.

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

Caroline Lucretia Herschel, 1750–1848

by Katrina Ince-Lum, Toronto Centre
(astroyyz@my.yorku.ca)

"This comet was first discovered August 1, 1786, at Slough, near Windsor, by Miss Caroline Herschel, sister to Dr. William Herschel, and assistant to him, and almost as zealous an astronomer as himself; who, in his absence, swept the heavens with her telescope for that purpose."

– Observations by Rev. Francis Wollaston, 1786, referring to Caroline Herschel's discovery of Comet C/1786 P1

At a time when women were generally homemakers and lived a predetermined life, couldn't vote, and were purposefully excluded as natural philosophers (a precursor word for scientists), Caroline Herschel was able to break through barriers of familial expectations, disease, education, inclusion, and sexism in 18th-century Europe. She created an independent and ambitious career where she discovered comets and documented the discovery of other astronomical phenomena such as open clusters, nebulae, and galaxies, with a legacy of astronomical catalogues that we use to this day. She became the first professional female astronomer. Her achievements, however, have taken on new meaning during the COVID-19 pandemic. She lived through not one but two diseases that spread widely and killed many thousands during a time before antibiotics and modern travel and technology, and yet, following that, emigrated and forged a life for herself in science. There's a life lesson there.

Caroline Lucretia Herschel was born in the German town of Hanover on 1750 March 16, the eighth of ten children to Isaac Herschel, an oboist, and Anna Ilse Moritzen. This was a household of makers and artisans, whereby music was front and centre, not to mention their livelihood. Not only were they talented musicians; William would later build telescopes that assisted him and Caroline to search the heavens in later years, with the assistance of yet another Herschel sibling, Alexander, who, while a cellist, was also a metalworker. William was making a name for himself as a musician, and yet Caroline was left at home, "who was trapped in the family home in Hanover at the beck and call of their domineering mother" (Hoskin 3).

An intellectual- and science-driven life would seem to be unlikely for her at this stage of her life, not only because her mother had earmarked her as her own personal household helper and maid (which saved the Herschel family the cost of hiring a servant) and had denied her an education more than was necessary, lest she be tempted to become a governess and leave, but also because she had already suffered life-changing hardship in her early life in a time before antibiotics and vaccinations. Typhus and smallpox, which killed thousands in Europe around this time—including her two-year-old brother, Frantz Johann—had physically affected her at age four, stunting her growth and scarring her appearance. She said that, "though recovered, I did not escape being totally disfigured and suffering from some injury in my left eye" (Brock, page 43). In addition, there was the opinion during the 18th century in some quarters that female brains were incapable of scientific and mathematical thought.

Figure 1 — Caroline Herschel Credit: NASA

The family business of music was to create a life-changing opportunity from her brother, William, who had left Germany to pursue a musical career in the spa town of Bath, England. It is worth noting that the eldest brother, Jacob, was also a musician. After the death of their father, he became the head of the Herschel household in Hanover. According to Brock, "Jacob, in similar fashion to his mother, treated his sister like a servant and had no intention of helping her" (67). It was therefore a happy coincidence that Jacob was away for work in August 1772 when William arrived to take Caroline back to Bath with him, initially to begin a musical career.

Speaking only German, she began a new life in England. William, while expecting her to perform household chores, was also tutoring her in English, singing, and music, and later would introduce her to the world of astronomy, ostensibly to be his assistant, helping him in the labourious task of polishing telescope mirrors and taking notes.

Herschel, who had been leading a lonely life of servitude in Germany, had the courage to leave her home and emigrate to a different country at a time when travel could be treacherous. Incredibly, she also learned a new language and became a soloist, singing in William's production of Handel's *Messiah* (Hoskin 6) in 1778 before a paying audience. That is, until William's interest in astronomy, lenses, and telescope making took priority and he no longer had the time to continue tutoring her.

But the lives of the Herschel siblings would change yet again when William Herschel made a momentous discovery that brought him to the attention of King George III.

At the start of 1781, and since classical times, humans were aware of five planets other than Earth: Mercury, Venus, Mars, Jupiter, and Saturn. By the end of 1781, one more planet,

Figure 2 — Diethe, Alfred., Sir William Herschel and Caroline Herschel. *ca 1986. Credit Wellcome collection https://wellcomecollection.org/works/dmbmc538 under Creative Commons attribution*

Uranus (that Herschel had originally dubbed *Georgium Sidus* in honour of His Majesty) would be added to the list.

William Herschel had constructed multiple reflecting telescopes, including one with a 20-foot (6096-mm) focal length, but it was the smaller more manoeuvrable 7-foot (2133-mm) focal length "matchless" (Hoskin 15) telescope that was his workhorse.

The appearance of stars and planets through a telescope is not the same. Planets, which are closer than stars other than our Sun, have a disk-like appearance and may even present some colour. If you mark them on a star chart and return to them a few days later, you will see that they have moved relative to the background stars, as the planets are closer to us. The word planet is derived from the ancient Greek word *planetes* meaning "wanderer."

And so it was on 1781 March 13, when Herschel was scanning the stars, that he came to one object that "he could see at a glance was no ordinary star. His curiosity aroused, he returned to it four days later, and he found that it had altered position relative to the nearby stars" (Hoskin 15). However, there are other objects that can appear to move in a short span of time, such as asteroids and comets. Comets can sometimes have a coma or a tail, this had neither. He wrote a report for the local Bath Philosophical Society that somehow made its way to the esteemed Royal Society and other observers, such as Nevil Maskelyne at Greenwich Observatory. The orbit was calculated, and by 1783 this new object was accepted as a new planet.

Uprooted again, William and Caroline made the move to Datchet, near Windsor. William became the court astronomer, in close proximity to His Majesty, who would sometimes entertain guests with astronomy demonstrations after dinner. Caroline became William's unpaid assistant and developed her knowledge of the sky, aiding him in not only documenting observations, but developing a keen observing eye and eventually observing independently of William. Moving to this new town, however, meant an end to her singing career.

When she wasn't aiding William with his own observations, Caroline began observing in earnest with a reflecting telescope William had made.

"Because William could not interrupt his examination of the sky to take notes, he installed Caroline at a window to keep records with a clock and dial…and copied down his shouted instructions, going to bed around 4:00 a.m." (Olsen and Pasachoff 4).

Not only observing while William was present, Herschel's first comet discovery occurred while William was away delivering a telescope. Herschel had taught herself the sky well enough that she could identify something new or different. She stated in a letter to Dr. Charles Blagden of the Royal Society, to make her discovery known, "I have taken the opportunity of his absence to sweep in the neighbourhood of the sun, in search of comets; and last light…I found an object…I suspected it to be a comet" (Herschel 2), and she describes the motion of the object over the next few hours. This object was later to be designated C/1786 P1.

Following William's marriage in 1788, Herschel was no longer required as his housekeeper and the King was paying an annual stipend for her astronomical work. She was then able to work at her own pace and could take notes for her own observations. Her first comet discovery was no accident: she went on to discover C/35P 1788 Y1 (Herschel-Rigollet).

(This comet was rediscovered by Roger Rigollet when it reappeared in 1939, and was determined by the International Astronomical Union to have an orbital period of 158 years.)

Following that came C/1790 A1 (Herschel), and also in 1790, C/1790 H1 (Herschel). In 1791, she observed C/1791 X1 (Herschel). In 1793, she spotted C/1793 S2 (Messier), also confirmed by William (Charles Messier had seen it before her, so it was named after him).

Comet 2P/Encke was observed by Caroline in 1795, but she was by no means the only observer comet hunting. It was later in 1822 that Johann Encke suggested the orbit for this comet and was thus named for him. This comet orbits the Sun every 3.3 years, and NASA has imaged it with two spacecraft, *MESSENGER* and *STEREO*.

As Olsen and Pasachoff state, "this periodic comet could have easily had an alternate name that included Herschel" (13).

In 1797 came Herschel's last generally accepted comet discovery, C/1797 P1 (Bouvard-Herschel), which she observed not with her treasured telescope but naked eye. Given the competitive nature of comet discoveries, Herschel wasted no time in announcing this discovery. She decided to report the discovery personally to friend and Astronomer Royal, Nevil Maskelyne, by traversing the marathon-length distance between them by horse—at night, wearing a bulky dress, on a side-saddle.

The working conditions for astronomers have significantly changed since Herschel's time. The work of a modern astronomer consists of spending a lot of time in front of a computer. Sending remote instructions to telescopes sometimes on the other side of the world, analyzing and reducing data, and not going outside to observe the sky in some cases. In the case of the modern amateur astronomer, light pollution limits what visual observing can be done from cities, although brighter objects such as the Moon, planets, and stars are still frequently observed. If one travels out of the city to observe dimmer objects like comets, galaxies, and nebulae, there is a lot of equipment made to make the experience more comfortable, such as hand warmers and red-light flashlights, and clothing. Suffice it to say, modern observers do not need to observe in the constrictive, voluminous dresses ladies wore in the late 18th century. One cannot imagine what it was like to climb a wobbly ladder to look through a telescope eyepiece in such restrictive, bulky garments.

William and Caroline Herschel discovered so many objects that were not accounted for on the star charts of the day that an update was necessary. As Brock states, "Since the Herschel siblings had began sweeping for nebulae and clusters of stars when they moved to Datchet in 1782, they had dramatically increased the number of known nebulae from about 100 to 2,500" (201).

Figure 3 — Comet C/2 Encke, taken by the MESSENGER *spacecraft. Credit: NASA*

Gender stereotypes were a factor from when Herschel was a young girl. She was expected to stay home and take care of the household and not earn a wage, and later when she did finally earn some measure of independence after her first comet discovery, where King George III granted her a salary of 50 pounds a year (at the behest of William), it was a quarter of the amount that William had been awarded.

There's a modern echo in this disparity. To date, women are not always paid equally, and many women still undertake the role of unpaid carer or housekeeper. She did not want to be dependent on her brother, and independence was important to her. Rev. Wollaston's comments suggest that he's trying to justify her presence in the field as she was "sister to Dr. William Herschel."

Caroline Herschel is an inspiration to anyone wanting to pursue a career in the sciences who has experienced setbacks. Indeed, she is an example of stubborn perseverance and that obstacles can be overcome, beginning when she was a sickly typhus-stricken child with few prospects, who went on to live a long life of 98 years with many astronomical discoveries to her name and was awarded the gold medal from the Royal Astronomical Society. More than 170 years after her death, many professional and amateur astronomers still use the New General Catalogue (NGC) of objects to which she and William contributed many objects. I hope that when Comet 35P/Herschel-Rigollet is again at perihelion 72 years from now, that is still the case. ✷

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Skyward

Stars are People, too, and Sadness on Capitol Hill

by David Levy, Kingston & Montréal Centres

In last month's Skyward, I included that four-word phrase, "Stars are people, too," but the first time I used it was actually in an article about the life of the star Betelgeuse, for *Astronomy* magazine. When I met Richard Berry, the editor at the time, he began by reciting those words: "Stars are people, too." He added that he accepted the article for publication in his magazine after he read those words.

As I explained last month, stars live out their lives much as we do. They are born in gaseous stellar nurseries, or diffuse nebulae. In our sky, two of the most famous nebulae can be found: in the summer, the Lagoon Nebula in Sagittarius, and in winter, the Orion Nebula in Orion. The little stars within the nebula vary in brightness, usually by a few tenths of a magnitude, but they can change quite quickly. There are a few others in the Hyades star cluster in Taurus, the Bull. I saw one star there change rapidly over a period of a few minutes. These stars mimic the behaviour and misbehaviour of human youth.

Also like us, stars settle down as they grow older. Our Sun is an example of a star in middle age. It has shone steadily for almost 5 billion years and will continue this way for another several billion. Except for a cycle of 11 years during which the numbers of sunspots, which are storms on the face of the Sun, rise and fall, the Sun behaves constantly and predictably. There are vague hints of a 12,000-year cycle dating back to biblical times but I have not found any evidence for this.

As our Sun enters old age, it will begin to act erratically again. Its hydrogen supply will be almost exhausted. It will begin to fuse its helium. At some point during its red-giant phase, it will suffer a helium flash. This event might feature only a few minutes of strong helium fusion, but during which the Sun briefly will emit an enormous amount of energy equivalent to that of our whole galaxy. As it continues its red-giant phase, it might vary in brightness by several magnitudes over many months. Mira, a star in Cetus, the Whale, is such a star. A Mira star's core begins to contract under the force of its own gravity and whatever hydrogen is left will ignite into a shell around the core. Mira, like other red giants, was once a Sun-like star that had used up its supply of hydrogen. Once the helium is exhausted, its core will be left with heavier elements like oxygen and carbon. The outer layers of these old stars will explode as novae every few hundreds or thousands of years. Eventually, with their outer layers gone, the core will become a white-dwarf star.

If a star is much more massive than our Sun, it would end its life far more dramatically—as a supernova. Such an event is really catastrophic. There are two kinds. In the first, the smaller member of a two-star system will keep on attracting material from its larger companion. But instead of repeated nova explosions, the small star will get more and more massive. When that star's core reaches a certain limit, in less than a second, the star finally will collapse on itself and will blow itself apart.

The other kind involves a very massive star, say three or four times the mass of the Sun. Just like in the smaller star, its supply of hydrogen will be gone. With little helium left, the still contracting core is left with carbon and oxygen. When the core reaches a certain temperature, the remaining carbon will ignite all at once to tear the star apart.

If the star is very massive, say 9 or 10 times the mass of the Sun, its very hot core allows the carbon to ignite and fuse as before, but gradually, not all at once. Heavier elements like phosphorus and sulphur will be formed in shorter and shorter intervals, until silicon is generated. After just one day, the silicon will fuse into iron. Iron cannot fuse to anything heavier. Instead, in less than a second, the core will crash in on itself. In the resulting explosion, the star's outer layers will be blown away. The brightness rise is so dramatic that the single supernova will outshine its entire galaxy. What is left is either a very dense neutron star, where a cubic inch of matter would weigh a tonne or more here on Earth, or in the case of the most massive stars, a black hole forms from which even light cannot escape.

Although stars do not have consciousness like we do, they lead extraordinary lives that are well worth our appreciation and study. Don't forget: Stars are people, too.

Sadness on Capitol Hill

2021 January 6

Just one day after the Earth passed its closest point to the Sun in its orbit, its perihelion, the American Astronomical Society was having its annual meeting online, the United States Congress was validating the results of the 2020 national election, and Wendee and I were settling in for a civics lesson about the way the United States Government works.

Shortly before noon, on our television set, a news ticker appeared. It announced that two buildings in the Library of Congress (LoC), the James Madison, and quickly afterward, the Adams and Jefferson buildings, were being evacuated. That news sent a chill through me. The LoC is one of the finest libraries in the entire world. It contains more than 170 million books, of which more than 30 are books I wrote entirely or I

Figure 1 — A photograph of the U.S. Capitol Building the author took while standing under the steps on the Senate side, so the main entrance and the House side are visible.

at least wrote a foreword. It also includes all of the more than 200 "Star Trails" columns I wrote for *Sky & Telescope* magazine between 1988 and 2008, and dozens more I wrote for other magazines and journals. Only the British Library, with more than 200 million books, is larger than the Library of Congress.

This event was personal for me. A few minutes later, when the entire Capitol complex was stormed, it was personal for all of us. We all had reactions to this, but in addition to the feelings I shared with most of you, I had an additional feeling—specifically about the library.

How many books does it take to make a library? When I was a child in 1963, a teacher gave the best answer I've ever heard: "two books." For me, a library—any library—is every bit as priceless as a dark sky. The wisdom of the ages is contained in each library, from the LoC to a child's collection. I have never gone into a library without feeling better when I exited. The idea that this magnificent collection was threatened that day was terrifying.

I have read many books over my lifetime, from *The Cat in the Hat* to my boxed set of *Lord of the Rings*. One small treasure, Jene Lyon's Golden book *Our Sun and the Worlds Around It*, began a lifetime of stargazing. That gem, by the way, also lives in the LoC. What is more, I have never encountered a really bad book. When an author places her or his thoughts on paper in a book, that book immortalizes those thoughts.

I hope that Capitol Hill and the Library of Congress are never threatened again. They belong to "we the people" and stand beautifully in Washington, D.C. to govern us, teach us, and encourage us to follow our dreams and reach for the stars. ✶

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

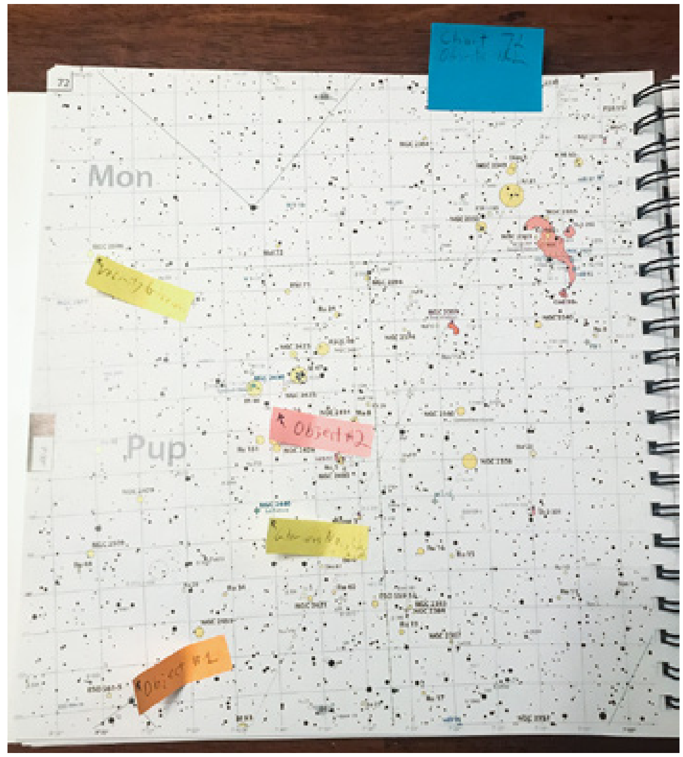
Observing

Creating Your Own Observing Program

by Chris Beckett, National Member
(cabeckett@gmail.com)

In my last article I shared some of Rev. T.W. Webb's discoveries from his *Celestial Objects for Common Telescopes*. While working on that article I became interested in many of the double stars, asterisms, and other deep-sky objects Webb observed. While these are all well-known objects, they present significant historical value, plus I found his work inspirational for small-telescope observers since he used a 94-mm refractor for most of his observations. During a prolonged cold snap this past winter, I made use of my evenings by pulling out about 120 objects from Webb's work that might make good targets for my particular equipment. I made up an observing guide and plotted the targets on my atlas, then shared a couple photos plus the document with an observing friend. While he wasn't deeply interested in my subject, he began applying the methods I use and mentioned these might be useful to other observers.

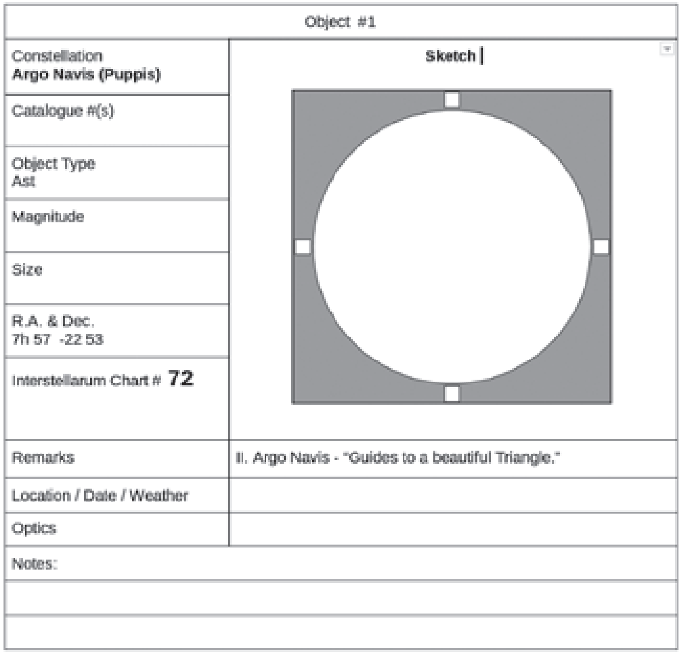
Before joining the RASC, I had already completed the Messier list and observed several hundred of the most popular NGC objects. In fact, I started attending meetings to see what other people observed and was fortunate to learn a great deal from my fellow Halifax Centre members who undertook their own personal explorations of the night sky. Additionally, magazines like *Sky&Telescope,* feature articles by deep-sky observers detailing large and small projects not formally recognized as certificates but requiring significant planning and logging. I learned a common technique was "constellation mopping" where an observer selects a constellation and works their way through it thoroughly. For example, they might observe a particular set of objects like galaxies or anything brighter than a certain magnitude. Still other observers would work through



less popular catalogues or, like one observer, observe everything in *Burnham's Celestial Handbook*!

Such self-directed sky studies are extremely fun to read about and can lead to a unique experience with the night sky unencumbered by any outside structures. However, the challenge can be to sustain one's observing interest and to organize oneself to make a series of observations often over many years and only for the sheer love of observing alone.

So, how can you turn your observing project into a sustainable and enjoyable long-term project? I decided to make up a bit of a tool kit for observers who prefer self-directed observing. In the past, I have run my own studies observing E.E. Barnard's Dark Nebula Objects, Eridanus/Taurus/Orion Molecular Clouds, Richest Field Binocular and Telescopic Wide-Field Wonders and more recently early telescopic objects and asterisms before Messier. Initially, I enjoyed just making observing guides that I would work through and discovering



Object #1	
Constellation **Argo Navis (Puppis)**	**Sketch**
Catalogue #(s)	
Object Type Ast	
Magnitude	
Size	
R.A. & Dec. 7h 57 -22 53	
Interstellarum Chart # **72**	
Remarks	II. Argo Navis - "Guides to a beautiful Triangle."
Location / Date / Weather	
Optics	
Notes:	

what was and wasn't visible through my telescopes. This progressed to taking detailed notes and eventually sketches. A word of caution though—making your own programs can result in a lot of work, and too often all the preparation in the world won't make an object too faint to see through a small telescope visible, or rewrite the inaccurate plotting by an ancient astronomer.

Where to Start?

Bring a list(s) of objects together by depositing those that catch your interest in a centralized place. You can do this using planetarium software or just some text files or even jot them on paper. When I tidy up my office, I find pieces of scrap paper where I had four or five objects listed for an evening of observing. But I've found it best to organize by interest group. One set I've enjoyed is observing telescopic discoveries before Messier. While many objects were included in Messier's catalogue, dozens ended up as lost asterisms or unfound objects. Trolling old astronomical works can yield a few interesting results and a connection with observers who have gone before us as we observe those under-appreciated stellar groupings omitted from the catalogues. As you pursue your own interests, it is helpful to use Google Docs or other online resources to act as a repository for grouping objects.

Organize Your Work

As a list takes form, note consistent details for each object, such as magnitude, right ascension and declination, as well as constellation. It is also extremely useful to sub-group the constellations by season. This will help make sure objects get observed as constellations come into visibility while others leave the evening sky. It is extremely useful to make up your own template. While a generic template might work well, typically a focused study will require your own log format to work through the set of particular objects you have selected. This will include the usual information like that which is mentioned above but it is also useful to place the notes of the original discoverer(s) or other observers alongside the chart page numbers from the specific atlases you use. This will also make referencing the charts much faster in the field and means working more efficiently under the stars.

Mark up your Charts!

I confess I messed up my first copy of *Sky Atlas 2000* badly with permanent markers, but by marking out little patterns and pointing arrows at objects before heading out under the stars, it made observing a lot more fun and enjoyable. A quick look at charts, then back to the night sky vs. trying to figure out where the heck things are on a chart, which can be all too challenging when fatigue sets in during long sessions. I've graduated to using sticky notes, large ones with the chart and object numbers for easy access in the field, along with narrow "arrows" pointing out target objects in dark colours and nearby objects of interest I just want to look at in pale colours.

Resources

Several amateurs have already rolled their own programs, including Reiner Vogel www.reinervogel.net and Alvin Huey www.faintfuzzies.com, whose websites make available some interesting observing guides, such as the Sharpless Objects and Abell Planetary Nebulae. However, their pattern of finder charts and brief descriptions is a winning combination. Use your screen capture tool to make your own custom charts from your planetarium software. The Digital Sky Survey archive.stsci.edu/dss also allows users to add finder images, though these can go much fainter than many backyard telescopes will be able to.

Other Options

If you are just getting started or recently joined the RASC and are looking for new programs, there are many excellent options already laid out on the Observing Committee pages for members and non-members alike. From Explore the Universe to Explore the Moon and now a Double Star Program, much awaits observers eager for new challenges at rasc.ca/certificate-programs. ✶

Chris Beckett is a long-time binocular and small-telescope observer and author of the RASC Observer's Handbook *WIDE-FIELD WONDERS. Since 2012 he has been the Continuing Education Astronomy Instructor at the University of Regina and enjoys observing under the dark skies of Grasslands National Park in southwestern Saskatchewan.*

Binary Universe

Stellarium in Your Pocket

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

I wrote about *Stellarium* in the *Journal* a long time ago. February 2015, in fact. That's a millennia in information technology time! I discussed the full computer product and showcased version 0.13.1. Much has changed with version 0.21.0. Now, the popular application offers planning capabilities, many different sky cultures, and support for mount control. *Stellarium* remains one of the most beautiful planetarium applications with its realistic visual display. For the first time, I took a close look at the mobile product.

Is it Free?

I cringe when people say "*Stellarium* is free." Not necessarily.

The powerful, rich, full software for Windows, Apple, and Linux is completely free.

Stellarium Mobile (SM) for Android is free but this is a stripped-down edition.

Stellarium Mobile Plus (SMP), on the other hand—with all features unlocked—is available if you hand over some cash. It's $25 at the Google Play apps store. It's $14 at the Apple App Store. That's in the same snack bracket as *SkySafari Plus*.

If I understand correctly, there is a 30-day free trial available. You can also pay as you go for a small monthly fee.

I downloaded and started using the free, minimal SM for my Android phone.

What's Possible?

What can you do with the "basic" free version?

SM shows a nicely rendered view of the night sky with coloured stars and planets with labels, some markers for deep-sky objects, and the Milky Way over a darkened landscape. Compass cardinal points are indicated with red letters. You might see an artificial satellite drift across the simulated sky.

You can easily pan by swiping and zoom in by pinching. Zooming tightly on a Messier or NGC object will reveal a rendered image (although somewhat dim). Jupiter up close shows cloud bands, the Great Red Spot, and tiny black shadows under the Jovian moons. Tap a celestial object to see its name and brief description. Swipe up to see the distance, apparent magnitude, size, coordinates, and other details.

The display sports the time and "layer" icon at the bottom of the screen. In my case, the Android on-screen controls for Home, Back, and Running Apps disappeared, allowing SM to run in full-screen mode. This creates an immersive experience, although it took me a while to figure out how to get out of the app!

Tapping on the "layer" icon reveals a small toolbar (see Figure 1). The Grids and Lines button toggles the azimuthal grid with values. Constellations show the familiar stick figures,

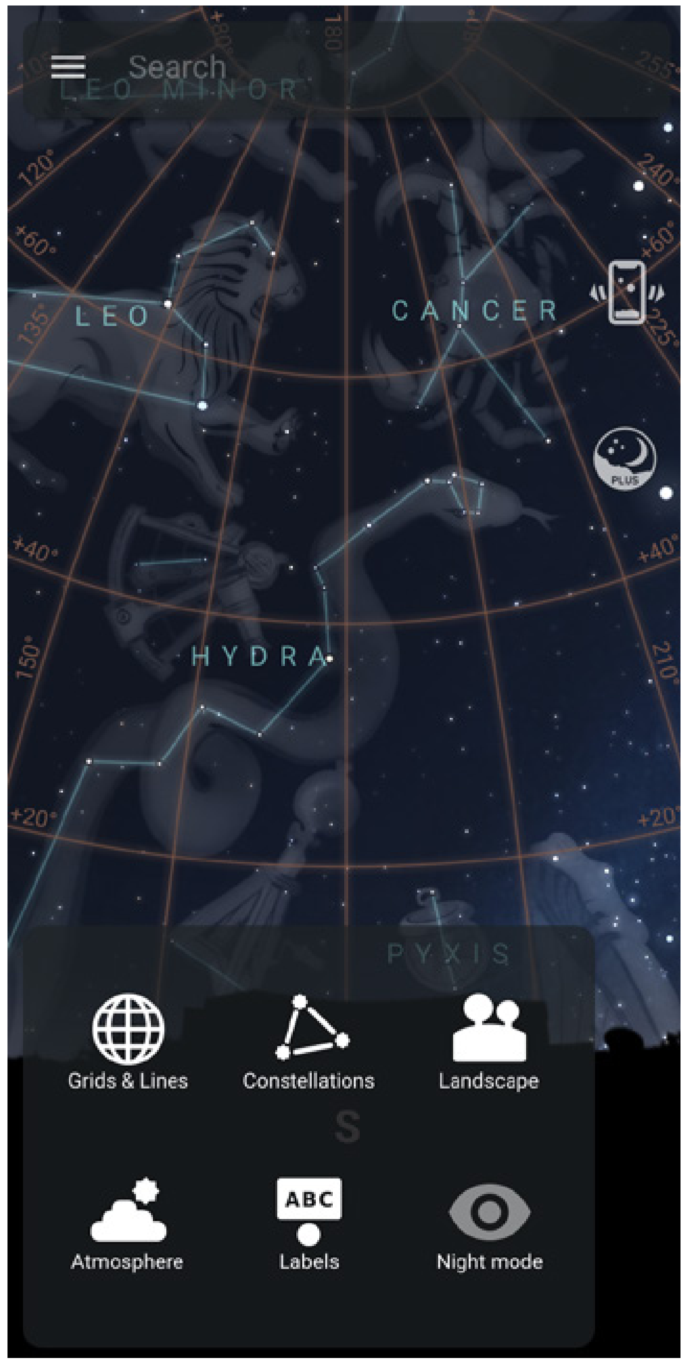


Figure 1 — Constellations, artwork, and gridlines showing in the simulated sky of Stellarium Mobile. *Toolbar offers toggle buttons.*

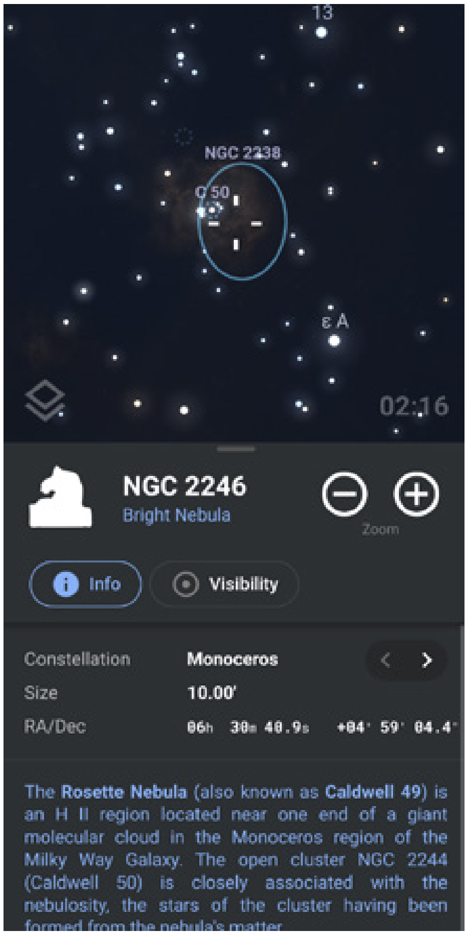


Figure 2 — Stellarium Mobile *with Rosette Nebula selected. Detailed description shows below the starfield and zoom buttons.*

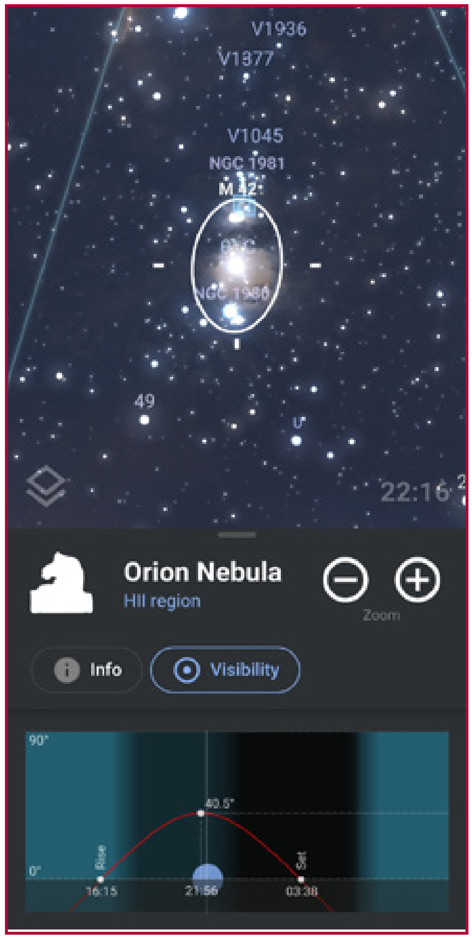


Figure 3 — The Visibility graph shows when the Orion Nebula rises, culminates, and sets in the evening.

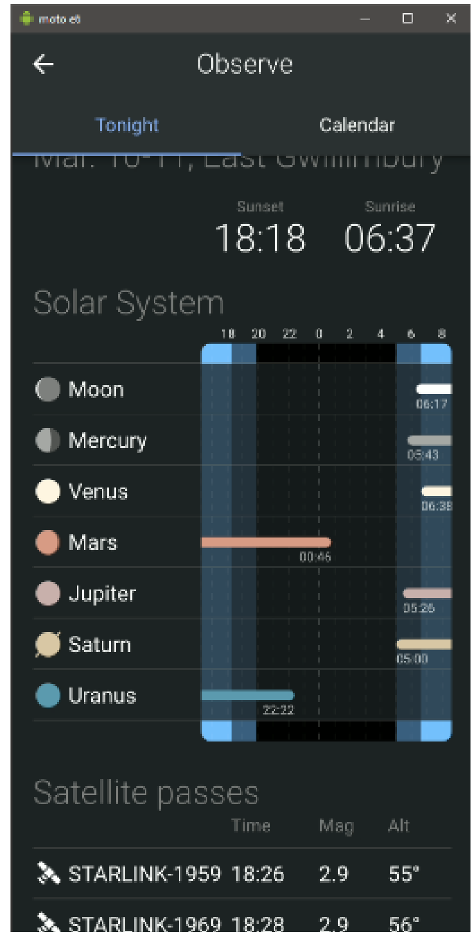


Figure 4 — The Observe menu Tonight display shows a planet visibility bar chart and lists satellite flyovers.

names, and artwork (Western culture). You can switch the Landscape off, if necessary, along with the Atmosphere. The Labels button toggles the text beside stars and planets together with the deep-sky markers. Night Mode changes the entire screen to red.

It's not obvious, but a long-press action on these buttons offers more commands. In Constellations, there are independent controls for the Lines, Labels, Drawings, and Boundaries. The Centered Only emphasizes one constellation at a time. Hold the Landscape button for different scenes.

If one taps on the clock at the bottom-right, a small panel appears. Tapping on the date or time here brings up a control for jumping to a specific date.

Tapping on nothing or in empty space makes the search bar appear along with a menu icon. Searching or browsing by type is straightforward; searching by location is accomplished by entering full coordinates. When you tap the "hamburger" or three-lines button, a menu appears. We are given options for changing our Location, adjusting Settings, and reviewing Help. The padlock icon reminds us we're using a limited edition.

What's Different?

Stellarium Mobile is not an exact "port" or transfer of the desktop computer software to a small device. It is different in a number of ways.

The app supports portrait orientation, given the common way we hold our phones. The ground automatically turns transparent and object names appear when you look down. The time control offers arrow buttons to advance or retreat one day and the slider can be used to do time-dragging. On-screen zoom buttons are provided! Extraordinarily rich text accompanies selected objects, revealed by swiping up again (Figure 2). Like many of the other mobile planetarium apps, you can employ the phone's sensors, while aiming carefully, to determine what you're looking at.

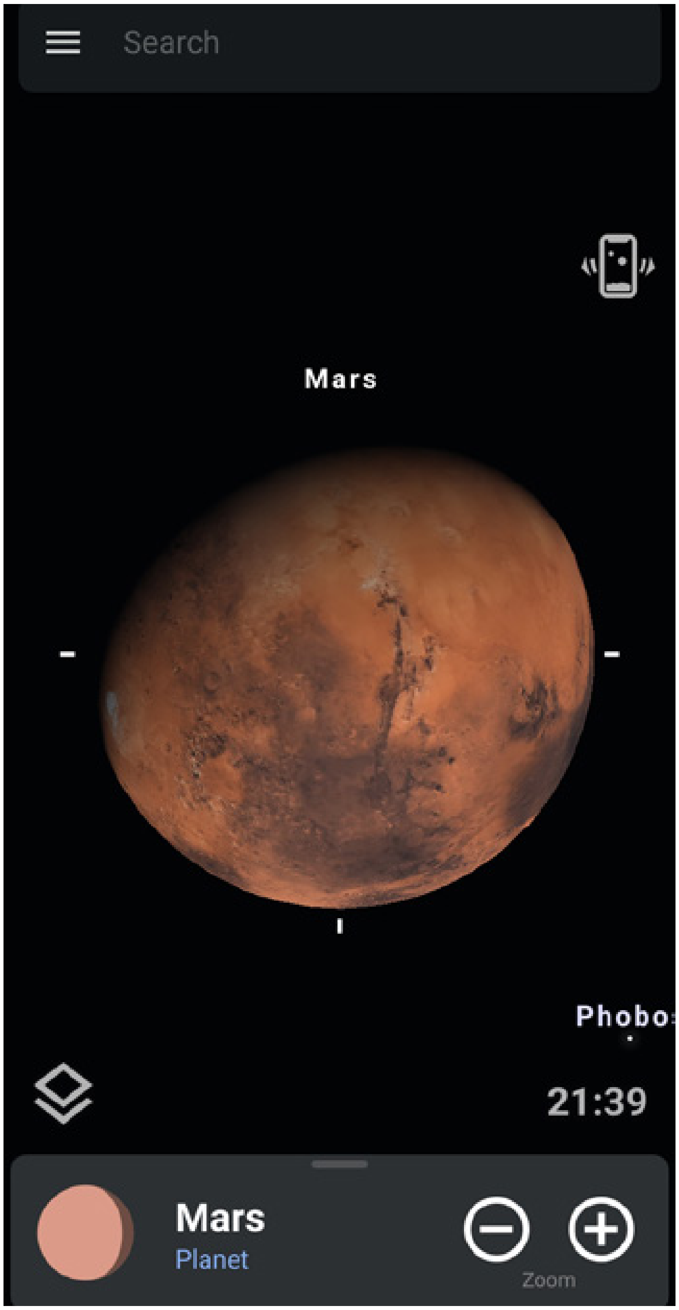


Figure 5 — Stellarium Mobile, like the desktop product, shows realistic planet views with moons.

What's Extra?

A number of capabilities are unlocked with money. Installing the *Stellarium Mobile Plus* app takes about 10 minutes, while the extended data is downloaded. This includes more than one billion stars from the Gaia DR2 dataset, many asteroids, two million deep-sky objects, and high-resolution planet images.

In the object information panel, the Visibility button shows a night chart alluding to when the Sun will set and rise and the impact of moonlight (Figure 3). A line indicates when the object will culminate.

The equatorial grid, ecliptic line, and the meridian can be shown in the paid version. There's a Light Pollution slider under Atmosphere. Additional label settings allow adjustments to the text density for stars, Solar System, deep sky, and satellite objects.

The menu command Observe shows a table with planet and satellite flyover predictions on the Tonight tab (Figure 4). The Calendar reveals an impressive list of upcoming events for the next six months! All these listed items can be selected, and you then view the object in the virtual sky at the designated time.

The unlocked Instruments menu provides access to the telescope submenu. This allows the phone to be used as a controller. There is support for NexStar, SynScan, or LX200 mounts by WiFi. Also, Bluetooth or a USB Host adapter may be used on an Android phone. With the unlocked Oculars submenu, you can enable Telrad circles or configure the shape, size, and orientation for an eyepiece or camera outline. That's like the Field of View circles in the desktop app. I ran into a strange issue at this stage where I could not properly enter a label for the custom eyepiece, but it was caused when my phone was tethered to my PC.

Accessible Advanced Settings let you control how the app starts, the limiting magnitude for dim stars, and the brightness of stars and nebulae.

What's Missing?

I didn't have high expectations. There's no way that every feature found in the full computer-based application would exist in the mobile product but there were a couple of things I had hoped for. It was irksome not being able to turn off the cardinal points. It looks like you cannot use custom locations or landscapes. I haven't noticed any meteors zipping through the simulated sky. Alas, these are minor issues.

What's Surprising?

Again, I did not expect *Stellarium* on a mobile device to be very thorough, so I was pleasantly surprised while testing the app. The free SM product, is decent and looks good—that famous *Stellarium* realism "wow" factor.

When you pay for SMP, many excellent features become available.

I tested version 1.6.5 and enjoyed the clean interface and realistic sky. Over the course of writing the article, a number of updates were applied, up to version 1.7.1. The *Stellarium* app is provided by Noctua Software Ltd, run by brothers Fabien and Guillaume Chereau, and is available for Android and iOS. It is rated 4.7 for Android and 4.8 on the Apple App Store.

There is extensive documentation onboard and on the web. From the website one can access a forum to interact with other users and the developers. See the *Stellarium* Labs site for more information. www.*Stellarium*-labs.com

I was excited to display a realistic globe view of Mars (Figure 5)! Sadly, there are no labels for albedo features.

Want *Stellarium Mobile Plus?*

Do you want Stellarium in your pocket? When discussing the app with the Stellarium Labs crew, they graciously sent over some promotion codes. We have four codes for Android users interested in upgrading to the unlocked full version of the app. We have one code for an iOS user. Let me know if you'd like a Stellarium Mobile Plus code. First come, first served.

I thank John Wunderlich for helping me test SMP on an iOS device and Rhonda Gribbon once again for proofing my drafts.

Bits And Bytes

Aladin 11 is out! I reviewed version 9 in July 2016 and have been using 10 (with dark mode) for a while. I expect 11 to be better still.✶

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

John Percy's Universe

Sixty Years a RASCal

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

I joined the RASC in 1961, probably at the urging of my professors Jack Heard and Ruth Northcott. This "diamond jubilee reflection" is not intended to be a scholarly addition to RASC history: Peter Broughton's (1994) excellent book does that. Nor will I provide any earthshaking revelations!

In 1961, some professional astronomers, such as Jack Heard and Ruth Northcott, were active in the RASC. Not until the founding of the Canadian Astronomical Society (CASCA) in 1971 did professionals have a society of their own. This year, CASCA is celebrating its 50th birthday! Some professionals remained active in the RASC and contributed significantly to its leadership and publications. They became my "kindred spirits." Most RASC members were amateurs and greying white males, as they still are today (and as I am). For me, they were a new breed; I had not been an amateur astronomer in my youth. They had a variety of interesting day jobs, but they turned into astronomers at night. People like "Fitz" FitzGerald and Vern Ramsay definitely had an impact on me. Looking back, I have met many award-winning astronomy writers, astrophotographers, historians, instrument-builders, educators, and discoverers and keen observers of comets, asteroids, variable stars, and more—all of them technically "amateurs." Now the RASC has an array of awards to honour these superstars as well as others who voluntarily keep our Society operating so well.

National Council

In 1965, I joined the National Council as Librarian. I unwrapped, catalogued, and shelved the incoming books and journals—and read some of them with interest. The library at 252 College Street seemed like a wonderful old museum, with books and *Journal*s going back almost a century. But sparkling conversation with Executive Secretary Marie Fidler livened it up. After her departure to Calgary, Rosemary Freeman was equally cheerful and efficient.

National Council meetings were always interesting and enjoyable. They included the kindred-spirit professionals, and a very diverse and impressive group of amateurs from across the country. They helped to kindle my interdisciplinary interests in astronomy.

Publications were always on the agenda. The Handbook was our cash cow; the *Journal* was more problematic, as I discuss below. That was one part of the problem of how to serve a diverse membership, which included professionals and amateurs with a wide range of expertise and interests. And how could we serve members in the two francophone Centres? Our publications were primarily in English. The growth of the Fédération des astronomes amateurs du Québec (FAAQ) has solved that problem for them. We should partner with the FAAQ where appropriate and possible. There was always some tension between the Centres and the National Society, especially as to how the membership fees should be divided up. Nevertheless, I regard the RASC as an exemplary balance between local and national activities.

There was more to the RASC than serious business. The General Assemblies are a highlight. That is one way that my wife, daughter, and I got to see Canada from coast to coast. I particularly enjoyed GAs that were joint with organizations such as AAVSO and CASCA, including the RASC, AAVSO, and Astronomical Society of the Pacific "heat wave" conference in 1999, around the theme "Amateur-Professional Partnerships in Astronomy." The GAs highlighted the Centres and their members, their different personalities, their achievements, their local astronomical facilities—and tourist attractions. The GAs also brought the National Society to the Centres. And the GAs are fun!

As President, I set out to visit all the Centres. Due to crossed wires, the St. Johns Centre was not expecting me, but I spent a pleasant afternoon tea with the inimitable Dora Russell. I even revived my fractured high school French to visit and address the two francophone Centres. But I was sesquilingual, at best, and still am.

The *Journal*

A century ago, the *Journal* was a showcase for Canadian astronomy but, by the 1960s, most professional content was published elsewhere. *JRASC* continued to publish some research papers, abstracts, and other professionally oriented material. The publishing costs were covered by authors' page charges, but the mostly amateur members were rightfully concerned that the majority of the *Journal* content was not of interest to them.

Although I was not directly involved in editing the *Journal* (other than helping Ruth Northcott with the centennial issue—Vol. 61, #5, Oct. 1967, which I can still recommend), I had a part in three initiatives to make the *Journal* more suitable for a wider audience. The first was to serve as the first editor of the *National Newsletter*, a "green pages" insert that contained articles and information specifically for and about the Centres and their members. The second was "Education Notes," a column reflecting my interests, and the fact that RASC members were active in many forms of education and outreach; and there were very few other journals that published education papers. The third was to serve as book review editor from 1989–1995. As long as books and other such resources are created, especially by Canadians, there should be a place for thoughtful reviews. And I've published over 135 papers in *JRASC*, a third of them since 2013, i.e. this column.

I'm very glad that the *Journal* has gradually evolved into its present form. Along with *SkyNews*, it provides our members with excellent resources for astronomy, broadly defined. I remember *SkyNews* when it was a newsletter created by Mary Gray in Ottawa, and then as a first-class magazine edited by Terry Dickinson. Congratulations to the present editors, staff, and contributors to our publications. I read your material faithfully!

The Handbook

From 1970 to 1980, I edited the *Observers Handbook*. I had been assisting Ruth Northcott in the last year of her life, and was motivated to continue her work. The *Handbook* was the RASC's main source of revenue. Besides, most of the work was done by the enthusiastic volunteer contributors—more kindred spirits—and by my summer students, and by the Executive Secretary. Among other things, I added two new sections that reflected my interests: "Variable Star of the Year," and "Teaching and the *Observer's Handbook*." The former has been continued by the AAVSO; the latter by Heather Theijsmeijer, and more recently by Julie Bolduc-Duval. I have marvelled at the growth of the Handbook in the last 40 years, especially under the editorship (and continuing contributorship) of Roy Bishop.

The Toronto Centre

When I joined the RASC in 1961, the Toronto Centre met in a rather stodgy university lecture hall. I remember my first meeting well. When the McLaughlin Planetarium opened in 1968, the Toronto Centre moved there. We had a modern, comfortable lecture room that encouraged informality and interaction. The council included both younger members and women, as you can see from the group photo in Broughton (1994), page 273. We had an especially active group of youth members, particularly from Don Mills Junior High School, and later Don Mills Collegiate. Some of this group eventually went on to become professional astronomers. I remember chasing my first and last occultation. I didn't catch it. Randy Attwood and colleagues created the highly professional *Astronomy Toronto* cable TV series. There were star parties; the ones for Comet Halley attracted thousands of people—in mid-winter. The Centre partnered in many ways with my astronomy group at the University of Toronto. They still do.

Later, I served several terms as Second Vice-President, with the specific duty of finding interesting speakers for our lecture meetings. With my interdisciplinary interests and connections, and arm-twisting experience, I found an endless supply. I (and often my wife) got to take them and other council members to a very pleasant dinner at a local restaurant before the meeting. Those were happy days for the Centre, and for me.

The 1980s and 1990s

Having finished with the ten-year presidential ladder, I settled into a more advisory role with the RASC, and became active in the RASC's older sister—the Royal Canadian Institute for Science (then just the RCI). The RCI, an occasional RASC lecture co-sponsor, was two decades older than the RASC's predecessor, and much more formal. The president's wife had been expected to help serve tea after the lectures. Black tie had been *de rigeur* at the annual meeting. At the RASC's annual meetings, however, there were songfests by some of our younger members, and a human pyramid! But there were exciting new RCI projects in the 1980s, including a science radio series, and a Youth Science Academy co-led by Sara

Seager, now an eminent astronomer and RASC Honorary Member. Engaging youth in the RCI—or the RASC—has always been a challenge. So has making the membership more diverse.

In the 1990s, I spent six years as Vice-Chair of the Board of Trustees of the Ontario Science Centre. Halfway through my term, a change of provincial government brought the "Common-Sense Revolution," which, among other things, prompted the unfortunate and (in my opinion) unnecessary closure of the Royal Ontario Museum's McLaughlin Planetarium. The Toronto Centre needed a new home, and the OSC offered one. In fact, the OSC became the *de facto* centre for school and public astronomy outreach in Ontario. The OSC had a small but powerful planetarium, but a larger one was needed in our city, and still is. I made a strong pitch to the OSC leadership, but they had just finished building Ontario's first OMNIMAX theatre, in difficult times. A new and larger planetarium was not in the works.

The Later Years

In 2003, Randy Attwood and others established the Mississauga Astronomical Society, which in 2006 became the RASC Mississauga Centre. The University of Toronto Mississauga, where I had been based since 1967 (Percy 2016) became their home. I and my colleague Ulrich Krull—a keen amateur astronomer and later Principal of UTM—were their sponsors. They were UTM's instant astronomy club. UTM already had scientific and educational partnerships with the nearby Riverwood Conservancy, Mississauga's "Central Park," and the Conservancy became home to the Mississauga Centre's monthly star parties. It was a partnership made in heaven!

Meanwhile, during these times, the Toronto Centre was developing its E.C. Carr Observatory under dark skies near Thornbury, Ontario, and, for a few years, was operating the David Dunlap Observatory in Richmond Hill as well. Congratulations to all the volunteers who did this, while carrying out all the other Centre activities!

Around the millennium, I drifted away from the RASC, busy completing my book (Percy 2007) and preparing for "retirement." But I did co-nominate the RASC for the prestigious national Michael Smith Award for excellence in science promotion and was delighted to attend the award presentation in Ottawa. And I did follow the very important work that was being done by National Council to revise and strengthen the RASC's governance structure, and to encourage more revenue from donations and grants. Very few professional astronomers were now involved in RASC leadership, but we do have an Executive and Board with very strong and diverse talents that are so essential for the RASC in the 21st century. Thank you! But when will we have another non-professional female president? Or was Mary Lou Whitehorne unique?

As International Year of Astronomy 2009 approached, I got swept up in Canada's preparations, under the inspired leadership of Jim Hesser. It was an outstanding success, with over 3,700 events reaching almost 2 million people, an exemplary partnership between amateur and professional astronomers and educators across the country, including CASCA, FAAQ, and RASC.

Then in 2013, I was invited to become RASC Honorary President, an honour that I was delighted to accept—especially following in the footsteps of Jim Hesser. But what could I do as Honorary President? Another cross-country tour of RASC Centres? For various reasons, I had given up most travelling, so I came up with the idea of this regular column in *JRASC* as a way to share my interests and experiences with you, the members and readers. Having the 2019 GA in Toronto, at York University, jointly with the AAVSO was a real treat—icing on the cake! I could get there on the subway!

I predict that the RASC will continue to thrive. Astronomy generates science interest, engagement, and literacy for people of all ages. It can be an inexpensive (for most people!) hobby that connects them with the sky and with the rest of the natural environment. Times may change, but the Universe will always be there.

Acknowledgements

It's a pleasure to thank the hundreds of other RASCals who have made my time in the RASC so enjoyable and productive and continue to do so. In my initial draft of this column, I mentioned a lot of people who stood out, but then I thought of so many other names that I should include, so I have named names sparingly. But you know who you are. Special thanks for the Honorary Presidency, and for the opportunity to contribute this column. Special thanks also to Peter Broughton, whose centennial history of the RASC provides a detailed, accurate, and engaging backdrop to these informal reflections. I re-read it before writing this column. ✶

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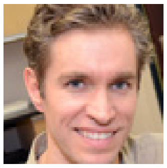
John Percy FRASC is Professor Emeritus, Astronomy & Astrophysics and Science Education, University of Toronto, and a former President (1978–1980) and Honorary President (2013–2017) of the RASC.

Dish on the Cosmos

M87's Magnetic Jet Engine



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

The Event Horizon Telescope (EHT) made the headlines again by revealing the magnetic properties of the black hole in the centre of the nearby galaxy M87. The first images released by the EHT in 2019 showed the shadow of the supermassive black hole, shaping the radio emission from the hot plasma around the black hole. There, the shape and brightness allowed the EHT team to measure the properties of the black hole and study the environment near the event horizon for the first time. However, the radio emission that was key to those first results also carries information about the magnetic field. New, careful measurements of the EHT data have revealed that magnetic fields play a major role in shaping the environment around this massive black hole and driving fast jets of particles out of the galaxy.

The EHT is a global collaboration between submillimetre telescopes to make images of black-hole environments with the highest resolution possible. Black holes themselves do not give off any light, but they do bend light passing around them, and the extreme conditions in the matter spiralling into the black hole causes it to emit light across the electromagnetic spectrum. The EHT focuses on the long-wavelength light for two reasons. First, the black holes in galactic centres are frequently obscured from view by dust. At long wavelengths, the dust cannot block the light, so radio waves pass through these dust clouds unaffected. Second, the EHT relies on radio interferometry, meaning that the individual telescopes must be able to precisely time the arrival of the light wave at each telescope. This is only possible for relatively long-wavelength, low-frequency light. Thus, the EHT focuses on light with a wavelength of about 1.3 millimetres (frequency of 230 gigahertz).

The new results from the EHT rely on measuring the polarization of the electromagnetic radiation. Figure 1 shows the two parts of an electromagnetic wave: the oscillating electric and magnetic fields, which are perpendicular to each other. The polarization of a light wave has a specific orientation defined by the direction of its electric field (vertical, in Figure 1). Most light that we see is a mixture of all electric field directions and is said to be unpolarized. In astronomy, fully polarized light is also rare, and most emission we see is either unpolarized or partially polarized, where there is a slight preferential direction to the orientation of the light. Polarization of light occurs in two main cases in astronomy: either visible light reflecting off dust grains in reflection nebulae like the Horsehead Nebula or

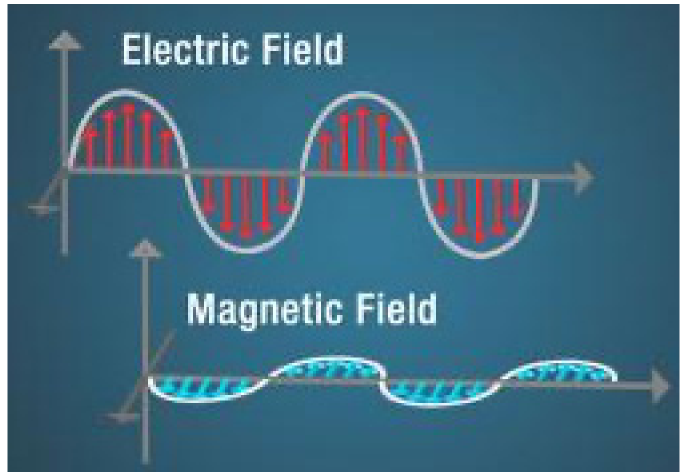


Figure 1 — Anatomy of a light wave. The two graphs pull apart the electric and magnetic fields of an electromagnetic wave, showing their relative orientation and the direction of travel (to the right). The polarization of a light wave is set by the orientation of the electric field. Image credit: NASA.

when the emission comes from magnetized gas, as is the case for emission from M87.

Figure 2 shows three different views of the millimetre-wave emission from M87, progressively zooming in on the black hole. In each case, the shape of the radio emission is shown, but the striping across the figure shows the direction of the polarization of the emission. In the largest-scale figure, the mapping shows the long jet of light that is being blown out of the black hole. The jet consists of high-energy particles that have been accelerated to near the speed of light by the extreme conditions near the black hole. The powerful jet extends well beyond the M87 galaxy and carries a vast amount of energy: about the same amount of energy as is produced by all the stars in the Milky Way galaxy. One of the main reasons to study black holes is to find out how exactly these jets are driven. In this image of the jet and the next zoomed-in scale, the polarized emission is tangled, showing the chaotic interplay between the magnetic field and high-energy particles in the jet.

The bottom part of Figure 2 shows the main result from the EHT: the polarization image of the emission near the black hole itself. This image shows the now-classic ring of emission around the shadow of the black hole, but the striping texture from the polarization measurements are new. These are shown spiralling around the location of the black hole, indicating the structure of the magnetic field.

While the shape and brightness of the emission ring was key to the original EHT results, these new data tell us more about the environment in the immediate vicinity of the black hole. The first result is the amount of the polarized light: only a few percent of the total emission. However, the presence of any polarization at all confirms that the light we are seeing

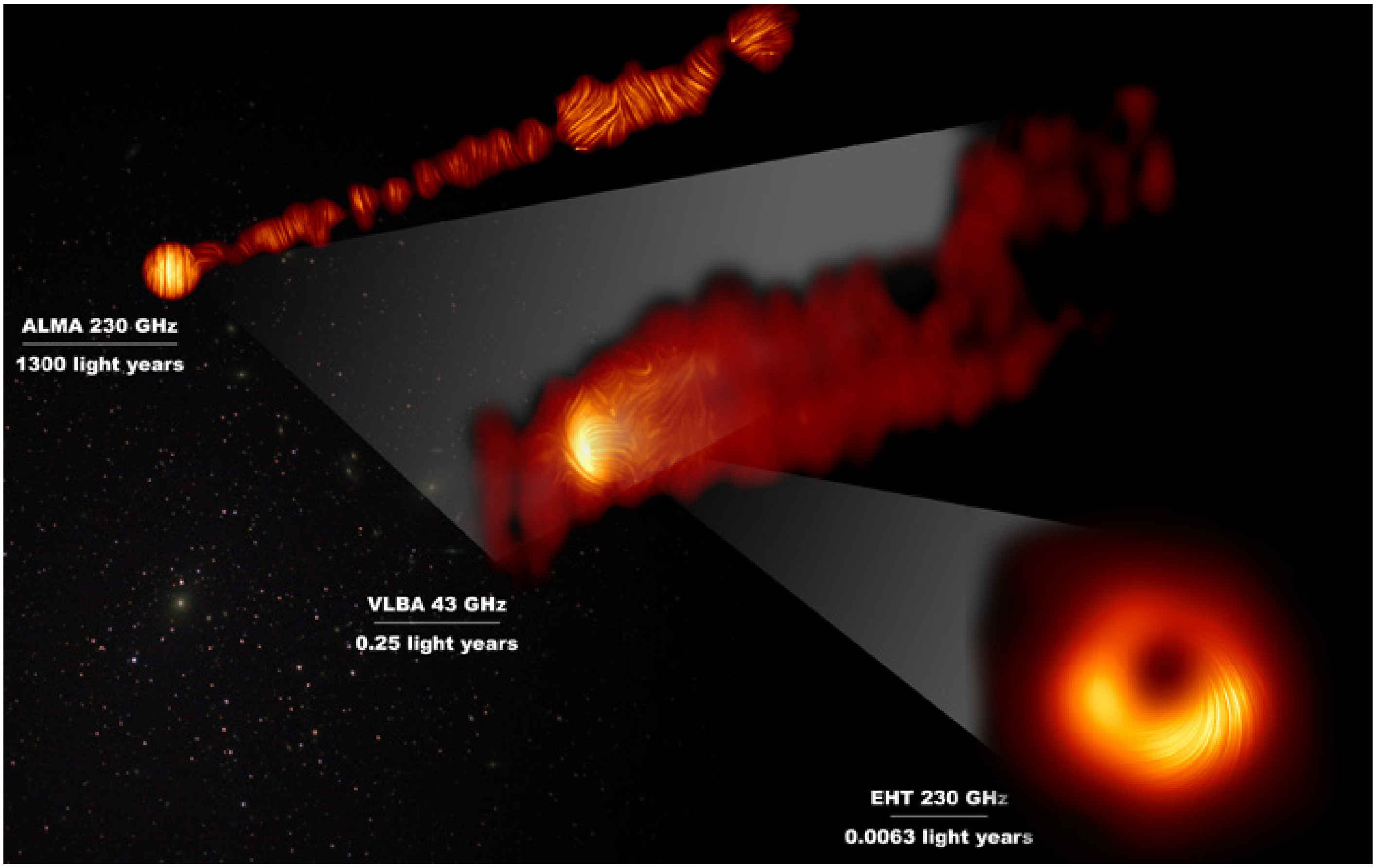


Figure 2 — Three views of the polarized emission from the black hole at the centre of the nearby galaxy M87. The top two views show the large-scale view of emission captured by the ALMA telescope. These two images show the relativistic jet of emission extending from the black hole and the texturing on the image shows the direction of the polarization of light. The bottom panel is the new image from the Event Horizon Telescope, with the texture showing the structure of the polarized light near the event horizon.

is from synchrotron emission, which arises when high-speed electrons orbit around strong magnetic fields. The synchrotron emission is normally strongly polarized, so the relatively low polarization fraction implies that the magnetic field is tangled up near the event horizon. Since the magnetic field is tangled, the strongly polarized emission comes out at many different angles and the average of those angles only weakly favours the direction indicated in the image.

Despite most of the information about the magnetic field direction being lost in the tangle, there are still enough clues to learn about the general properties of the magnetic field near the black hole. These insights come from computer simulations: experts in the theory of black holes and general relativity build large suites of simulations using supercomputers, with the hope of capturing all the possible shapes of the magnetic field and plasma near the black hole. Then, these simulations are put through a series of tests to determine which, if any, of the models match up with the pictures being obtained from the EHT. Despite starting with a large number of contestants, there are only a few winners for this look-alike contest. These look-alikes are not necessarily the exact description of what is happening near the black hole, but they are our best guesses.

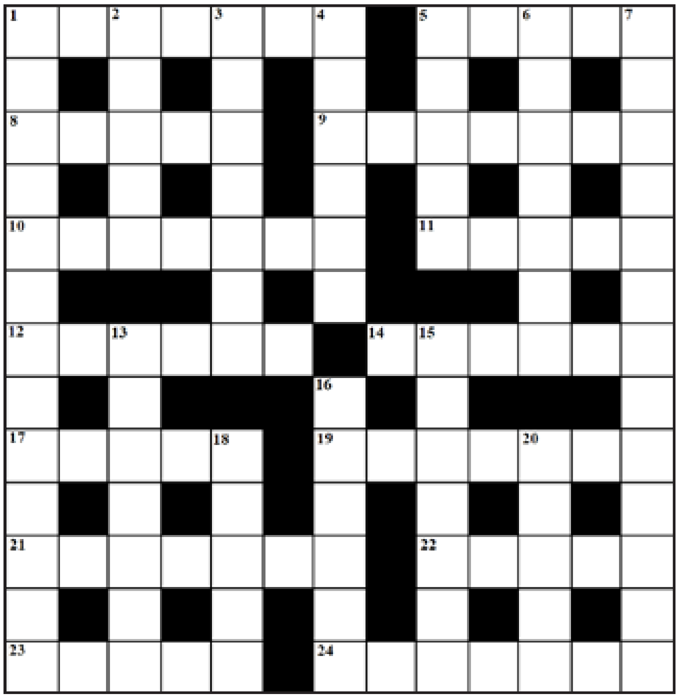
However, every one of the good matches features a strong magnetic field wrapping around the synchrotron-emitting plasma. These strong fields make it hard for material to fall into the black hole, but they also start to explain the engine that drives the strong jets coming from the galaxy.

The final, new result that came from this study is that the emission structure is changing. The EHT can actually see the effects of knots of gas and the tangles of the magnetic field twisting around the black hole. These first observations only noticed these changes, but the next observation campaigns with the EHT will be focusing on how the field structure is changing over time. The EHT work has been paused because of the COVID-19 pandemic, but, as I write this, ALMA is slowly starting to make new observations. Over the next two years, a clearer picture will emerge about the turmoil on the event horizon. ✶

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

Astrocryptic

by Curt Nason



ACROSS

1. Stellar horseman hears you in a dizzy trance (7)
5. Percival Lowell at U of T, Ontario for capital talks on Planet X (5)
8. Prime lens maker first named in Central Vancouver (5)
9. Horsehead once was a black and deep brown horse (4,3)
10. Sister campaigns for a Sun god (7)
11. Planets reflect on what stars do (5)
12. Oumuamua foreteller in stationary orbit (6)
14. Orbiter backed a light year between Saskatchewan and Alberta (6)
17. Dwarf swallowed by a sorceress (5)
19. Who makes solar filters to see Venus after sunrise? (7)
21. Al's Laugh-In star is eagle-eyed (7)
22. Uranium with coil twisted around dome windows (5)
23. Dutch icon seen in nebula by Cygnus X-1 (5)
24. Smoothing time for Hesperus (7)

DOWN

1. President of our wonderful Universe (8,5)
2. Oven breaks around a number of afterburners (5)
3. Talk in a funny way about a winter star (7)
4. Tires made for such velocity (6)
5. Trojan possibly seen at Cassini's observatory (5)
6. After hesitation, cheese begins lap around Uranus (7)
7. Run Gen Y boxing camp on process of massive stars (6,7)
13. Cause of atmospheric extinction or a sole eruption (7)
15. One can peek through it at a cloud in the keel (7)
16. Nodes upset to the east of where Tycho once lived (6)
18. RASC turned quietly toward a lunar fault (5)
20. Doughnuts soundly obtained from the bull (5)

Answers to previous puzzle

Across: 1 CRATER (2 def); **4** BRIGGS (hom); **8** IAPETUS (I(m=a)petus); **9** PARKS (hom); **11** ESSEN (hid); **12** RYDBERG (2 def); **13** COMPTON (anag, p=n); **15** MOUNT (2 def); **16** LASER (anag); **18** MINTAKA (mint+aka); **20** SPITZER (an(t)ag); **21** MAORI (anag); **22** STARRY (2 def); **23** AMUSES (2 def)

Down: 1 CHI HERCULIS (an(E)ag); **2** ALPES (anag); **3** EXTINCT (2 def); **5** RAPID (anag+d); **6** GARNEAU (anag+au); **7** ASTRONOMERS (anag); **10** SAGITTARIUS (anag); **14** MUSCIDA (Musc(ID)a); **15** MINIMUM (mini+mum); **17** RAZOR (R+az+or); **19** ATOMS (anag)

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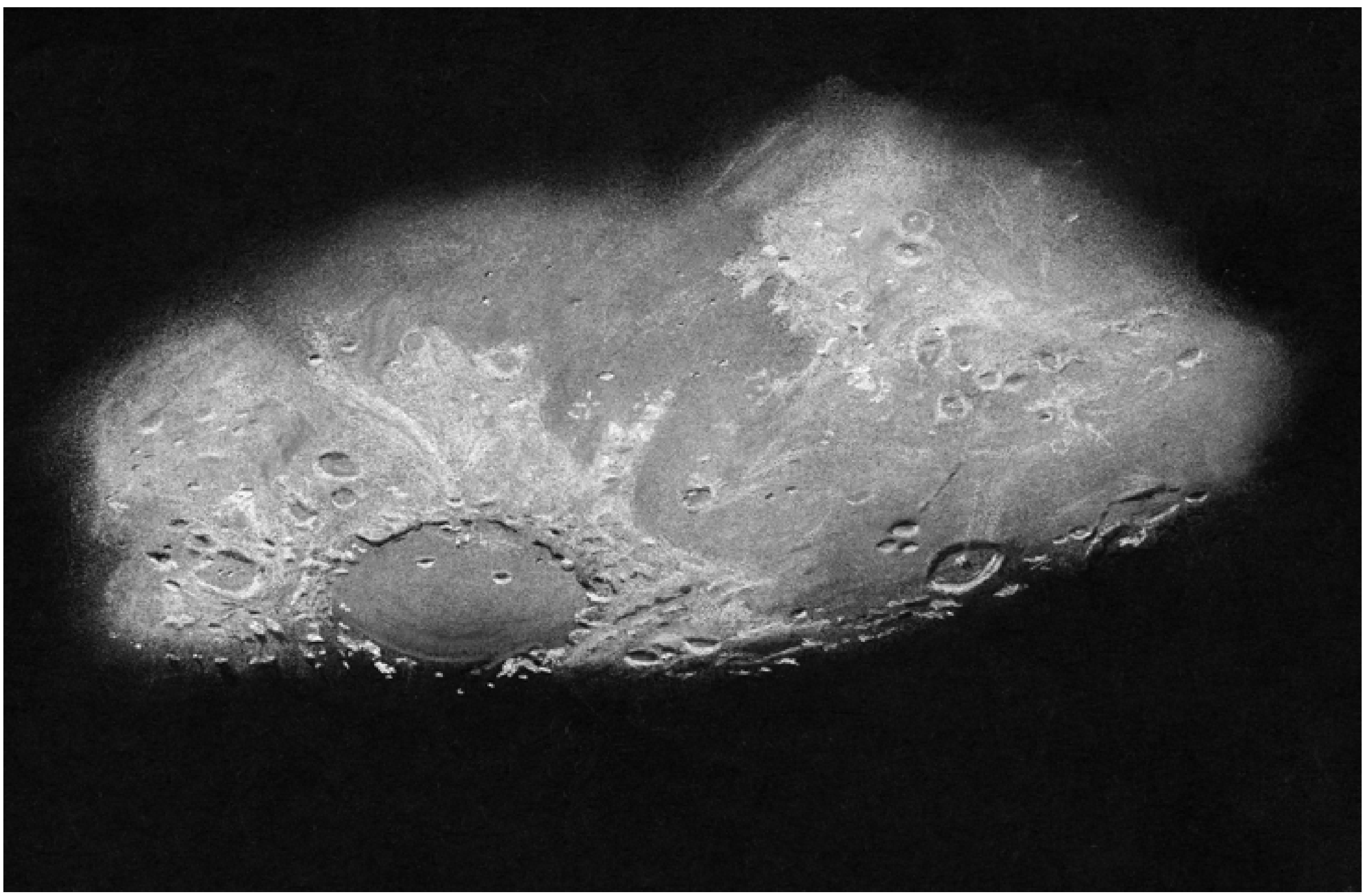
- Discovery through the scientific method

Great Images

by Erik Klaszus



This image of the Moon's Mare Crisium and neighbours was sketched by Eric Klaszus on 2020 December 1 from the Calgary Centre's Wilson Coulee Observatory. The telescope is a Celestron C14, and Eric used a Tele Vue Panoptic 24-mm eyepiece with a magnification of 163×. He used white, grey, and black pastels on black paper.

Journal

This intricate narrowband image of the Bubble Nebula was taken by Ed Mizzi from his observatory in Waterdown, Ontario, in June 2020. The nebula is located in Cassiopeia, roughly 7,000 light-years from Earth. Ed used his Sky-Watcher Esprit 100 APO telescope and a ZWO AS 183 Mono camera, sitting on an EQ6-R Pro mount with Sequence Generator Pro and the image was stacked and processed using PixInsight.