The Journal of The Royal Astronomical Society of Canada

# Journal

Le Journal de la Société royale d'astronomie du Canada

PROMOTING ASTRONOMY IN CANADA

June/Juin 2020
Volume/volume 114
Number/numéro 3 [802]

*Inside this issue:*



*Carina's Jewels*

# The Best of Monochrome.

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

*Michael Watson imaged our beautiful Luna using a Nikon Z7 camera body on Explore Scientific 152 mm (6") apochromatic refracting telescope, mounted on a Sky-Watcher AZ-EQ6 SynScan mount at ISO 80, for a 1/250-second exposure at ƒ/8. He processed the final image in Photoshop CS6. Michael says, "Something noteworthy about this view is that the Moon's sub-Earth point (libration) was 6.2 degrees south, which is close to the maximum for 2020. So, for example, the prominent crater Tycho appears noticeably closer to the centre of the Moon's disk than usual, and we can see a corresponding amount 'around' the south pole of the Moon."*

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*This beautiful image of NGC 3324, found in the southern constellation Carina, is a collaboration between Russ Jacob in Australia, who acquired the data, and Shawn Nielson from Kitchener-Waterloo, who processed the image in the SHO palette (silicon, hydrogen, and oxygen). It was imaged using a Sky-Watcher 8″ ƒ/5 reflector with a ZWO ASI1600mm pro cooled CMOS camera on an NEQ6 Sky-Watcher mount, and Hα, OIII, SII 6.5-nm Astronomic filters for a total of 6 hours. Processing was done in PixInsight.*

Journal

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



Her Excellency the Right Honourable **Julie Payette**, C.C., C.M.M., C.O.M., C.Q., C.D., Governor General of Canada, is the Viceregal Patron of the RASC.

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# President's Corner

*by Christopher Gainor, Ph.D., Victoria Centre (cgainor@shaw.ca)*

During my term as president, The Royal Astronomical Society of Canada has faced some unusual challenges, but no one will be surprised to learn that all of them were eclipsed by the coronavirus pandemic that struck Canada and much of the rest of the world with great force starting in March.

With the social distancing measures that led to closures of businesses and organizations and cancellations of meetings and other events, it is hard to think of any organization that has not been affected by COVID-19. The RASC National Office was closed, staff picked up their work at home, and all manner of RASC meetings and public outreach events, including the 2020 General Assembly in Vancouver, have been cancelled, postponed, or shifted to cyberspace.

As an historian and a proud member of the RASC History Committee, I have spent some of my enforced time at home in recent weeks researching the history of this Society to see if the actions we have taken to cope with the coronavirus are actually without precedent in the more than 150 years since the RASC's beginnings in 1868.

It turns out that a century ago, Canada and the RASC were emerging from the great influenza pandemic that ranged through much of the world from 1918 to 1920, claiming about 55,000 Canadian lives and more than 50 million lives worldwide. I found that many RASC meetings were also cancelled during that pandemic, and some Centres, already weakened by the impact of World War I, went under, at least temporarily.

The influenza pandemic struck in four waves spread by the movement of troops and others as the war was coming to an end. The second and deadliest wave struck in the fall of 1918. The RASC had about 400 members located in Toronto, Hamilton, Guelph, Peterborough, Ottawa, Montreal, Winnipeg, Regina, and Victoria. The Centres in Hamilton, Guelph, Peterborough, and Regina ceased operation due to the war, and attempts to revive them later on succeeded only in Hamilton and Regina. Guelph reported that influenza frustrated its attempts to meet when the war ended in 1918.

The newly formed Montréal Centre and the Ottawa Centre appear not to have been affected by influenza. Winnipeg did not meet for many months in 1918, and Toronto reported one meeting cancellation in October 1918 due to the pandemic. Victoria also cancelled its public meetings between May and December 1918, and again for many months in 1919.

The influenza in that pandemic struck mainly younger people in the prime of their lives. RASC member Dr. Leslie

Gladstone Pearce of Brantford, Ontario, died of influenza in 1918 at age 28. Dr. Pearce was a physician who pursued astronomy as a hobby, and his younger brother, Joseph A. Pearce, went on to become one of Canada's most prominent astronomers, serving as the third director of the Dominion Astrophysical Observatory in Victoria from 1940 to 1951.

Today with stronger public health organizations at all levels of government and with many communications tools undreamt of a century ago, Canadians are responding much more aggressively to the threat presented by COVID-19 than our forebears did with influenza.

Fortunately, many of us are able to continue observing the Universe during the time of the coronavirus through the medium of backyard or balcony astronomy, and our social activities in the RASC will carry on thanks to online communications, including conferencing programs.

Much of the story of the 2020 pandemic remains to unfold as I write this report. But we have already seen the RASC's first Self Isolation Star Party and online RASC meetings. Coming up are national RASC webcasts and our first online RASC Annual General Meeting.

History shows that the RASC emerged intact from the influenza pandemic 100 years ago, and I am sure that it will also get through today's pandemic, possibly enhanced by the experiences we have shared online while maintaining physical isolation. ✶

# News Notes / En manchette

*compiled by Jay Anderson*

## Comet Borisov spawns a companion

*Hubble Space Telescope* images acquired in late March show that the interstellar visitor, Comet Borisov, seems to have split in two. Images from March 28 and March 30 show an extended nucleus, a distinct contrast to one on March 23, which shows a single stellar core. The new non-stellar appearance is consistent with two unresolved components separated by 0.3 arcsecond (570 km at the comet) and aligned with the axis of dust emissions. The ejected fragment is moving away from the main nucleus with a speed of at least 0.5 m/s, a value typical of the gravitation escape velocity of a sub-kilometre Solar System body.

The gradual separation of the second body from the parent points to a breakup date of 2020 March 7, around the time when the comet had a small outburst. The fragment is believed to have a size less than 100m based on its assumed albedo. The March HST images also show the presence of two jets emanating from the comet body.

In an interview with Space.com, UCLA astronomer David Jewitt noted that the equal brightness of the two cores did not imply that the components were of equal size. A small piece that breaks loose from a larger nucleus would expose fresh ices from the comet interior that would immediately begin to sublimate, making the smaller fragment a producer of large amounts of dust and gas. Jewitt estimated that the fragment could be as small as 0.1 percent to 1 percent of the original mass. Additional observations that better show the rate of separation could constrain the size of the broken piece.

Though it rounded the Sun in December, when evaporation forces would be at their strongest, it is not unusual that the fragmentation has been delayed several months. An increase

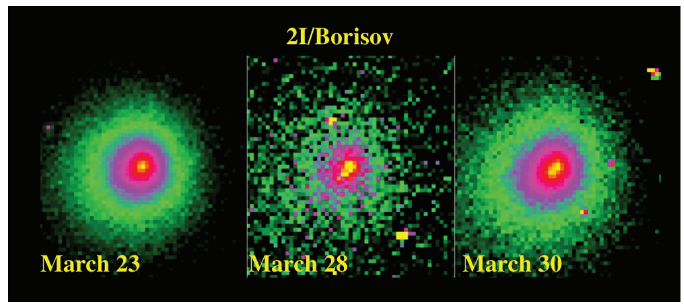



*Figure 1 — Images of interstellar Comet Borisov captured by the* Hubble Space Telescope *suggest that a piece broke off the object's nucleus around 2020 March 7. The middle photo was taken with a different filter than the two on the sides, explaining its different appearance. Image: NASA/ESA/Hubble/STScI/Jewitt et. al.*

in angular momentum as the comet spin adjusts to the loss of material in its solar passage takes several months to build according to one model of comet behaviour. Other models describe the build-up of pressure as a result of heating during a close pass by the Sun; the comet may even have been hit by another object.

Comet Borisov was discovered in August 2019 as it approached the Sun from an interstellar orbit, the second known non-Solar System object detected by modern telescopes.

*Prepared with material from Space.com and* The Astronomer's Telegram.

## Negative results limit brightness of kilonova

Using MegaCam, the Canada-France-Hawaii Telescope (CFHT)'s imaging instrument, a Canadian-led team of researchers placed one of the tightest limits to date on the light produced by what is likely the first observed merger between a neutron star and a black hole.

On 2019 August 14, a gravitational-wave signal was detected by both the Laser Interferometer Gravitational-wave Observatory (LIGO) and its European counterpart Virgo. This signal was probably produced by the last moments of the in-spiral of a neutron star and its companion black hole, followed by the merging of the two objects. The gravitational waves created by the merger travelled almost 900 million light years before reaching the two LIGO detectors in Hanford, Washington, and Livingston, Louisiana, and the Virgo detector near Pisa, Italy. The detected signal, named GW190814, was one of the strongest gravitational-wave signals so far received. The LIGO-Virgo collaboration traced the event to a region in the sky of about 27 square degrees—approximately the size of a fist held at arm's length.

"The merger between a neutron star and a black hole, the most exciting scenario for this case of GW190814, sits at a new frontier in astronomy," said Nicholas Vieira, lead author on the research.

"Events like GW190814 can be 'multi-messenger,' in which we learn about the detailed astrophysics of the merger by linking one cosmic messenger, the gravitational waves detected by LIGO and Virgo, to another cosmic messenger, in this case the light we can observe with a telescope like CFHT."

During the merger of a neutron star and a black hole, the violent tides in the system tear apart the neutron star and fling away extremely neutron-rich material. This neutron-rich material produces radioactive forms of the heaviest elements, including gold and platinum. These elements radioactively decay, powering a rapidly evolving, short-lived event called a kilonova. Kilonovae typically reach their peak brightness in visible light within ~2 days of the merger and in the infrared over the next 5–10 days. The first and only unambiguous kilonova to date was observed on 2017 August 17 in the landmark binary neutron-star merger GW170817.

Vieira, John Ruan (PI of the CFHT program), Daryl Haggard of McGill University, and Maria Drout of University of Toronto led the campaign to try to nail down an electromagnetic counterpart to the gravitational waves with CFHT's MegaCam, searching for a faint, declining, transient light source. The team started their observations less than two days after the detection of gravitational waves and continued up to nine days after the detection. They took advantage of MegaCam's large field of view of ~1 square degree to survey the core region of the sky that had a 50-percent probability of containing the gravitational-wave source and used observations of known galaxies in the surrounding 90 percent probability region to search for a kilonova event. Owing to the excellent depth reached by CFHT and the large field of view of MegaCam, these observations are among the deepest and most useful searches for a counterpart to GW190814 to date, almost reaching magnitude 24 in the near infrared (i-band).

After initial screening, by subtracting the images collected at CFHT from other reference images of the region, the team was left with 21,383 transient candidates. These were then vetted by a software package that used a trained neural network to classify each candidate detection, reducing the number of suspects to 2034 candidates of interest. Objects such as quasars, variable stars, and known transients were subtracted from the list, leaving 1972 objects that were either transients or image artifacts. Visual inspection reduced these to 115 candidates, which were then examined photometrically. In the end, one candidate remained, but its photometric light curve did not match theoretical expectations and it was rejected as the optical counterpart of the gravitational-wave merger.

The depths achieved by CFHT MegaCam's exquisite images can be understood as upper limits on the brightness of a kilonova. These limits on the brightness can then be translated into limits on the amount of material that was swallowed by the black hole and the amount that escaped this fate. The team calculated the mass that escaped to be less than 0.04 solar masses, or less than 4 percent of the mass of the Sun.

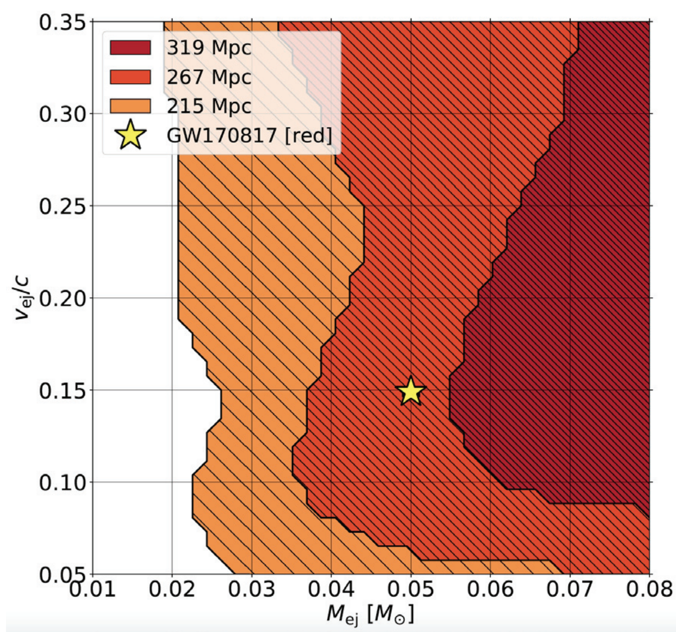



*Figure 2 — Allowed parameters for the "ejecta" (material ejected during the merger): the ejecta mass in solar masses and the velocity of the ejecta as a fraction of the speed of light. Regions that are coloured are those that were ruled out by deep CFHT MegaCam observations. The regions that are not allowed depend on the distance to the source, measured within a range of ~300 million light-years by LIGO/Virgo. Here, the constraints are shown for distances of 700 million light-years (215 Mpc), 870 million light-years (267 Mpc), and 1 billion light-years (319 Mpc). The yellow star shows the parameters measured for the "red" (material in the ejecta that shines mostly in the near-infrared) component of the kilonova associated with the binary neutron-star merger. A GW170817-like kilonova is ruled out to 870 million light-years, and the mass of the total ejecta is constrained to less than 0.04 solar masses.*

For a typical neutron star, which has a mass around 1.4 times that of the Sun, this means that at least 97 percent of the star was immediately swallowed by the black hole. This mass limit, which is the strictest presented to date, tells us that the neutron star companion must have been almost or completely gobbled up by the black hole. Alternative explanations, such as the possibility that the lighter object in the merger was not in fact a neutron star but actually a very low-mass black hole, are also being considered. Ultimately, an announcement from the LIGO-Virgo collaboration on the finer details of GW190814, expected later this year, may help settle these questions.

"While the team didn't detect an optical counterpart to this event, their follow-up observations show the importance of wide-field cameras like MegaCam in this new era of multi-messenger astronomy" said Daniel Devost, director of science operations at CFHT. "We look forward to CFHT playing a leading role in this new exploration of the Universe in the coming years."

*Compiled with material provided by CFHT.*

## Gravitational lensing reveals internal dynamics of distant galaxy

The combination of gravitational lensing and the high resolving power (0.03 to 0.07 arcseconds) of the Atacama Large Millimetre/submillimetre Array (ALMA) telescopes has allowed a team of astronomers from Japan to obtain the first resolved image of disturbed gas clouds in a galaxy 11 billion light-years (z=2.639) away. The team, led by Dr. Takeo Minezaki, an astronomer in the Institute of Astronomy at the University of Tokyo, found that the disruption is caused by young, powerful jets ejected from a supermassive black hole residing at the centre of the host galaxy.

It is commonly known that black holes exert strong gravitational attraction on surrounding matter and that some black holes have fast-moving streams of ionized matter, called jets. In some nearby galaxies, evolved jets blow off galactic gaseous clouds, resulting in suppressed star formation. To understand the evolution of galaxies, it is crucial to observe the interaction between black-hole jets and gaseous clouds throughout cosmic history. However, it had been difficult to obtain clear evidence of such interaction, especially in the early Universe.

Astronomers obtained the first resolved image of disturbed gaseous clouds in a galaxy 11 billion light-years away by using ALMA to study both continuum emissions from dust and gas and the line emission from CO (carbon monoxide). The team found that the disruption is caused by young, powerful bipolar jets ejected from a supermassive black hole (a quasar) residing at the centre of the host galaxy, known as MG J0414+0534.

In some nearby galaxies, evolved jets blow off galactic gaseous clouds, suppressing star formation. In order to understand the

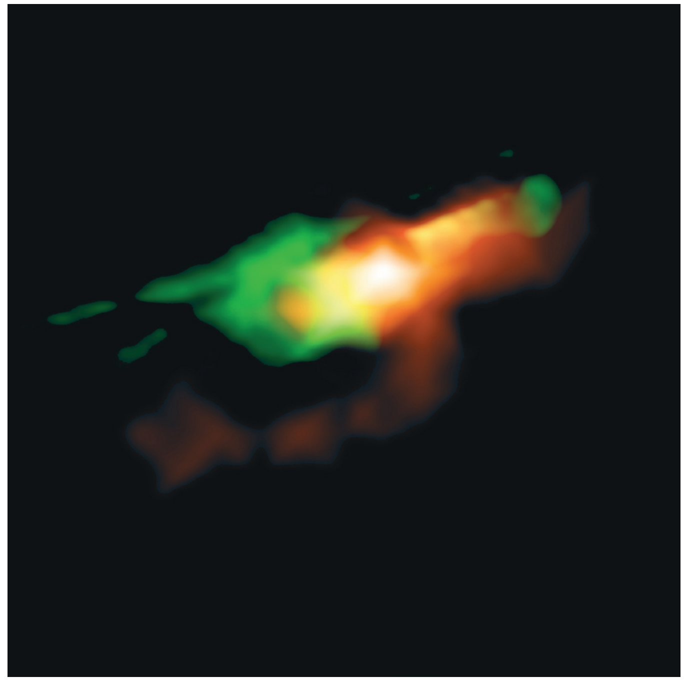


*Figure 3 — The reconstructed image of what MG J0414+0534 would look like if gravitational lensing effects were turned off. The continuum emissions from dust and ionized gas around a quasar are shown in red. The line emission from carbon monoxide gas is shown in green, which has a bipolar structure along the jets. Image: ALMA / ESO / NAOJ / NRAO / Inoue et al.*

evolution of galaxies, it is crucial to observe the interaction between black-hole jets and gaseous clouds throughout cosmic history. Until now, it had been difficult to obtain clear evidence of such interaction, especially in the early Universe.

A distinctive feature of MG J0414+0534 is that light rays travelling from the galaxy to Earth are significantly distorted by the gravity of a lensing galaxy that lies along the path. This lensing created four separate, magnified images of J0414. The research team was able to reconstruct an undistorted image of the host galaxy by combining the four separate images after carefully accounting for the gravitational effects exerted by the intervening lensing galaxy.

"This distortion works as a 'natural telescope' to enable a detailed view of distant objects," says Takeo Minezaki, an associate professor at the University of Tokyo.

"Combining this cosmic telescope and ALMA's high-resolution observations, we obtained exceptionally sharp vision, that is 9,000 times better than human eyesight," adds Kouichiro Nakanishi, a project associate professor at the National Astronomical Observatory of Japan/SOKENDAI. "With this extremely high resolution, we were able to obtain the distribution and motion of gaseous clouds around jets ejected from a supermassive black hole."

The team succeeded in resolving the jet/dust and CO gas in the quasar host galaxy, both extending up to ~1 kpc, with a resolution of ~50 pc. Both the continuum emission and the

CO line have a similar bimodal structure aligned with the quasar jets (~200 pc). The CO gas in the vicinity of both the eastern and western jet components at the location of ~80 pc from the quasar core are moving at high velocities, up to ±600 km $s^{-1}$ relative to the core. Features show clear evidence of strong interaction between the jets and interstellar medium (ISM), a conclusion supported by high-temperature and high-density environments in the ISM of the quasar host galaxy suggested by the CO emission.

The sizes of the impacted gaseous clouds and the jets are much smaller than the typical size of a galaxy at this age, an indication that quasar radio activity is in its infancy. "We are perhaps witnessing the very early phase of jet evolution in the galaxy," says Satoki Matsushita, a research fellow at Academia Sinica Institute of Astronomy and Astrophysics. "It could be as early as several tens of thousands of years after the launch of the jets."

"MG J0414+0534 is an excellent example because of the youth of the jets," summarizes Kaiki Inoue, a professor at Kindai University, Japan, and the lead author of the research paper. "We found telltale evidence of significant interaction between jets and gaseous clouds even in the very early evolutionary phase of jets. I think that our discovery will pave the way for a better understanding of the evolutionary process of galaxies in the early Universe."

*Prepared with material provided by the Institute of Astronomy at the University of Tokyo.* ✶

# Feature Articles / Articles de fond

## Philipp Fauth: Last of the Great Lunar Mappers

*by Klaus Brasch*

*"Everyone is a moon and has a dark side which he never shows to anyone."*
– Mark Twain

*"We are all like the bright moon, we still have our darker side."*
– Kahlil Gibran

*"Moonlight drowns out all but the brightest stars."*
– J.R.R. Tolkien


### Abstract

Lunar mapping and cartography during the 19th and early 20th centuries were almost exclusively the domain of German amateurs doing progressively better and more accurate visual work. Philipp Johann Heinrich Fauth was a leading early 20th century selenographer and planetary observer, and widely recognized for his outstanding visual work and craftsmanship. He aspired to produce the largest and most detailed map of the Moon available at the time. Sadly, he also became a very controversial figure because of his persistent support and advocacy of the "glacial cosmogony" theory positing that *ice was the basic substance of all cosmic processes, and ice moons, ice planets, and the* "global ether" (also made of ice) had determined the entire development of the Universe, a pseudo-scientific idea proposed by the eccentric and erratic, Hanns Hörbiger. Despite these travails, Fauth's legitimate astronomical work was recognized by the IAU and a lunar crater is named in his honour.


My mother passed away recently at the age of 101. Among her many remarkable qualities was a lifelong fascination with astronomy and whether or not we are alone in the Universe. Though not scientists, my parents were both instrumental in my becoming one and instilling in me a deep appreciation of the natural world. Although I eventually became a biologist, my first (and still) love is astronomy, something that pleased my mother very much, as she felt I had inherited that from her. After all, she maintained, her maiden name was Fauth, and that she was directly related to renowned early 20th-century selenographer Philipp Fauth.

Philipp J.H. Fauth (1867–1941) (Figure 1) was one of the last lunar amateur observers and cartographers relying primarily on visual work, at a time when photography was progressively yielding more accurate, if not yet as detailed, maps of our closest neighbor in space (Brasch, 2015; 2016). In this regard, he followed in the footsteps of a long line of 18th- and 19th-century German selenographers beginning with Johann Schröter, followed by W. Lohrmann, W. Beer, and J. von Mädler, and ending with Johann Krieger, Fauth's contemporary. Only the work of English amateurs H. Percy Wilkins and Patrick Moore exceeded such efforts in their massive, but overly crowded 300-inch map of the Moon (Wilkins and Moore, 1955). Born in the Bad Dürkheim area of Germany, Fauth was a musical prodigy who became a schoolteacher, but whose abiding interest in astronomy was sparked early in life during the apparition of the spectacular naked-eye Comet Coggia in 1874 (Sheehan and Dobbins, 2001; Dobbins, 2014).

Like so many amateur astronomers then as now, Philipp began with a modest 76-mm refractor, but later acquired a 162-mm aperture refractor and started serious lunar work in 1890 in

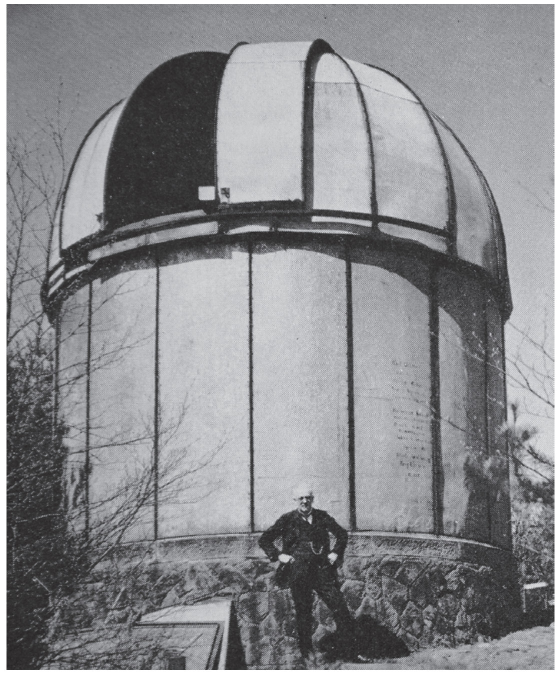


*Figure 1 — Philipp Fauth ca. 1930. (Ph. Fauth Archives)*

*Figure 2 — Fauth's observatory housing his 385-mm Schupmann-Medial refractor. (public domain)*

southern Germany in the city of Kaiserslautern. (Coincidently, that was also the birth city of my maternal grandfather, likewise named Philip Fauth). In 1895, with support from the Prussian Academy of Sciences, he built an observatory on a hilltop (Kirchberg) west of Kaiserslautern at Landstuhl, where he subsequently acquired a series of first-rate telescopes, including a 176-mm Pauly apochromat, as well as a 200- and 260-mm Schmidt reflectors (Behm, 2011). In 1911, thanks to Ellen Waldhauser, a wealthy benefactor, he acquired a superb if rare design 385-mm diameter Schupmann-Medial apochromatic refractor for his imposing new observatory on Kirchberg (Figure 2) (Fauth, 1959; Sheehan and Dobbins, 2011; de.Wikipedia, 2019).

As Joseph Ashbrook (1965) indicated, "Fauth was perhaps the most capable and versatile of all active visual observers of the moon between about 1890 and 1940. He combined descriptive selenography with cartography, measurements of craters, and statistical studies." In the process, he developed a very distinctive hachure drawing style (Figure 3), later replaced by contours to emphasize vertical relief (Figure 4).

In addition to the Moon, Fauth was also a keen solar and planetary observer, most notably of Jupiter and Mars (Fauth, 1924). He undertook extended surveys of Jupiter's ever-changing cloud drift rates, including the Great Red Spot and applied his equally meticulous drawing style in depicting these subtle features (Figure 5). In the same monograph, his masterful renditions of Martian albedo features are also noteworthy (Figure 6). In his summary of the 1924 opposition of Mars, he remarks on the appearance of the "Kanäle" (canals), which he pointedly puts in quotation marks, "They appear as wide, soft-toned lines and are only rarely seen

*Figure 3 — The crater Clavius as portrayed by Fauth using hachure style (public domain)*

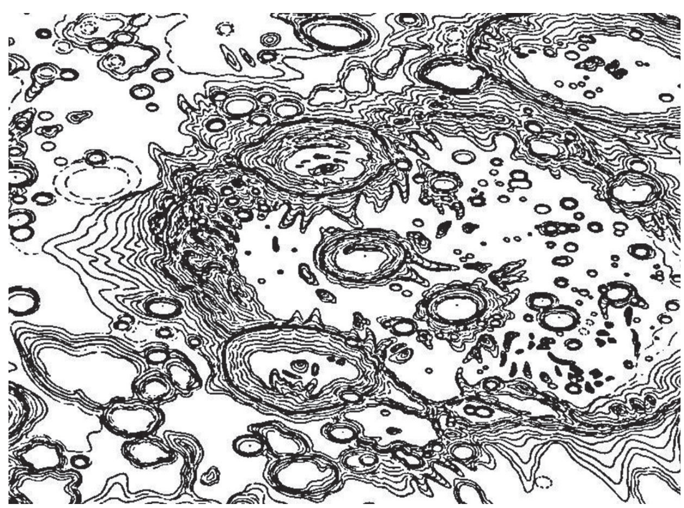


*Figure 4 — Clavius in semi-contour style used by Fauth in his later work (public domain)*

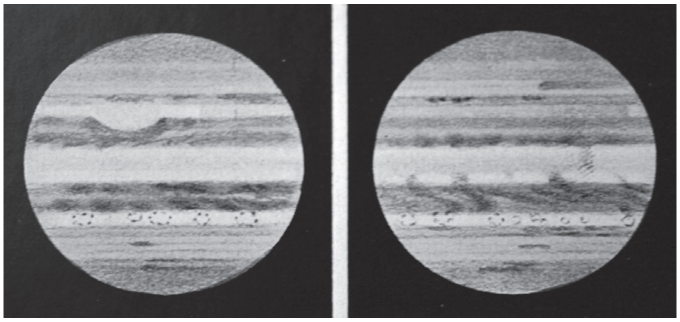


*Figure 5 — Sketches of Jupiter by Fauth in 1916–17 (K. Brasch Archives)*

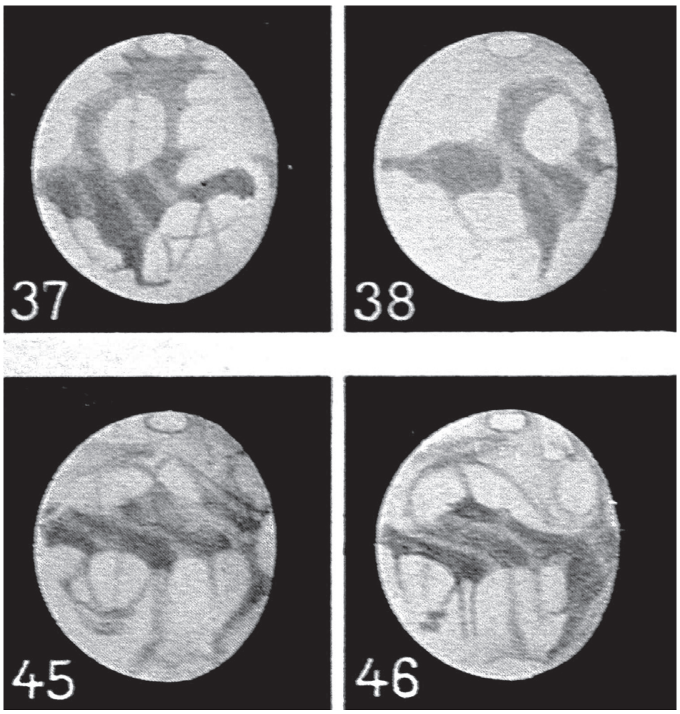



*Figure 6 — Sketches of Mars by Fauth from the 1924 opposition (K. Brasch Archives)*

extending from the dazzlingly bright south Polar Regions." This suggests that Fauth viewed the canals not as artificial structures but natural contrast features and quite diffuse at that. Although by 1924, the "artificial vs natural" debate over the supposed Martian canals had subsided, it was really not fully resolved until the *Mariner 4* flyby in 1965 (Brasch, 2018).

After publication of two notable monographs (Fauth, 1893; 1895), as well as articles in German astronomical journals, Fauth gained considerable recognition both as observer and cartographer. He also corresponded regularly with other astronomers, including most notably Max Wolf at the University of Heidelberg, a pioneer in astrophotography and discoverer of several minor planets and comets (Fauth, 1959). To quote Thomas Dobbins (2014), "The depth of understanding of the nature of lunar topography demonstrated by Fauth was superior to that possessed by the majority of his contemporaries. The morphology revealed by his methodical measurements of

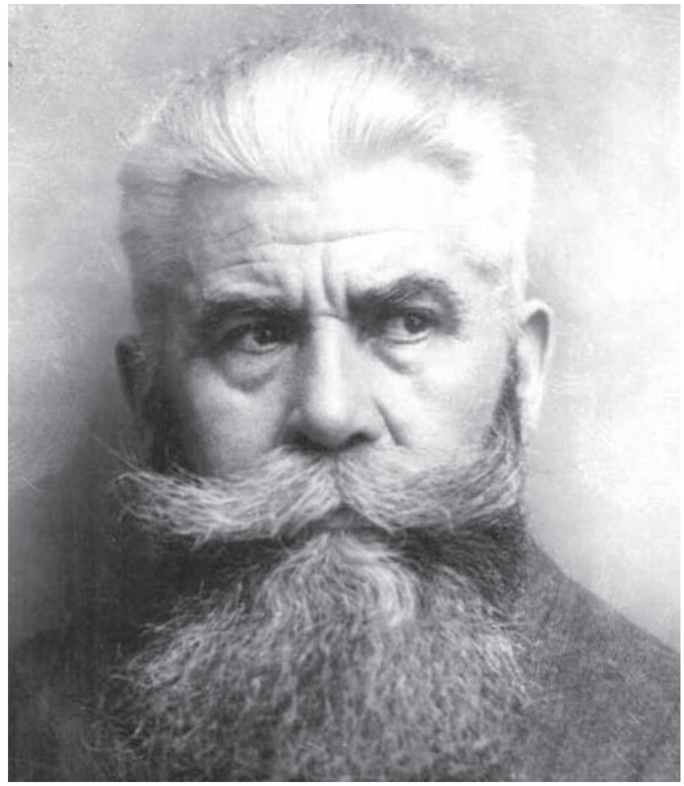


*Figure 7 — Hanns Hörbiger in later life (Wikipedia)*

the depth-to-diameter ratios of hundreds of lunar craters and the slopes of their exterior and interior walls led him to reject the prevailing volcanic theories of the origin of lunar craters." The volcanic origin of the craters was very much favoured in the late 1800s thanks to Nasmyth and Carpenter's compelling, if flawed, "fountain" theory and their magnificent plaster of Paris models of the lunar surface (Brasch, 2015).

Fauth's reputation continued to rise after that. Because of truly acute vision and careful observation, he discovered numerous new craterlets, rilles, and fissures on the Moon that had not been previously charted. He published his first significant book (Fauth, 1906) and the only one translated into English in 1907 under the title *The Moon in Modern Astronomy*.

Unfortunately, just as he was gaining recognition as a talented astronomer and was even offered a position at the newly established National Observatory in Mexico City, Fauth came under the influence of another amateur astronomer, Hanns Hörbiger (Figure 7). This eccentric individual, a successful Austrian inventor and engineer, was also the author of several fanciful cosmological theories none of which were based on solid science (Ashbrook, 1965; Sheehan and Dobbins, 2001). Most infamous was his glacial cosmogony theory, which among other things, held that ice is universal in the cosmos and covers most planets, comets and meteorites, solar explosions and sunspots result from chunks of ice falling into it, all geological events are catastrophic and rapid, humans and dinosaurs co-existed, and so forth. Regrettably, despite its total lack of scientific validity, this theory still has some adherents

*Figure 8 — Fauth & Co, surveyor telescope ca. 1880. (public domain)*

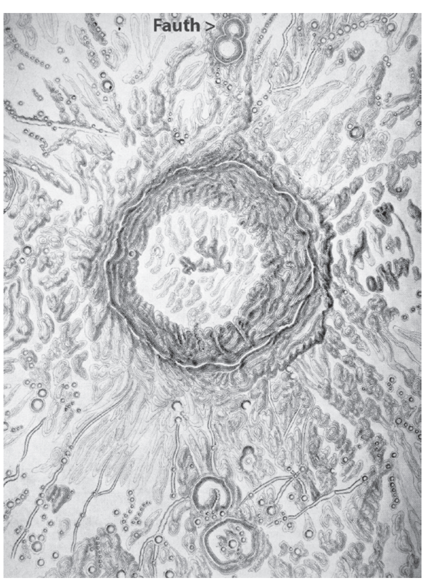
today (Topper, 2004) under the acronym of WEL, after the German *Welteislehre* (Cosmic Ice Doctrine).

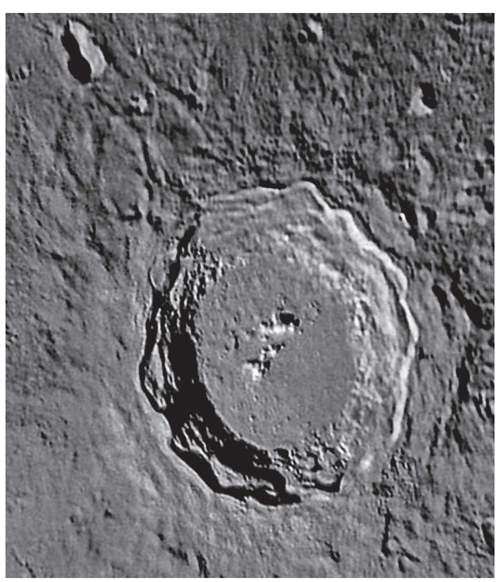
After publication in 1913 of his and Hörbiger's nearly 800-page tome *Hörbigers Glazial-Kosmogonie* (Hörbiger's Glacial Cosmogony) in 1913, Fauth's astronomical reputation was irreparably damaged (de.wikipedia 2019). This was an erratic, pseudo-scientific work and immediately rejected by the scientific community at the time (Ashbrook, 1965). Both authors, known for their unyielding and combative personalities, attributed their rejection by others as reactionary and jealousy. Although some authors maintain that Fauth tried to distance himself from the glacial cosmology idea later in life (Behm, 2011), that seems unlikely given his rigid personality. Others, who grudgingly still valued Fauth's observational work, regarded him as gifted but deranged. For a full analysis of Hörbiger's delusional and paranoid personality, see Sheehan and Dobbins (2001).

Despite his fall from scientific grace, Fauth continued working on his planned 1:1,000,000 scale *Grosse Mondkarte* (Great Moon atlas) after Hörbiger's death in 1931. On 1928 May 24, while residing in Munich, he wrote to Yerkes Observatory in what appears to be an attempt to regain acceptability as a legitimate astronomer. Although it is not clear he ever sent it, the letter is addressed "Dear Sirs" and proceeds as follows: "I have the honor of sending you some specimens of the results of my studies of the moon obtained by the 385 mm Medial of my observatory at Landstuhl. You would oblige me very much by putting at my disposal photos of the moon of recent date obtained by the 40-inch refractor of the Yerkes Observatory, as these would advance considerably my studies. Thanking you very much in anticipation, I am, Dear Sirs, yours very truly (signed) Phil. Fauth."

Sadly, Fauth did not finish his *magnum opus* by the time of his death in 1941. He did, however, finish some 22 sheets toward that end. In 1936, he published *Unser Mond* (Our Moon), by far his most useful and acclaimed publication (Ashbrook, 1965). His son Hermann (Fauth, 1959) finally completed his father's *Mondatlas* (Fauth, 1964), by which time it had become largely obsolete, except as a useful historical reference.

Philipp Fauth's tarnished reputation aside, his skills as lunar and planetary observer and cartographer were acknowledged in a number of ways. Streets bear his name in Kaiserslautern and other locations where he worked, but more importantly, in 1923 the International Astronomical Union named a lunar crater after him (de.wikipedia, 2019). This small, double crater, is prominently located just south of majestic Copernicus (Figures 8 and 9), a fitting tribute to a very skilled, if misguided, amateur astronomer.



## Postscript

The Fauth family name is also linked with astronomy in another, more unusual, way. In an informative article by Bart Fried (1994), titled *The German-American Connection*, the author relates the history of three German optical entrepreneurs who came to the United States in the late 1800s. Camill Fauth (1847–1925) joined

*Figure 9 & 10 — The great crater Copernicus as portrayed by Fauth (left) and as imaged by the author (right). The doublet crater Fauth lies just above the southern wall of Copernicus. (Wikimedia and K. Brasch, respectively)* countryman and instrument maker William Würdermann in 1870, to help build and maintain instruments for the ongoing United States Coast Survey ordered in 1807 by Thomas Jefferson. Würdermann established a profitable business in Washington, DC, producing ever-better instruments including portable transit, surveyor, and zenith telescopes. Eventually Fauth and brothers-in-law George N. Saegmuller and Henry Lockwood established their own business in 1874, under the name of Fauth & Co. They manufactured various surveying and measuring instruments (Figure 10), as well as equatorial mounts for astronomical telescopes. In the process, they won awards at the Cincinnati Industrial Exhibitions of 1876 and 1882. After Fauth retired back to Germany in 1887, Saegmuller continued trading under the name Fauth & Co, until 1892. The largest known telescope made by Fauth & Co is an 8-inch refractor at Santa Clara University in California (Fried, 1994). ✶

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# The Biological Basis for the Canadian Guideline for Outdoor Lighting 1. General Scotobiology

*by Robert Dick, M.Eng., P.Eng., FRASC*

## Abstract


The subject of limiting outdoor lighting seems straightforward—it saves electricity and reduces glare, but society has a predilection for activity at night that requires more than natural light. This extends beyond urban areas. "Cottage country" is well lit along the shoreline, and even campgrounds filled with amateur astronomers have lots of unshielded lights. Although these tend to be red, they still undermine our night vision (Dick, 2016) and change the nocturnal ambience.

The main problem of whether outdoor lighting is good or bad depends on who is judge. Is there a less equivocal way to assess or define acceptable outdoor lighting, especially in rural areas? Must rural lighting follow "Best Practices" for cities?

This is the first in a series of papers that will discuss the science behind the ecological impacts of artificial (anthropogenic) light at night. It will propose rational solutions to reduce these impacts and will define the characteristics of artificial light that minimize these disruptions that we call lighting with "low-ecological impact."

Although taking an ecological approach to outdoor lighting is unusual, we have observed that if the nocturnal environment is preserved for wildlife, it is usually sufficient for astronomy. Although it is understood that observatories may require a curfew during the three weeks centred on the new Moon. This first paper will set the stage for this somewhat unorthodox exploration into light.


## Scotobiology

Scotobiology is the study of the biological need for periods of darkness. Unlike photobiology, it concentrates on the benefits of darkness, not the benefits of light— subtle but significant. This study began following the 2003 Ecology of the Night Conference hosted by Parks Canada in the Muskoka District north of Toronto. Although light pollution was generally believed to be a problem for astronomers, it became evident from the diversity of research topics; it is an ecological and human health issue.

Scotobiology transcends the usual fragmented fields of animal biology and behaviour, and human heath and vision, which

*Figure 1 — The Milky Way in early winter over Rideau Lake, Ontario. "Cottage country" is becoming increasingly contaminated with urban light as cottagers install urban-type lighting on buildings and along shorelines. (R. Dick, 2019)*

may be the reason for the lack of awareness in the scientific literature. Outdoor lighting was a niche subject in each field. However, by focusing on the similar patterns and sensitivities of nocturnal biology and behaviours, the impact of light in these diverse disciplines could be integrated.

When exploring the impact of artificial light at night (ALAN) on our health, and the ecosystem in general, we must be careful about what the science indicates and what it is silent on. To wit: the absence of proof is not the same as proof of absence. So, although there may be no "proof" on a topic, we should discount anecdotal reports. Indeed, we should not let our ignorance prevent us from making rational judgements.

Scotobiology is a new approach to studying the environment, so it is understandable there are many gaps in the knowledge. We have to extrapolate what is known with one species to judge its impact on another. There are three basic assumptions when applying scotobiology to ALAN.

1) The ecosystem is in balance if it has existed for a protracted period of time.

2) A change in the environment will impact the ecological balance.

3) Changing the ecological balance will impact all species in that environment.

Therefore, a change to the environment that has been found to affect one species will have an affect on others because the balance will be affected. Even though a specific environmental change has not been studied for a particular species, it does not follow that the species is not affected. And to understand how some species are affected we can apply those known effects (guardedly) to those that have not been studied.

## Introduction: In the Beginning

Life on Earth began with single-cell prokaryotes soon after the crust solidified. Two billion years later, some of these branched off to form more complex eukaryotes, which co-existed with the prokaryotes (*Scientific American* 1999). Only 600 million years ago multi-cellular organisms appeared. Life then increased in complexity and evolved into what we see today. So, life as we see it now is relatively recent (less than 1/8 the Earth's age).

Throughout all this time, the environment was subject to a diurnal and annual progression of day, night, lunar month, and the seasons. Tidal braking by the Moon slowed the rotation of the Earth, so the days became longer, and complex weather patterns ensured the year-to-year seasons were not constant. Since the occurrence of multi-cellular life, the day has lengthened from less than 21 hours (Kahnle 1987) to the current 24 hours. Excluding catastrophic events, changes were very slow.

Any life on the land experienced significant changes in climate as plate tectonics shifted the mobile crust from the equator to higher latitudes, and vice versa, but genetic evolution and adaptive behaviour were able to keep pace with these slow changes, allowing many creatures to evolve with the evolving environment. Genetic evolution can be revealed in just a few decades of environmental changes (Bonnet, 2019), but those that didn't adapt (behaviour) or evolve (genetic) went extinct.

Stephen Gould once wrote about the tree of life that peaked in diversity about 500 million years ago, "We must recognize that this tree may have contained a maximal number of branches near the beginning of multi-cellular life and that subsequent history is for the most part a process of elimination and lucky survivorship of a few." (*Scientific American* 1994) Or to maintain the metaphor: since that time, the tree of life has been losing its less adaptable branches.

*Figure 2 — A gathering of amateur astronomers in Southern Ontario. Visitors illuminate campgrounds in national, provincial, and private parks. Although most astronomers use red light, it disrupts the ambiance of the night. (R. Dick, 2012, Starfest)*

Slow change of the environment promotes evolution, but abrupt change leads to extinction.

## The Need for Night

The environmental difference between day and night is obvious and profound. The cycle of day and night has helped drive evolution that created an ecological balance between diurnal and nocturnal life. Light is the obvious difference between day and night, with temperature and humidity also being important. To survive day and night, animals must develop means to forage, mate, navigate, migrate, and avoid predators, and the predators must develop ways to see at night to hunt.

These two environments double the number of niches for life and make the ecosystem robust and tolerant to other changes in the environment, including weather and climate.

The current state of mammal vision dates back to the era of dinosaurs (phys.org, 2016) and is the result of several detours along the way. It has been proposed the human deficiency of blue-sensitive daylight cones may have originated from blue-sensitive cones evolving into the more sensitive rod cells for night vision. Then when human precursors returned to a diurnal species, we were left with a deficit of blue cones.

This demonstrates the relationship all species have to their photo environment, and given time, are subject to evolutionary change but these changes may take thousands or millions of years. Current mammals are, for the most part, locked into their diurnal and nocturnal preferences, but share aspects of similar eye geometry, architecture, and visual chemistry. Therefore, changing the day or the night will affect most species.

Artificial (anthropogenic) light at night fundamentally changes the environment into one for which no life has evolved. The impacts and the challenges are at all levels: behaviour, biochemistry, cognition, and genetics. As we shall discuss, ALAN undermines the ecological integrity of the ecosystem and puts the survival of all its members at risk. It should not be a surprise that since humans are animals, we are subject to the same impacts on our physical and mental health. To better understand these effects, we need to compare or contrast the differences between natural light at night and ALAN as it relates to vision, biology, and ultimately health and survival.

Global emissions of ALAN into the night sky have been monitored since the late 1950s, and more precisely for the last two decades (Cinzano et al., 2000; Falchi et al., 2016). These programs have shown the direct correlation between ALAN and urban areas, and our industrial and recreational activities. However, the rate of increase exceeds the growth of populations and economies, which suggests there are other social and technical reasons for the increase of ALAN (Kyba et al., 2020).

The impact of ALAN on life has been studied for over a century but only in the last few decades has this impact been shown to undermine human health as well (Davis et al., 2001), and the degree that it disrupts the ecological integrity of the environment (Rich and Longcore, 2006).

## Human Vision

Genetically, humans are hunter-gatherers, optimized for a lifestyle not that much different from the animals we hunted and study today, and we share the same natural photo environment.

Humans are the only species that want ALAN and need it for activity after dark. So, we need to explore the lighting requirements for human vision.

The primary use for ALAN is to make people aware of the environment around them. The more widely used term is "situation awareness" (Wikipedia) and it gives us a wide spatial perspective.

Situation awareness refers to more than just illuminating a patch of ground, which could be considered "task lighting." It refers to awareness of the region and how it changes as we walk through it. The Moon illuminates the landscape "as far as the eye can see," so a pedestrian's knowledge of the area develops as they walk toward and pass by features and hazards. In contrast, a single light fixture illuminates a much more limited area. The bright light prevents anyone from seeing "beyond" the illuminated patch, and thus reduces perspective and safety.

Much less light is needed for situation awareness as the illuminated area is expanded. This can be experienced in a city where a typical short residential street and adjacent properties may be illuminated with 2kW of electric lighting.[1] It reveals the neighbourhood. Whereas "spot lighting" does not provide a context—resulting in psychologically uncomfortable and potentially dangerous situations.

Our vision is a function of the structure of our eye and the action spectrum of its components. Critical to our view of the

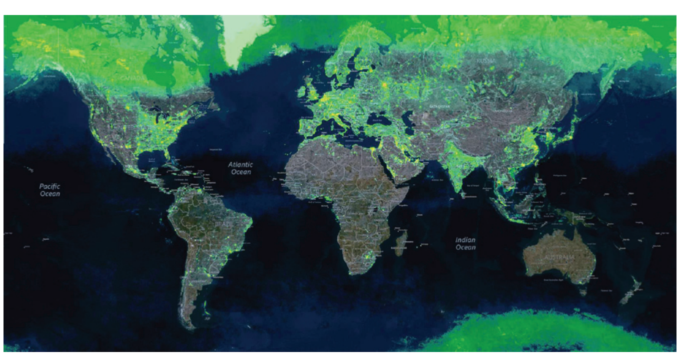

*Figure 3 — Distribution of ALAN over the Earth. The most densely populated areas emit the most light into the sky. However, even rural areas contribute by raising the background emissions. The wide green bands in the north and south are due to solar illumination "over the pole" (midnight Sun) in that hemisphere's summer. (www.lightpollutionmap.info, 2019 data)*

*Figure 4 — Vulnerable pedestrian "on display."*

world is also our brain, which applies "neural algorithms" to create coloured images that are pieced together and give us vision.

Natural light in the environment has a dynamic range of illumination of more than 1 billion:1. We have two sets of cells to cover this range and the spectral responses (action spectra) of these cells have differentiated between the bright day and dark night. Both have characteristics tailored, or optimized, for those two environments.

Which visual cells are used in our vision depends on the amount of ambient light. Cone-shaped cells provide our photopic vision during the day and are the only cells that give us the sensation of colour. The night is too dim for these cells, so our night vision defaults to our more sensitive scotopic vision that uses rod-shaped cells.

The cone cells have a peak spectral sensitivity at 555 nm (yellow). During the day there is a mechanical and a photochemical feedback mechanism to help protect our eyes from extreme brightness. First, our iris closes down reducing the amount of light that enters our eyes. Second, there are synaptic interactions in the retina (neural adaptation) that rapidly adjust (200 msec) for light variations of 100×–1000× (Boyce, 2014a). And third, the light-absorbing chemical (rhodopsin) in the cells becomes depleted at high light levels and reduces our cone sensitivity (Rushton & Henry, 1968; Geisler, 1978). The latter effect produces a dim "blind spot" in our field of view after looking at a bright light. Eventually these cells recover (a minute or so). This would not have been a problem for our ancestors due to the natural slow change in brightness from daylight to dark but can be a nuisance when walking from a bright room into the night, or when exposed to headlight glare from cars.

There are three sets of cone cells with "pigments" that absorb spectral bands centred on 420 nm (blue), 530 nm (yellow), and 580 nm (red) (Webvision). These are concentrated in the centre of our field of view— primarily within a 20-degree circle. Of particular interest is the number of each type of cell. The blue sensitive cells make up only 6 percent of the cones, with the yellow and red cells making up the remainder. The lack of blue cones means our visual acuity in blue light is very poor, which aligns with the relatively poor blue colour correction and focal distance of our eye's lenses.

At low light levels, the far more sensitive rod cells provide our night vision. During the day they are bleached by the bright sunlight but recover during the fading twilight to progressively replace the loss of our cone-vision. The rod cells are crowded out of the centre of our field of view by the cones but dominate the periphery. This is why astronomers use averted vision—so the faint light of celestial objects will fall on the more sensitive night vision cells. Our rod cells are most sensitive to 505 nm (green light), which is the peak wavelength of the reflected light from the Moon. So, they are spectrally well suited to our survival at night. The price of their sensitivity is the lack of colour vision.

During twilight we use a combination of our photopic and scotopic vision called mesopic vision. We can recognize this state because colours are visible but become de-saturated as the light dims—halving in brightness every five minutes or so. The mesopic vision is critical for safety, yet it is a particularly difficult time for our vision. If light levels fall too quickly (in a few seconds or so as experienced with urban lighting), our rod cells cannot recover fast enough from being bleached by the high photopic levels. This leaves a period where neither the cones nor rods can function—we are temporarily blind. So, there is little benefit from our mesopic vision with urban settings.

Our iris constriction is controlled, in part, by the detection of light by non-visual cells called the intrinsically photosensitive Retinal Ganglion Cells (ipRGCs). A luminance level of about 1 cd/m$^2$ will begin to constrict our iris (Watson & Yellott, 2012) (approximately the luminance of Venus in our sky). At about 2.5 cd/m$^2$, our pupil area is halved, letting in 50 percent of the incident light. So even relatively dim light sources, emitting spectra to which the ipRGCs are sensitive, will contract our pupil.

These ipRGCs are extremely sensitive, responding to single photons (Pickard & Sollars, 2011), but react slowly to faint light. They also provide information to regulate our circadian rhythm and related biochemical processes. They contain the photochemical called melanopsin, which is different from the rod and cone cells. It has a peak spectral sensitivity at about

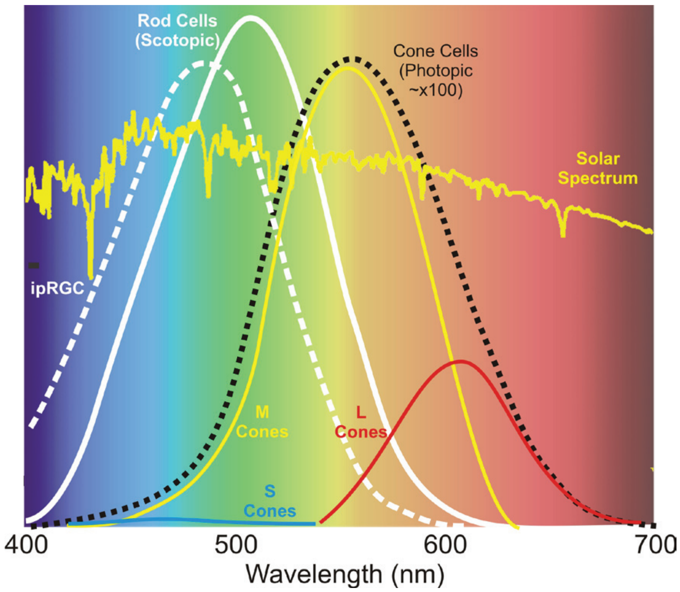


*Figure 5 — Action Spectra for three sets of light detectors in our retina. The three types of cone cells detect colour with a peak sensitivity at 555 nm photopic vision,1931 CIE). The rod cells have a peak sensitivity at 505 nm (CIE 1951). The ipRGCs (twilight detectors) have a peak sensitivity at about 480 nm.*

480 nm that corresponds to the blue sky of twilight. This is more than coincidence—it provides a survival advantage during twilight, so we refer to these cells with the less-prosaic name of "twilight detectors."

Our eyesight degrades as we age—with about 40 years being the time when our visual acuity, light sensitivity, and colour recognition requires us to wear eyeglasses, use a lower illumination level, and more illumination, respectively (Boyce 2014b). The eye's components become less transparent and scatter short wavelengths greater than younger eyes do. As hunter-gatherers, humans did not live much beyond 40 years, but today we live long enough to experience the degradation of our vision.

## Summary

Although ALAN is for humans, it also affects the biology and behaviour of wildlife. The degree of impact will depend on the species and their photo environment (day, crepuscular, or night), behaviour (foraging, predator, or prey) and how these are affected by weather and seasonal change.

The tolerance of animals to ALAN will set the ecological limit for outdoor lighting and is the reason for the ecological focus of a lighting guideline, and not just the human predilection for light at night or for stargazing. At night the animals are the majority. They share the night with us. It would be rude to ignore their needs when we are their uninvited guests.

The next paper in this series will address the ecological impact of the brightness of ALAN. Later in this series will be papers reporting on the impact of the extent of the light, its spectra, and timing. ✶

## Endnotes

1 Based on illuminating a 600-metre-long road from house-front to house-front (20,000 m2) with 100 lm/W luminaires to about 10 lux. Uniformity (maximum/average) of residential streets is roughly 10:1.

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# My Herschel 400 Observing Project

*by Luca Vanzella, Edmonton Centre*
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By August 2015 at the Saskatchewan Summer Star Party (SSSP), I had observed all but six objects in the RASC Finest NGC list. Following what I thought was a natural progression for deep-sky observing after the Messier Catalogue (already completed) and the RASC Finest NGC List, I decided that my next observing project would be the Herschel 400 (and I would pick up the remaining Finest NGCs along the way).

The Herschel 400 is a list of 400 galaxies, nebulae, and star clusters selected from the Catalogue of Nebulae and Clusters of Stars published by William Herschel and his sister Caroline. The objects were selected by members of the Ancient City Astronomy Club in St. Augustine, Florida, circa 1980, to provide amateur astronomers with an observing project beyond the Messier Catalogue. The Herschel 400 forms the basis of the Astronomical League's Herschel 400 Observing Program[1]. The objects range in brightness from 4th to 13th magnitude, with the vast majority (321 objects) from 9th to 12th magnitude.

The Herschel 400 contains 17 objects that are also in the Messier Catalogue[2] and 83 objects in the RASC Finest NGC List[3]. Since the latter two lists have no overlap, by August 2015, although I didn't realize it at the time, I had in fact already observed about one quarter of the Herschel 400. My plan was to observe all 400 objects even if I had previously observed them (although in the end it didn't work out quite that way).

By this time, I was using SkySafari for planning and tracking my observing projects. The SkySafari website contains a repository of observing lists crowd-contributed by users (but not necessarily vetted by anyone)[4]. The website has two offerings for the Herschel 400: by constellation and by season[5]. I decided to download and use the four SkySafari sky-list files for the Herschel 400 by season since that's how I had worked on the Finest NGCs. At this point, unbeknownst to me, Murphy joined my observing project and would make three appearances.

On the particularly nice evening of New Year's Day January 2016 at the future home of the Black Nugget Lake Observatory (BNLO), I started on the Herschel 400 with the first four objects in the winter group. In May 2016 at BNLO, I really got going on the list by observing 90 objects in the spring group. In August 2016 at SSSP, I picked up another 35 objects. In March 2017 (after an aborted bi-marathon in Maui[7]), I

*Figure 1 — Luca Vanzella and his 10″ Genstar telescope in Maui.*

observed 75 objects in three nights. Another 27 objects were identified at BNLO one particularly nice night in December 2017. I scooped up another 21 objects over two nights in March 2018 at BNLO. In May 2018, I was able to get 42 objects at a family camping location in Alberta. Another 24 objects were logged in three nights across September, November, and December 2018 at BNLO.

## The Saga of the 400th H400 *(Enter Murphy)*

By March 2019, I thought all I had left to do was one object in the winter group, 31 in the spring group and 29 in the summer group. I figured I could get them that month, which I did in three great all-nighters in Maui. I thought I was done, but then I noticed that somehow, I had MISSED getting one of the fall group objects (NGC 613) along the way. I tried in vain to get NGC 613 in the very early evening in Maui, but the sky was just too bright before the object set. *Oh well*, I thought, *I will get the 400th object back in Alberta*.

As I prepared to observe the 400th object in October 2019, I reviewed my observations in SkySafari and realized that I had also MISSED getting one of the spring group objects (NGC 4752) along the way. *Okay*, I thought, *I will observe NGC 613 in October and NGC 4752 in the spring of 2020*. In October 2019 in Arizona, while working on the Astronomical League's Multiple Star observing program[8], I got NGC 613. The 399th object down, one to go.

On 2020 March 20, at BNLO, I swung the 18″ Barry Arnold Memorial Telescope (BAMT) to NGC 4752 in Coma Berenices and tried to observe the 400th object. It was then that I noticed NGC 4752 is a 15th mag. spiral galaxy. I should be able to get it with an 18″ scope, I thought. Hah! I nailed the

| List | Catalog ID | Type | Mag | Con | Date | Comments |
|---|---|---|---|---|---|---|
| 10 | NGC 253 | GX | 8.9 | Scl | 2018-12-08 21:00 | Nice galaxy, bit of structure. |
| 12 | NGC 288 | GC | 7.2 | Scl | 2018-12-08 21:02 | Faint. |
| 37 | NGC 908 | GX | 11 | Cet | 2018-12-08 22:19 | Faint |
| 53 | NGC 1535 | PN | 9.3 | Eri | 2018-12-08 22:37 | |
| 47 | NGC 1407 | GX | 10.6 | Eri | 2018-12-08 22:46 | 31mm Nagler showed smudge, 14mm Meade ultrawide revealed a core. |
| | | | | | | |
| 64 | NGC 1964 | GX | 11.6 | Lep | 2019-03-01 23:23 | Ghostly, slightly elongated. |
| 118 | NGC 2613 | GX | 11 | Pyx | 2019-03-02 00:22 | Ghostly, roundish. |
| 128 | NGC 2811 | GX | 11.7 | Hyd | 2019-03-02 00:42 | Brighter core, slightly elongated. |
| 134 | NGC 2974 | GX | 11 | Sex | 2019-03-02 00:53 | Slightly elongated. Star right beside, not shown in Sky Safari. Shows as NGC 2974 in SS. |
| 144 | NGC 3184 | GX | 9.6 | UMa | 2019-03-02 02:31 | Big and ghostly. |
| 181 | NGC 3675 | GX | 11.5 | UMa | 2019-03-02 02:38 | Brighter core, elongated, reminds of spiral. One of the better H400. |
| 186 | NGC 3813 | GX | 11.7 | UMa | 2019-03-02 02:48 | Elongated. |
| 193 | NGC 3941 | GX | 9.8 | UMa | 2019-03-02 02:53 | Bright core, round halo, looks like a galaxy. |
| 187 | NGC 3877 | GX | 10.9 | UMa | 2019-03-02 03:01 | Nice thin galaxy! |
| 188 | NGC 3893 | GX | 11.3 | UMa | 2019-03-02 03:06 | Good one! Mottled looking. Can also see NGC 3896 right beside. |
| 195 | NGC 3949 | GX | 11 | UMa | 2019-03-02 03:09 | Nice. Reminds of Andromeda in a small scope. |
| 183 | NGC 3726 | GX | 10.8 | UMa | 2019-03-02 03:14 | Amorphous looking roundish blob. |
| 192 | NGC 3938 | GX | 11.5 | UMa | 2019-03-02 03:24 | Roundish, vaguely spiral. |
| 207 | NGC 4051 | GX | 11 | UMa | 2019-03-02 03:29 | Amorphous but galactic looking. |
| 208 | NGC 4085 | GX | 11.8 | UMa | 2019-03-02 03:59 | Skinny, elongated. In same field as 4088. |
| 209 | NGC 4088 | GX | 10.9 | UMa | 2019-03-02 03:59 | Fatter, elongated. In same field as 4085. |
| 184 | NGC 3729 | GX | 11.7 | UMa | 2019-03-02 04:03 | Roundish, small core. Also 3718 in same field. |
| 177 | NGC 3631 | GX | 11.2 | UMa | 2019-03-02 04:12 | Vaguely round, bit of core. |
| 154 | NGC 3310 | GX | 10.1 | UMa | 2019-03-02 04:22 | Round blob with bright core. |
| 171 | NGC 3610 | GX | 11.2 | UMa | 2019-03-02 04:28 | Small blob, core looks stellar. |
| 172 | NGC 3613 | GX | 11.2 | UMa | 2019-03-02 04:31 | Meh. |
| 173 | NGC 3619 | GX | 11.7 | UMa | 2019-03-02 04:31 | Meh. |
| 141 | NGC 3147 | GX | 10.9 | Dra | 2019-03-02 05:12 | Roundish blob, slight brightening at core. |
| 137 | NGC 3034, M 82 | GX | 8.8 | UMa | 2019-03-02 05:20 | Also viewed M 81. |
| 197 | NGC 3962 | GX | 11.3 | Crt | 2019-03-02 06:23 | Slightly out of round, bit of core brightening. |
| 202 | NGC 4027 | GX | 11.5 | Crv | 2019-03-02 06:29 | Amorphous blob with slight brightening at core. |

*Figure 2 — An excerpt of my Herschel 400 observing log.*

field, but I could not see it. I asked uber-experienced, deep-sky observer Alister Ling to come have a look. He thought he teased it out, but I could not honestly say that I had seen it. Perhaps the snow-covered landscape contributed to too much sky brightness? Maybe next new Moon window with no snow on the ground, I thought.

Since I was close to completing the project, I decided to compile my observing log from the observations I had tracked in SkySafari. SkySafari includes a cloud storage option called LiveSky to backup and manage observations on the web. I downloaded all of the Herschel 400 observations from LiveSky in CSV format to create a spreadsheet, but the data did not download cleanly. This made for quite a job getting the data into shape—but that's another story. To my surprise, the downloaded data included an observation for NGC 4752 back in March 2017! I don't know why the observation was in the LiveSky cloud storage but not in SkySafari on my tablet (I guess some sync error had occurred—yet another story). My comment on the March 2017 observation of NGC 4752 said "Vfff." I wondered why I saw it in a 10″ scope, albeit "Vfff," but not in the 18″ BAMT. It didn't occur to me to ask why was a 15th-magnitude galaxy in the Herschel 400? Oh well, I had bagged the 400th object and the project's complete—time to write it up.

I decided to do a final comparison of the objects listed in my Herschel 400 list (based on the four SkySafari sky-list files for the Herschel 400 by season) against the list published on the Astronomical League website. Turns out that the sky-list file for the spring group contains NGC 4752, whereas the Astronomical League lists NGC 4725 (a 9th-magnitude galaxy). Someone had apparently TRANSPOSED two digits. Talk about an error that's hard to notice[9]: Both 4752 and 4725 are galaxies in Coma Berenices, fairly near each other in the constellation and to boot, both objects appear in the same position in the Herschel 400 if included.

So, I was back to needing one more object to complete the Herschel 400. Or was I? I checked in SkySafari to see if I had recorded any observations for NGC 4725. Boom, an observation appeared from February 2013. Turns out I had observed

NGC 4725 when doing the Finest NGC list! In my excitement, even though the observation was from a prior observing list, I decided to count it. Whew, my Herschel 400 project was complete!

Overall, the project has been rewarding and fun. Over the last few years, whenever I found myself under clear nighttime skies equipped with a telescope, whether or not I had an observing plan, I always had the Herschel 400 list to provide targets. Of the four telescopes I used, two were GoTo and two were manual. Sometimes the GoTo worked well and other times not so much (I'm looking at you Sky-Watcher). With the manual telescopes, the star hops to acquire the targets were fun since there was always something interesting to see along the hop. If you are an aficionado of faint fuzzies, the Herschel 400 should be in your observing plans.

*Figure 3 — NCG 4725, from the The STScI Digitized Sky Survey*

## Vital Statistics

Elapsed time to complete project: 6 years, 8 months, 15 days

Started: 2013 February 6 (NGC 4725)

Ended: 2019 October 20 (NGC 613)

The bulk of the observations (393 objects) was made in about 3 years from May 2016 to March 2019[6].

**Most Productive Sessions: 4 (268 objects)**

- 90 2016 May 2, 3, 4 at BNLO (Alberta)
- 75 2017 March 25, 27, 29, at La Perouse Bay and Kihei (Maui)
- 42 May 2018 19, 20, 21 at Bumsted (Alberta)
- 61 2019 March 2, 4, 5 at Ahihi Bay (Maui)

**Number of observing sites: 8**

- 3 in Alberta
- 3 in Maui
- 1 in Saskatchewan
- 1 in Arizona

**Number of Telescopes Used: 4**

- My 10″ Genstar (Newtonian Reflector)
- A friend's 11″ Celestron CPC (Schmidt-Cassegrain) (thanks Sheldon and Kelly!)
- My 12″ Sky-Watcher (Newtonian Reflector)
- Edmonton Centre's 18″ BAMT (Newtonian Reflector)

**Most Used Eyepieces:**

- 10-mm Tele Vue Delos (360 objects)
- 127x (10″ Genstar)
- 150x (12″ SkyWatcher)
- 280x (11″ Celestron CPC)

**Notes**

1 www.astroleague.org/al/obsclubs/herschel/h400lstc.html

2 www.rasc.ca/messier-objects

3 www.rasc.ca/finest-ngc-objects

4 www.skysafariastronomy.com/repositories/index.php?dir=skylist&theme=onyx

5 The Astronomical League website states "there is an object on the list on the website that is different from an object that appears on the list in the manual." The website lists NGC 7814 whereas the manual lists NGC 1750. Evidently the SkySafari sky-list files by season are based on the manual, since they include NGC 1750, whereas the sky-list files by constellation include NGC 7814. The Astronomical League accepts either object.

6 In May 2016 at BNLO, I somehow missed getting two of the remaining six Finest NGCs. In August 2016 at SSSP, I got four of the remaining six, and I bagged the final two in March 2017.

7 warrenfinlay.com/list_of_bimarathoners.html

8 www.astroleague.org/content/multiple-star-observing-program

9 As of March 2020, the sky-list files "3_Herschel The Spring Group" and "H400_All" still contain the erroneous NGC 4752. This has been reported in the support forums[10]. As it turns out, on the SkySafari website, the SkySafari sky-list files for the Herschel 400 by constellation contain the correct object NGC 4725.

10 support.simulationcurriculum.com/hc/en-us/community/topics

*Figure 1 — Dan Meek used the RASC Robotic Telescope at the Sierra Remote Observatories in California this February to image a favourite, the Horsehead Nebula (Barnard 33). Dan imaged the nebula in narrow-band, at 11 x 1800 seconds in H$\alpha$, 10 x 1800 seconds in SII and 15 x 1800 seconds in OIII for a total of 18 hours. Final image was processed in PixInsight.*

*Figure 2 — The Lagoon Nebula and Trifid Nebula are captured in all their glory in this image by Stefanie Harron. Stefanie captured the image from the summit of Mount Buchanan in British Columbia—an altitude of 2042 metres—using a Canon 400-mm lens with a Canon 5D Mark IV camera, mounted on a Celestron EQ 5 with Orion autoguider. Total exposure was 14 minutes.*

*Figure 3 — Sheila Wiwchar imaged the magnificent Sombrero Galaxy (Messier 104/NGC 4594) on March 28 from Kaleida, Manitoba, using an RC 6″ Astrotech ƒ/9 and a Canon 60Da on an EQ 6 mount. Exposure, 20 x 4 minutes at ISO 6400.*

*Figure 4 — The launch of SpaceX's* Starlink *satellites, aimed at providing worldwide internet service, has caused much controversy in the astronomical community. Debra Ceravolo, who captured this image of the satellite constellation says, "At this current time with 360* Starlink *satellites out there, every time I do any astrophotography now, these things contaminate my images. Even in my deep-sky image frames, they show up."* Starlink *plans to launch up to more than 40,000 of these satellites. Debra captured the satellites on 2020 March 16, in this combination of 50 separate images, at 13 seconds exposure. She also notes that bright Venus and Pleiades are seen in the star trails. She used a Canon 6D with 20mm lens at ƒ/1.4.*

# Aurora Borealis and Great Comets

*by David Levy, Kingston & Montréal Centres*

Ever since I saw my first major display of the northern lights on 1966 July 8, I have been fascinated and delighted by this always-welcome show of greenish lights in the sky. But of all the displays I've seen, few can match the thrill of watching them from an airplane cruising high above the Arctic Circle.

In January 2020, I was part of the Aurora 360 experience, an event consisting of scientific and cultural presentations surrounding the unique displays of northern lights than can be seen often from the 60-degree latitude of Whitehorse, in Canada's Yukon territory.


*Figure 1 — The Alaska Highway really does stretch through Whitehorse.*

Whitehorse is a fabulous town. It is named after a rock structure on the banks of the Yukon River that resembles the mane of a large white horse. It was in use for thousands of years by First Nations cultures before undergoing significant growth and change with the discovery of gold in the Klondike in 1896.. The Alaska Highway, built rapidly during WWII, passes through Whitehorse.

To me, the city symbolizes two things. One of course, is the aurora borealis. On the Saturday evening of our trip we boarded an Air North 737 and took a never-to-be-forgotten flight from Whitehorse to Whitehorse, crossing the Arctic Circle. The sky had been cloudy and very cold, with temperatures hovering around –18 °C. Looking out of an eastward-facing window, I spotted a greenish auroral glow the instant the plane cleared the cloud tops. As we headed north, the glow brightened rapidly, and soon there were rays, a bright green rayed arc, and dancing green arcs splattered across the sky. As we entered the "auroral oval" just above the Arctic Circle, there was no spot in the sky that was not covered by at least an

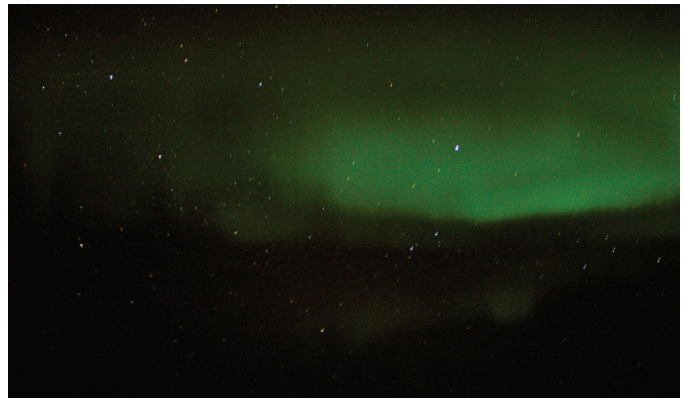

*Figure 2 — With camera forced against an airplane window, I got this picture of a rayed-arc aurora from above the Arctic Circle.*

auroral glow. The northern lights literally surrounded all 360 degrees of the airplane. The three-hour flight was stupefyingly wonderful. I have seen other great aurorae, from the big one at the Adirondack Science Camp in 1966 to a night over Tucson, Arizona. But the Aurora 360 experience was unique.

What about the other claim to fame of Whitehorse? The city is the centrepiece of one of the most famous poems in all of Canadian history, Robert W. Service's "The Cremation of Sam McGee." It tells the story of Sam McGee who left his home in Tennessee to join the Klondike Gold Rush, and who forces the poem's speaker to cremate him if and when he perishes from the cold. There was a real Sam McGee whom Service met in a bank; his cabin still stands on the grounds of a Whitehorse museum. My father, and most of our family, could quote sections of the poem, but Dad's brother (Uncle Sidney) knew and quoted every word. And when I quoted the final two stanzas during a lecture at the Yukon Centre of The Royal Astronomical Society of Canada, several people in the audience quoted it along with me.

Several days after Sam McGee dies in the poem, an abandoned boat, the Alice May, is used as a makeshift crematorium. As the flames grow higher, the speaker decides to open the furnace:

> *"…Then the door I opened wide.*
>
> *And there sat Sam, looking cool and calm, in the heart of the furnace roar;*
>
> *And he wore a smile you could see a mile, and he said: "Please close that door.*
>
> *It's fine in here, but I greatly fear you'll let in the cold and storm—*
>
> *Since I left Plumtree, down in Tennessee, it's the first time I've been warm."*
>
> *There are strange things done in the midnight sun*

*By the men who moil for gold;*

*The Arctic trails have their secret tales*

*That would make your blood run cold;*

*The Northern Lights have seen queer sights,*

*But the queerest they ever did see*

*Was that night on the marge of Lake Lebarge*

*I cremated Sam McGee."*

## Comets of the Past

The Great Comet of 1844, and the Great Comet of 2020?

On 1844 December 19, a sea captain named Wilmot discovered a bright comet without using a telescope. The comet was easily bright enough to be seen with the unaided eye and remained so throughout January. Then, with a telescope, it could be followed through the end of March. The comet was as bright as Halley's Comet was, earlier, at its appearance in 1835. At the time, there was some speculation as to whether this comet might have been on a similar orbit to that of the Great Comet of 1556, but George Bond, after having investigated that possibility, ruled it out by concluding the orbits were not similar enough.

What cannot be ruled out is that the Great Comet of 1844 might have been a large fragment of a much larger, and earlier, comet. On 2019 December 28, the ATLAS project discovered a very faint comet (ATLAS is an acronym for Asteroid Terrestrial-impact Last Alert System, which discovered the comet). The comet was magnitude 19.6 at the time of its discovery, too faint even for large amateur telescopes. ATLAS used a 0.5-metre (20-inch) diameter telescope near the top of Mauna Loa in Hawaii to make the discovery.

Early in 2020, the ATLAS comet rapidly brightened. On March 15, I looked at the irregular cigar-shaped galaxy Messier 82. Just beneath it in the field of view was Messier 81, a large galaxy that is gravitationally interacting with M82. By themselves, these two galaxies are lovely. But when I moved the telescope just a little lower, the comet appeared. It was easy to see, but I was not aware at the time that this was the comet that was brightening so quickly.

If all goes well, the comet will pass by the Earth on May 23, and then pass perihelion—its closest point to the Sun, about a week later. If it rivals its earlier cousin, the Comet of 1844, it could be as bright as Jupiter, or maybe even as bright as Venus, being easily visible without any telescope or binoculars. Or it could fizzle. There have been several comets that were supposed to become bright, like Kohoutek in 1973, Austin in 1990, and ISON in 2012, but either they failed to live up to expectations, or they simply broke apart and vanished.

*Figure 3 — Comet Okazaki-Levy-Rudenko, late summer 1989 (Steve Larson and David Levy)*

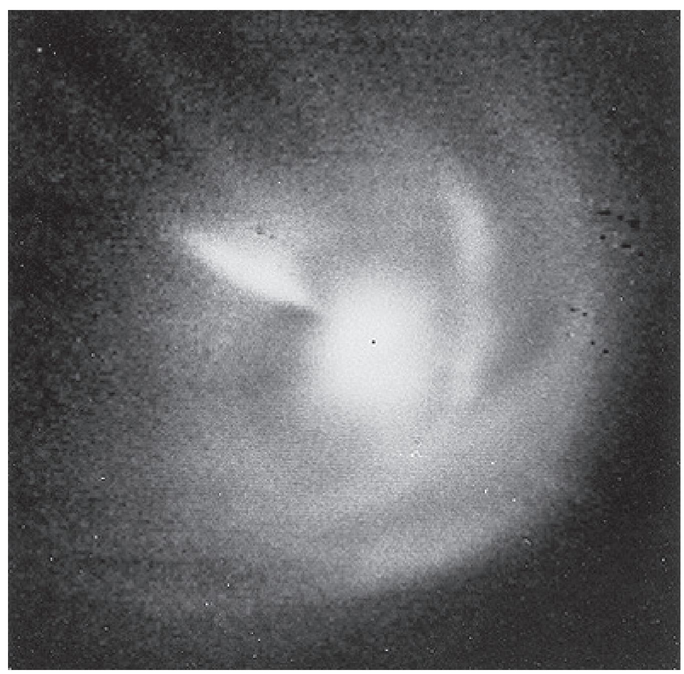

*Figure 4— Halley's comet, taken 1986 January 6, using the 61-inch (now named Kuiper) telescope at Mount Bigelow, northeast of Tucson, Arizona. You can see considerable detail near the nucleus of the comet, including a "tail-ward jet" of dust going into the comet's tail. (Steve Larson and David Levy)*

Comets do their own thing, as if they have minds of their own. I am fond of saying that comets are like cats: they both have tails, and they both do precisely what they want. ✶

*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!, *and has a monthly column, "Skyward," in the local* Vail Voice *paper and in other publications. David continues to hunt for comets and asteroids, and he lectures worldwide. David was President of the National Sharing the Sky Foundation, which tries to inspire people young and old to enjoy the night sky.*

# John Percy's Universe

## What's Up with Betelgeuse?

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

### Abstract

In January 2020, the bright red supergiant variable star Betelgeuse had faded to V magnitude +1.6, slightly fainter than ever recorded before. This set off media speculation that Betelgeuse was about to go supernova. Here, we review Betelgeuse's known variability. It has a pulsation period of about 390 days, and a "long secondary period" of about 2000 days. Both have variable amplitudes. At the time of fading, both periods were at minima in their cycles, and the amplitudes of the two periods were unusually large. These four factors conspired to produce the "super-minimum." The variability of Betelgeuse may be further complicated by the growth and decay of large convective cells, by the rotation of these on and off the visible face of the star, and by obscuration by ejected matter.

### Introduction

Betelgeuse has been in the news lately. It's been acting up. By January 2020, it had faded to V magnitude +1.6, from its usual range of 0.0 to +1.3 (the *Observer's Handbook* values). Guinan *et al.* (2019a) called attention to this "fainting," and this led to the speculation that Betelgeuse was about to go supernova. We know that this will happen eventually; it's something that we often mention at star parties. The "fainting" led to excited articles in major news media, including *The New York Times.* Is Betelgeuse really about to blow? Is its core, where the supernova process occurs, really coupled to the outer layers where the pulsation occurs? My students and I have worked with American Association of Variable Star Observers (AAVSO) data on this and other stars like it for many years. So, here's my take on it.

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

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

### Some Background

I started, as many people do, with Wikipedia. Usually we go to Wikipedia to find out what's known about a subject. In this case, however, Wikipedia also tells us about what's *not* known about Betelgeuse, or what's uncertain or controversial. That is good.

To start with: the name Betelgeuse probably does not refer in Arabic to "the armpit of the great one," but more likely to a more prosaic body part—the hand, arm, or shoulder. The star is associated with the hand or shoulder of a man-figure in other cultures around the world. Constellations are a cultural construct. Even the appropriate pronunciation of Betelgeuse is unclear.

Mass is the primary determinant of a star's evolution and lifetime. The mass of Betelgeuse is known only indirectly and approximately, because it lacks a binary companion whose orbital motion can "weigh" the primary. Masses of 7 to 20 suns have been proposed, based on indirect evidence. Its distance is about 650±150 light-years. This distance can be used to convert measurements of angular diameter into linear diameter, but there are several complicating factors above and beyond the observational errors in the distance and the angular diameter. Betelgeuse pulsates, so its diameter changes. It is surrounded by matter that it has ejected over time. Being a gas, it has no firm boundary. Its diameter depends on the wavelength at which you look; if the star's atmosphere is opaque at that wavelength, the star looks larger; if it is transparent at that wavelength, you can see to deeper layers, and the star looks smaller. All these uncertainties make it difficult to estimate the star's radius (estimates range from 3 to 6 astronomical units) and thereby the luminosity—which is itself variable. The latter probably exceeds 100,000 solar luminosities.

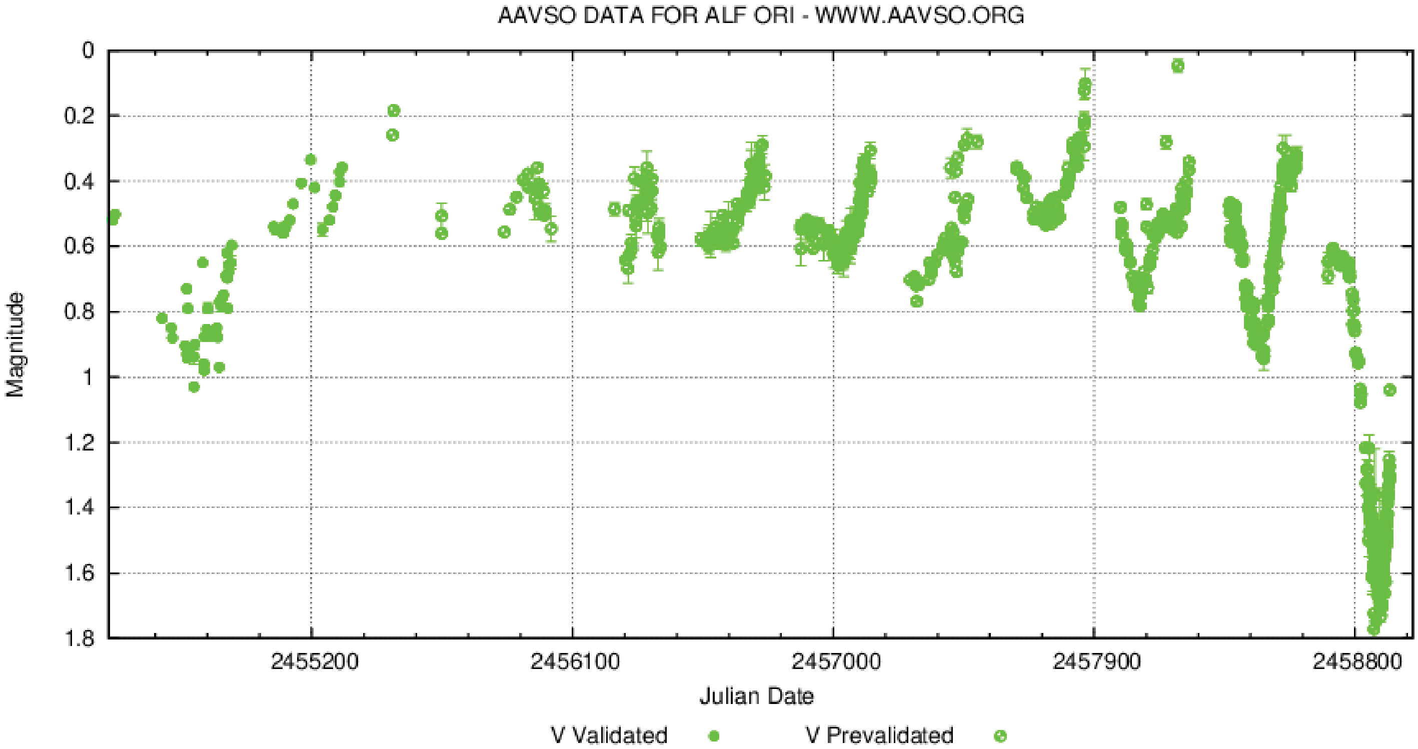


*Figure 1 — The Johnson V light curve of Betelgeuse, between JD 2454500 and 2459000 (4500 days), based on AAVSO data (Kafka 2020). Note the 390-day pulsation period, with increasing amplitude. There is also a 2000-day-long secondary period.*

Betelgeuse's most plausible "background" (see Wikipedia) is that it was born in the Orion OB1 stellar association 10–12 million years ago, with a mass of about 20 solar masses, and is moving away from its birthplace at about 30 km/sec, shedding some fraction of its mass through a stellar wind.

## How Betelgeuse Varies

Betelgeuse has been observed by the AAVSO, both visually and photoelectrically, for decades, and their data is freely available online (1). Fourier analysis of the visual and Johnson V data, using the AAVSO's VSTAR time-series analysis package (2) gives a pulsation period of about 388±30 days and an *average* amplitude of 0.21 mag. Cycles of this length are clearly visible, especially in recent data (Figure 1). Note that, in this article, I use amplitude to refer to the coefficient of the best-fit sine curve with the period indicated. The peak-to-peak *range* would be twice this.

It's been known for almost a century that the periods of pulsating red giants "wander" by a few percent on time scales of decades (Eddington and Plakidis 1929), and the periods of pulsating red supergiants probably do likewise. It's harder to tell, because red supergiants tend to have smaller pulsation amplitudes, more irregular variability, and longer pulsation periods. Percy and Abachi (2013) showed that, in red giants, the pulsation amplitude varies by up to a factor of 10 on a timescale of tens of pulsation periods. Percy and Khatu (2014) found the same in pulsating red supergiants, including Betelgeuse. In the last decade or two (Figure 1), the pulsation amplitude of Betelgeuse has increased from 0.03 to 0.24 mag!

About a third of pulsating red giants also have a "long secondary period" (LSP), 5–10 times longer than the pulsation period (Wood 2000). The nature and cause of the LSP is uncertain. Pulsating red supergiants also have LSPs (Kiss *et al.* 2006). Percy and Sato (2009) found an LSP of 2050±460 days in Betelgeuse. Over the course of the last century, the amplitude of Betelgeuse's LSP first decreased from about 0.17 to 0.09 and has since increased to 0.22 mag.

Theory and observation both tell us that Betelgeuse's surface is dominated by huge convection cells of gas, rising and falling as they transfer energy outward. This means that the outer layers of the star are not uniform but have large brighter and cooler regions. This could help explain the "wandering" of the pulsation period. The growth and decay of the convection cells will cause brightness variations on some long timescale, as will the rotation of the cells around the star; the rotation period is of order 10,000 days. These processes could perhaps help explain the LSP and/or the variations in the pulsation amplitude.

See (3) for a recent image of Betelgeuse.

Pulsation can drive mass loss in red giants. Pulsation-driven mass loss is a major factor in the evolution of the large-amplitude Mira stars (Bowen 1988). Dust forms within the cool ejected matter, and it can cause the star to fade—as it does in the R Coronae Borealis stars—if it is between us and the star.

Betelgeuse is not unique. The variable red supergiant Antares lies across the sky from Betelgeuse. Many cultures attached significance to this. The variability of μ Cephei, "the garnet star," is as interesting as that of Betelgeuse, as you can see by plotting its light curve with the AAVSO's light-curve generator (4). You have to enter "miu cep" to distinguish it from MU Cep.

## The 2019–2020 "Fainting"

As Guinan *et al.* (2019b) have pointed out, and our analyses confirm: the fainting coincides with a minimum of both the pulsation period and the LSP. We can add another factor: the amplitudes of both the pulsation and the LSP have increased significantly, resulting in a "super-minimum." As of the date of writing this column (March 2020), Betelgeuse has bottomed out at a V magnitude of +1.6 and is now brightening again. It didn't explode.

## What of the Future?

Our understanding of the present behaviour of Betelgeuse, such as the "fainting," has been aided by the work of many visual and photoelectric observers over many decades. We can probably assume that Betelgeuse will continue to behave as it has in the past—in complicated fashion. But only observations will tell. Betelgeuse is too bright for most professional observers. Skilled amateurs can and will undoubtedly continue to provide crucial data. And eventually Betelgeuse *will* go supernova. ✶


## Acknowledgements

I thank the AAVSO observers for a century of measuring Betelgeuse, and the AAVSO staff for making the measurements publicly available, along with the VSTAR package for analyzing them. I also thank the many students who have worked with me in trying to understand the many peculiarities of pulsating red giants and supergiants.


## Notes

1 www.aavso.org/main-data
2 www.aavso.org/vstar
3 www.eso.org/public/images/eso2003a/
4 www.aavso.org/lcg

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# CFHT Chronicle

## Life in Hawaii During the Time of COVID-19

*by Mary Beth Laychak, Director of Strategic Communications, Canada-France-Hawaii Telescope*
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I am again in the position of starting my column off with a note to my readers. As I've mentioned before, I (and everyone who writes for the RASC *Journal*) write my column well before you will read it—in April. For the second time in the past twelve months, all of the Maunakea Observatories are shut down, this time due to the global pandemic of COVID-19. CFHT moved to staff working from home on March 17. At that time, we continued to observe. As my last column made clear, remote observing with a single person is par for the course at CFHT. The rest of our staff did what they could from home with our instrumentation and operations group visiting the summit twice a week in reduced numbers to promote social distancing.

David Ige, the governor of Hawaii, issued a shelter-in-place order on March 23. Under the order, all residents must stay at home unless they work in essential businesses, like health care, grocery stores, etc., very similar to the orders seen across the world. Collectively, the Maunakea Observatories made the decision to stop operations. Our remote observers need to be in the office to observe. We felt asking them to drive daily into the office to continue to observe went against the intent of the governor's orders. We were also concerned about emergencies at the summit. No one on Maunakea is collecting data; we are all watching, waiting, and hoping like so many others around the world for an end to the pandemic.

The CFHT staff is doing well. We can send crews to the summit when needed for critical preventive maintenance. Staff are working from home however they can; our observers monitor critical systems and security cameras nightly, payroll is still processed, and we are doing a lot of virtual safety training.

### Projects

I want to highlight two projects that are particularly interesting: one is a project of Tom Benedict (engineer) and Tom e: Vermeulen (software) to figure out how to detect condensation on our primary mirror more effectively; the other is MKO@Home, a virtual outreach program across the Maunakea Observatories.

Project Tom is a great example of how staff are using their time to work on a project they can do from home. The CFHT primary mirror is 3.6 metres in diameter. The mirror is covered during the day by pneumatically driven mirror covers. The mirror covers protect the mirror from potential dust and debris in the dome as well as damage from overhead work. The remote observer opens the mirror covers at the start of every night after opening the shutter. The opening sequence begins 30 to 60 minutes before sunset, giving the dome and mirror ample time to flush out. If humidity is above a certain threshold, the dome and the mirror covers remain closed until the humidity is below the threshold for a set period of time. Despite our current precautions, we want to have a better indication of how often we see condensation on the primary mirror.

I asked Tom Benedict why he was working on this project now. His response: "This is one piece of the puzzle to improving reflectively and scatter, and potentially prolonging the life of the (mirror) coating." One of Benedict's areas of expertise is the process of recoating our primary mirror—improving the process of recoating and collecting data to optimize how often we need to recoat the mirror. Our mirror coating process requires us stopping observations for a week. The timing of each recoating decision is an internal cost benefit analysis—how often do we need to recoat to improve our reflectivity versus the time lost. One of Tom's regular projects
is trying to determine best practices for mirror cleaning between coatings. Our current cadence is a mirror coating every three years.

"A degradation in zero points [due to a degraded coating] equates to longer exposures to get the same amount of light. It's lost time on the sky, but so is downtime for coating. It's about finding that balance," said Benedict.

With the stage set for Benedict's experiment, let us take a look at the experiment itself. In his home bathroom, he created a foamcore mock-up of our mirror covers over his bathroom mirror (stand in for the CFHT primary). On the right side is a Raspberry Pi with an 8-MP camera. The wide expanse of the black foamcore simulates the mirror covers. The far side acts like the central mirror spigot, which is imaged in reflection by the camera.

When we look inside the setup (Figure 2), everything is sideways because Tom's bathroom mirror hangs on the wall and doesn't point toward the sky. The rectangular spots on the mirror cover are left over from a previous incarnation of the experiment. The stripes at the far end simulate alternating white and black stripes, painted on the central spigot. They appear narrower at the top and bottom because the spigot is cylindrical, so the stripes would appear to get narrower as the spigot wraps around out of view.

The three images in Figure 3 are part of a time-lapse sequence taken from the camera. They show the mirror in a clear state, with the mirror starting to condense, and with the mirror

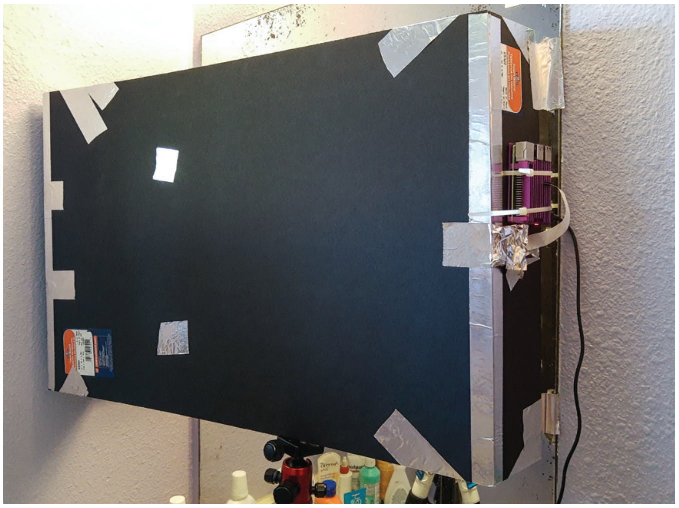


*Figure 1 — Tom's setup.*

*Figure 2 — Peering inside the experiment.*

thoroughly condensed. The camera images have a purple cast because the off-the-shelf camera selected for the experiment does not have an infrared blocking filter. The rationale—if this experiment works, CFHT technical staff may decide to replicate the experiment at the summit. If that occurs, they want to use the same camera tested in Tom's bathroom. We do not want to introduce more light into our optical system at the summit, so the lack of an infrared blocking filter maximizes the sensitivity of the camera in low-light situations.

Benedict handed his entire time lapse over to Tom Vermeulen to work on. Vermeulen's plan is to take cuts across the image, corresponding to radial distances out across the mirror, and to make a histogram of the pixel values for each cut. The more separation between the white and black pixels, the clearer the mirror. By the time the mirror is fully condensed, you can't even see a difference between the black-and-white striped regions. Hopefully the bathroom mirror experiment helps shed light on our primary mirror (pun intended).

Another project during our COVID-19 shutdown spans the entire Maunakea Observatory community—MKO@Home. MKO@Home is a virtual outreach program that allows us to continue to connect with our community—Big Island, across Hawaii, and around the world. Observatory staff have created short videos on a wide range of subjects; science talks, career Q&A, activity demonstrations, etc. The week of April 6 to 10 was designated Black Hole week in honour of the one-year anniversary of the announcement of the first recorded image of the black hole, M87* or Pōwehi as it's called in Hawaii. The culminating event for Black Hole week was a live Q&A panel about Black Holes called "Shedding Light on Pōwehi."

All the MKO@Home videos, including a recording of the live Q&A panel, can be found on our YouTube channel—bit.ly/mkoathome

## Science News

In the spirit of not all doom and gloom in the world, I want to share a recent science discovery from CFHT data.

Using MegaCam, the CFHT's imaging instrument, a Canadian-led team of researchers placed one of the tightest limits to date on the light produced by the first observed high-probability merger between a neutron star and a black hole.

On 2019 August 14, a gravitational-wave signal was detected by both the Laser Interferometer Gravitational-wave Observatory (LIGO) and its European counterpart, Virgo. This signal was likely produced by the last moments of the in-spiral of a neutron star and its companion black hole, followed by the merging of the two objects. The gravitational waves—ripples in the fabric of spacetime itself—created by the merger travelled almost 900 million light-years before reaching the two LIGO detectors in Hanford, Washington, and Livingston, Louisiana, and the Virgo detector near Pisa, Italy. This type of signal is aptly named a "chirp." Gravitational waves cannot be observed by conventional telescopes that detect light but can be detected by the specially designed LIGO and Virgo interferometers.

*Figure 3 — A montage of the condensation process sequence.*


*Figure 4 — MKO@Home live panel participants.*

The detected signal, named GW190814, was one of the strongest gravitational-wave signals ever received. The odds of the detection being a false alarm are incredibly remote: 1 in $10^{25}$ years, or 1 in a million, billion times the age of the Universe. The LIGO-Virgo collaboration traced the event to a region in the sky of about 27 square degrees— approximately the size of a fist held at arm's length—and promptly announced their detection so astronomers using conventional telescopes could join the observations.

"The merger between a neutron star and a black hole, the most exciting scenario for this case of GW190814, sits at a new frontier in astronomy," said Nicholas Vieira, lead author on the new paper. "Events like GW190814 can be 'multi-messenger,' in which we learn about the detailed astrophysics of the merger by linking one cosmic messenger, the gravitational waves detected by LIGO and Virgo, to another cosmic messenger, in this case the light we can observe with a telescope like CFHT."

During the merger of a pair of neutron stars or a neutron star and a black hole, the violent tides in the system tear apart one or both of the neutron stars and fling away extremely neutron-rich material. This neutron-rich material produces radioactive forms of the heaviest elements, including gold and platinum. Neutron-star mergers may be the dominant site for the production of these heavy elements across the Universe. These elements radioactively decay, powering a rapidly evolving, short-lived event called a kilonova. Kilonovae typically reach their peak brightness in visible light within ~2 days of the merger and in the infrared over the next 5 to 10 days. The first and only unambiguous kilonova to date was observed on 2017 August 17 in the landmark binary neutron-star merger GW170817.

Vieira, John Ruan (PI of the CFHT program), Daryl Haggard of McGill University, and Maria Drout of University of Toronto led this new campaign to try to nail down an electromagnetic counterpart to the gravitational waves with CFHT's MegaCam. The team started their observations less than two days after the detection of gravitational waves and continued up to nine days after the detection. They took advantage of MegaCam's large field of view of ~1 square degree to tile the region of the sky with a 50-percent probability of finding the gravitational-wave source and used targeted observations of known galaxies in the 90-percent probability region to search for a kilonova event. Owing to the excellent depth reached by CFHT and the large field of view of MegaCam, these observations are among the deepest and most useful searches for a counterpart to GW190814 to date.

No such optical counterpart was discovered by the authors or any other teams. However, the depths achieved by CFHT MegaCam's exquisite images can be understood as upper limits on the brightness of a kilonova. These limits on the brightness of the source can then be translated into limits on the amount of material swallowed by the black hole and the amount that escaped this fate. The team was able to use their observations to calculate the mass that escaped to be less than 0.04 solar masses, or less than 4 percent the mass of the Sun. For a typical neutron star, which has a mass around 1.4 times that of the Sun, this means that at least 97 percent of the star was immediately swallowed by the black hole.

This mass limit, which is the strictest presented to date, tells us that the neutron-star companion must have been almost or completely gobbled up by the black hole. Alternative explanations, such as the possibility that the lighter object in the merger was not in fact a neutron star but actually a very low-mass black hole, are also being considered. Ultimately, an announcement from the LIGO-Virgo collaboration on the details of GW190814, expected later this year, may help settle these questions. The insights of LIGO-Virgo and CFHT MegaCam observations in conjunction are much more than the sum of their parts.

"While the team didn't detect an optical counterpart to this event, their follow-up observations show the importance of wide-field cameras like MegaCam in this new era of multi-messenger astronomy," said Daniel Devost, director of science operations at CFHT. "We look forward to CFHT playing a leading role in this new exploration of the Universe in the coming years."

The team involved institutions from Canada and the United States.

See the paper here: arxiv.org/abs/2003.09437 ✶

Author's note: On May 5, 2020, Governor Ige identified the Maunakea Observatories as one of Hawaii's low-risk organizations and businesses that are safe to reopen with health and safety precautions in place. As a result, the Canada-France-Hawaii Telescope resumed observing on 2020 May 7.

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

# Observing

## New Light for Old Glass—Adventures in Buying and Using Classic Telescopes

*by Shane Ludtke, Regina Centre, and*
*Chris Beckett, National Member*
*(smludtke@gmail.com; cabeckett@gmail.com)*

Many of you might recall seeing the long, gleaming white tubes atop jet-black equatorial mounts gracing back covers of astronomy magazines. Some may even have had their first views of the Moon, planets, or a galaxy through such an instrument. But how do these instruments compare with today's affordable refractors? After all, shouldn't a good refractor from any age be just as good today?

While my first telescope had been a poor-quality Tasco (of course), I had long been tempted to own one of these marvels from the bygone days but could never make the leap. Fortunately, there are braver souls than me, and a new movement to repurpose and refurbish items has taken hold. As a result, some people have discovered that many telescopes don't have to be newer to be better. Shane Ludtke, one of my observing partners, is such a person. We recently spent an evening observing with his 63-mm Zeiss Telementor. I have to say there really is something magical about these old 'scopes, so I did a bit of a Q&A with Shane when he was a guest speaker at my astronomy class.

### So Why Get into Vintage Scopes?

Shane is someone who has considerable experience with a variety of telescopes and owns many small and large achromats and apochromats. After being impressed with some vintage binoculars, Shane says he took the plunge, bought a Sears 60-mm classic 'scope, and was surprised by the quality. Since then he's acquired many 60-mm telescopes, including several nice Zeiss optical pieces. They don't make a lot of the parts they used to, but some are extremely practical and would be worth resurrecting, such as miniature map lamps that attach to accessory trays and solar-projection screens.

The astronomical telescope has been around for over 400 years, and while there have been different designs, the fundamentals are the same with the main differences being the glass type and coatings applied to the glass; while important, good figures on old glass can still provide some affordable fantastic views. What stands out with the telescopes from the 1950s and 1960s is that the long tubes were built to last and contained lenses hand-ground by master optical craftsmen who really took the time to produce excellent lenses. During the 2018 Mars opposition, Shane was able to use a vintage Tasco 60-mm with a focal ratio of $f/16.7$ and says, "the Tasco really impressed upon me what a long-focal-length 60-mm refractor is capable of. Prior to that observation, I would not have considered using a 60-mm refractor for planetary observation, particularly for challenging Mars observations." These long-focal-ratio telescopes have a large sweet spot for focus making them easy on eyepieces, and they also cool down faster.

### Things to Know and Watch Out For

It seems that eyepieces are typically the poorest included accessory that accompany classic telescopes. These may include a mixture of Kellners and Hyugens, but there are some exceptionally good eyepieces from Nikon and Takahashi or the Pentax SMC Orthoscopics, if you get really lucky. In fact, the 0.965″ by Takashi Hi-ortho are among the highest regarded eyepieces in terms of contrast among aficionados. However, since most of the accessories are poor quality and 0.965″, it's best to adapt the telescope for the 1.25″ accessories you likely already own. The source for these is Vixen Optics, which make 1.25″ adapters that thread onto most models, but it's best to research this before making any purchases. This means you are going to have a narrow field of view compared to modern portable refractors, so be prepared for that trade off.

*Figure 1 — A Takahashi TS-65*

Shane says, "Sometimes your long-awaited scope, such as my Takahashi TS-65 I bought from Japan for too much money, will arrive with minor damage, where the only packing material seems to have been sourced from the nearest wastepaper basket." There can also be a lot of adjustments, tweaks, and minor tinkering that must be done to get the best out of these older 'scopes because often they've sat around collecting grease and grime. Sometimes you also get a hodgepodge of equipment from several scopes and usually a few parts are missing. Shane also mentions that some older mounts can be weak points, so he prefers to mount his vintage optics on modern alt-az or electronic equatorial mounts.

## How do Old Small Scopes Perform?

The other night, as I struggled with the cool down on my 60-mm quadruplet, Shane was able to take a 50-mm Zeiss up to 192× for crisp lunar observing. Before anyone gets roiled up about such powers on a little scope, after all, this is approaching 100× per inch of aperture, many of us have discovered that getting such a large image scale is beneficial for detecting near-threshold details on the planets. Sure, there's some chromatic aberration, but this is more the nature of the optical glass, and these finely crafted hand-ground lenses will show a little false colour on the lunar limb or edge of Venus, but that doesn't take away from how sharp and capable the optics are.

*Figure 2 — A Zeiss Telementor 63 mm*

## What Does it Cost to Get Looking Through Your Own Vintage Scope?

Shane says, "It'll roughly run you about $500 on the high end for a good 60-mm Sears-type refractor adapted to 1.25″ eyepieces. Good quality classics can be found in the range of $100–$300, but they might be missing some accessories like the original eyepieces. While it's still advisable for newcomers to start with that 8″ Dobsonian, these little vintage refractors can make great urban instruments for fast set-up and cool down for lunar, planetary, and double-star observing. And because of the long focal length, the background can appear darker even under light-polluted skies."

## What and Where to Buy

Recommended brands include: Royal Astro Optical and look for Royal Astro Makers Markings on other brands like Tasco and Sears. Makers Markings tell you where and by whom it was made. Also look for Zeiss, Takahashi, Nikon; you may find others but you have to do some research to make sure it has a good lens. Classic 'scopes can pop up anywhere from yard sales to specialty online Japanese auction houses but take a look at Kijiji, Canada Astro Buy and Sell, or Astromart. You may also be able to source a quality 'scope from a local amateur.

## Recommended Scopes:

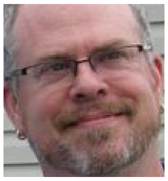
Tasco 7TE-5 – great quality, not rare, relatively affordable

Zeiss Telementor – premium quality but expensive

Tasco 20TE or Unitron 132E – these are unicorns, very rare 4″ refractor ✶

*Shane and Chris are friends who met through the RASC and enjoy observing and working on public outreach projects together. Their pandemic project is a reboot of the Actual Astronomy Podcast, an audio podcast focused on what's up in the night sky, equipment, and getting started in astronomy conversations.*

# Is Tonight Good for Stargazing?



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

## A Quick Indicator

My favourite thing about Good to Stargaze (GTS) is the simple indicator system. If it's green, let's go exploring. My second favourite thing about GTS is the customizable options.

The GTS website is similar to Clear Sky Charts and Clear Outside with the coloured *chips* alluding to sky conditions by various factors. What is the amount of cloud cover, what is the temperature (with wind chill), what is the predicted humidity, seeing, and transparency? How much moonlight will I have to deal with? What makes Clear Outside quite useful is its *roll up* factoring all conditions resulting in a high-level summary for each hour. Again, GTS does that.

But what sets GTS apart is that you can set your own parameters or criteria. You can specify what's good for you.

## Good to Stargaze Web

On the website, it is quite easy to indicate your thresholds by filling out the form and adjusting the options (see Figure 1). When you leave a box unchecked, you're saying it is not a constraining factor.

For example, if you don't like the cold, tick the checkbox for Min Temperature then enter or adjust your low number. Trigger the Wind Chill option as well. Don't like the Moon? Set the Max Moonlight option and enter the maximum percentage.

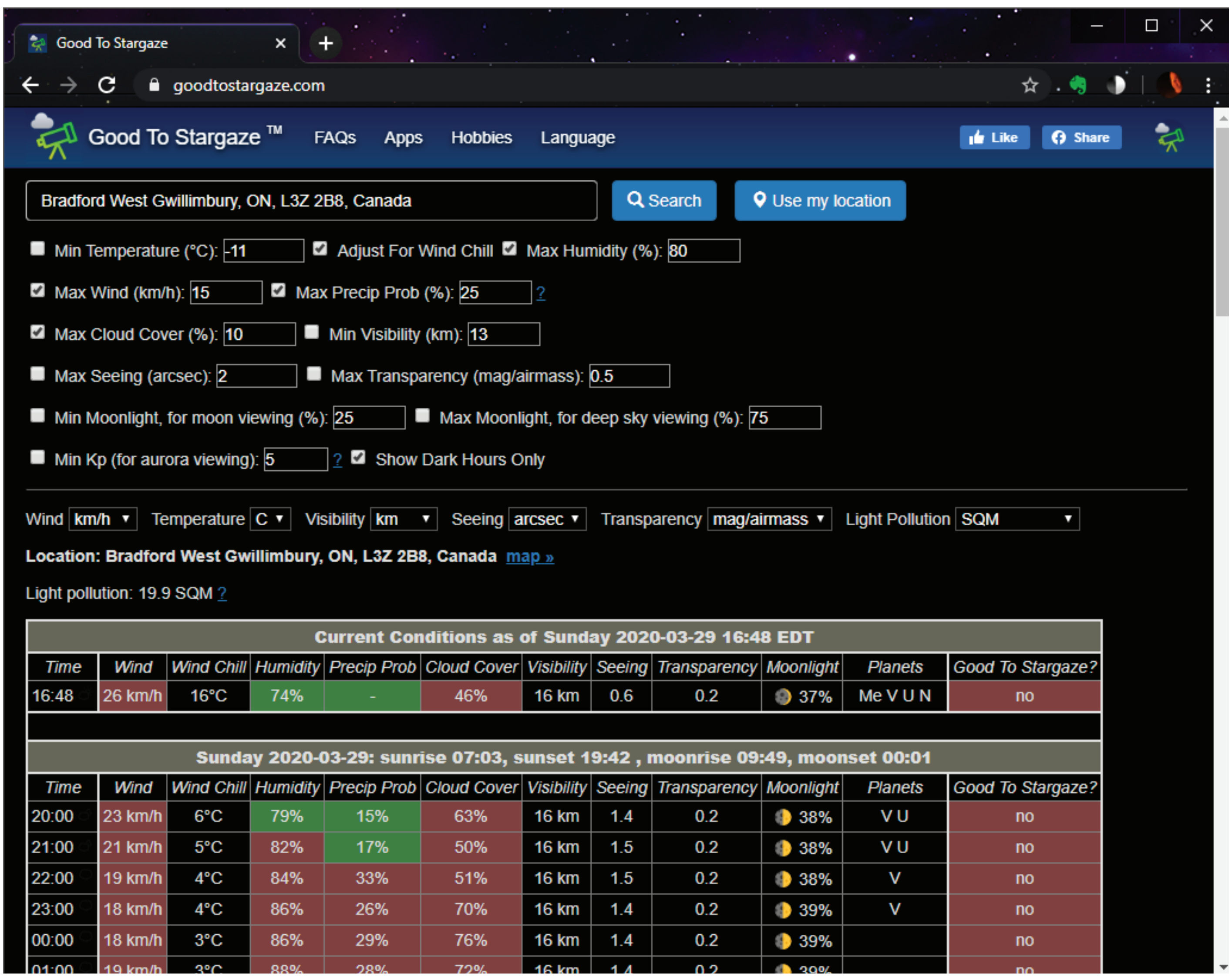
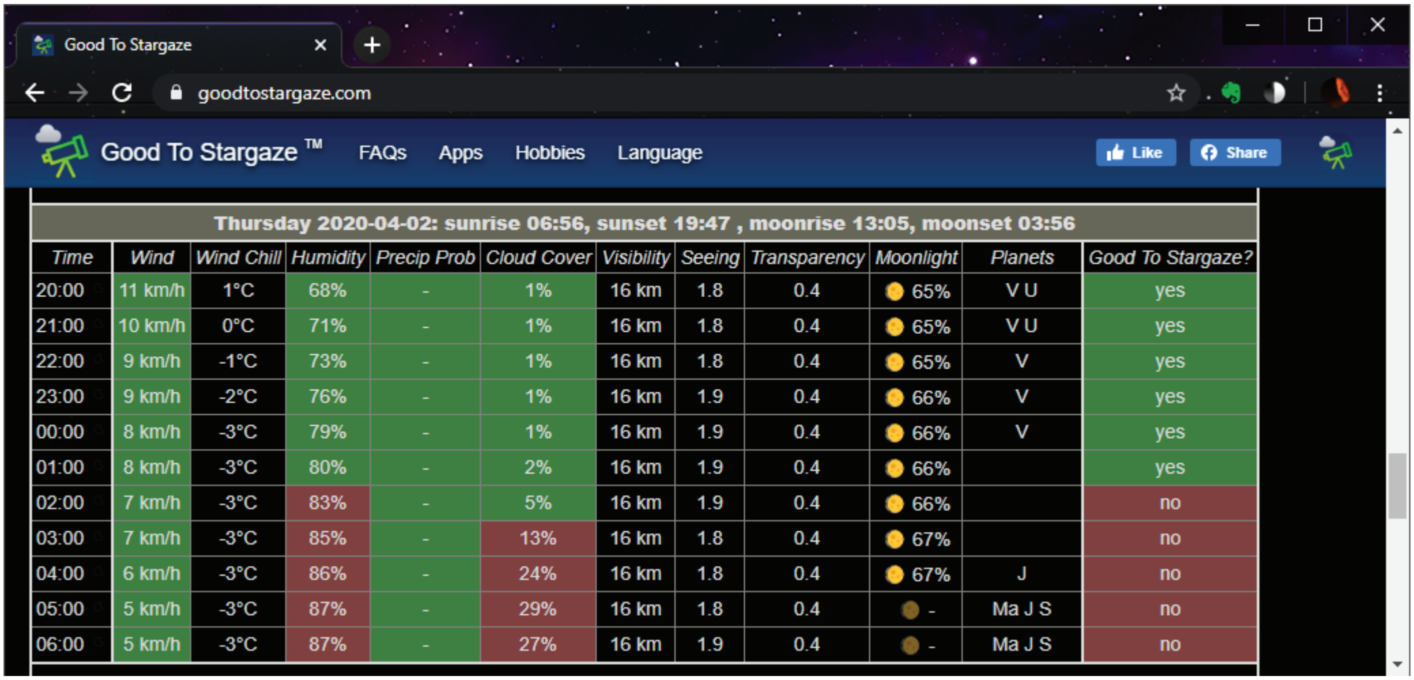



*Figure 1 — Good to Stargaze website with criteria form at top*





| Thursday 2020-04-02: sunrise 06:56, sunset 19:47 , moonrise 13:05, moonset 03:56 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | Wind | Wind Chill | Humidity | Precip Prob | Cloud Cover | Visibility | Seeing | Transparency | Moonlight | Planets | Good To Stargaze? |
| 20:00 | 11 km/h | 1°C | 68% | - | 1% | 16 km | 1.8 | 0.4 | 65% | V U | yes |
| 21:00 | 10 km/h | 0°C | 71% | - | 1% | 16 km | 1.8 | 0.4 | 65% | V U | yes |
| 22:00 | 9 km/h | -1°C | 73% | - | 1% | 16 km | 1.8 | 0.4 | 65% | V | yes |
| 23:00 | 9 km/h | -2°C | 76% | - | 1% | 16 km | 1.9 | 0.4 | 66% | V | yes |
| 00:00 | 8 km/h | -3°C | 79% | - | 1% | 16 km | 1.9 | 0.4 | 66% | V | yes |
| 01:00 | 8 km/h | -3°C | 80% | - | 2% | 16 km | 1.9 | 0.4 | 66% | | yes |
| 02:00 | 7 km/h | -3°C | 83% | - | 5% | 16 km | 1.9 | 0.4 | 66% | | no |
| 03:00 | 7 km/h | -3°C | 85% | - | 13% | 16 km | 1.8 | 0.4 | 67% | | no |
| 04:00 | 6 km/h | -3°C | 86% | - | 24% | 16 km | 1.8 | 0.4 | 67% | J | no |
| 05:00 | 5 km/h | -3°C | 87% | - | 29% | 16 km | 1.8 | 0.4 | - | Ma J S | no |
| 06:00 | 5 km/h | -3°C | 87% | - | 27% | 16 km | 1.9 | 0.4 | - | Ma J S | no |

*Figure 2 — Early Thursday night is looking promising according to GTS.*

My backyard constraints are cloud cover, wind, and humidity. I want less than 10 percent cloud, wind speed below 15 km/h, and humidity no higher than 85 percent. Then I look for a few good continuous hours.

## Should I Stay or Should I Go Now?

The Forecast tables (Figure 2) show the time, wind speed, temperature (adjusted for wind chill, if applicable), humidity, POP, cloud cover, visibility, seeing, transparency, moonlight (percentage and phase icon), visible planets, and overall summarization. Each row is for an hour in the evening. Each grouping is headed by the date with Sun and Moon set and rise times.

Reading the tables and taking in the last column with the final assessment, you can get a good idea what you'll be facing. You might decide, "tonight's a wash." But, "tomorrow should be good after 10:00 p.m." GTS tells you if it is "good to stargaze!"

## Good to Stargaze App

I consulted the website for years but had never used the mobile app. I downloaded the Android tool, version 2.2.26, which I found relatively small. It installed without incident. The app for iOS has the same version number and the screen snapshots look similar.

The main screen (Figure 3) is called Conditions. In this mode the device display, a dashboard of sorts, is filled with live tiles each giving a quick heads-up as to the current conditions. Some tiles, like the Weather one, are animated; some update automatically. You can force an update by swiping down.

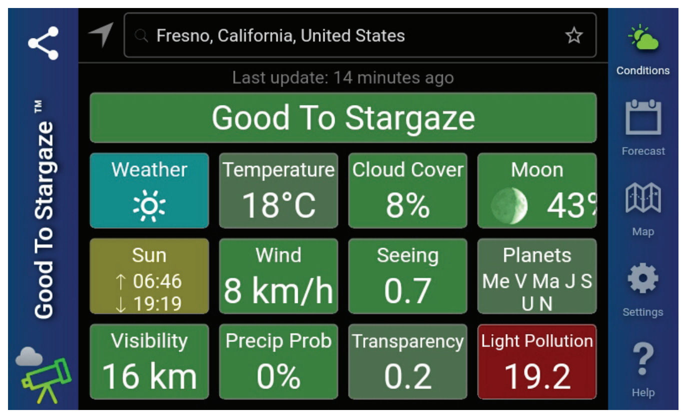




*Figure 3 — The GTS Conditions screen in landscape on the Android app.*

Like the blocks in the webpage, the tile colours are indicative. Bright green means good, an acceptable condition according to your threshold. Dull green means it is unrestricted. I wish, like the website, these were black. Red is bad, out of bounds. Weather alerts may show at the top of the display.

The font is a little large for my teeny phone.

The tiles react if you tap them. You get a tip pop-up from which you can adjust the threshold and measurement unit, where relevant.

The second screen is called Forecast. Switching to this mode is easily accomplished by tapping the button in the toolbar. The forecast tables are shown here, almost exactly how they appear on the website. The column headings are frozen to help when scrolling.

I was pleasantly surprised that this worked on my tiny screen. The app works well in portrait and landscape orientation.

## Light Pollution Map

Both the website and mobile app (see Figure 4) offer a map with road, satellite, and terrain data from Google.

A current light pollution overlay is displayed. The map with LP overlay (like the *Scope Nights* app I reviewed in December 2019) can help you find a dark location if you're trying to get a good view of a comet or you need a very dark site for imaging faint fuzzies.

If you want driving directions to travel to a dark site, you can drop a green pin. The website offers a map, but this is only for setting your location for the current sky condition assessment.

## You are Here

On the mobile app, atop the Conditions, Forecast, and Map panels there is a location bar. Here you can set up preferred (starred) locations or use your detected location (assuming you

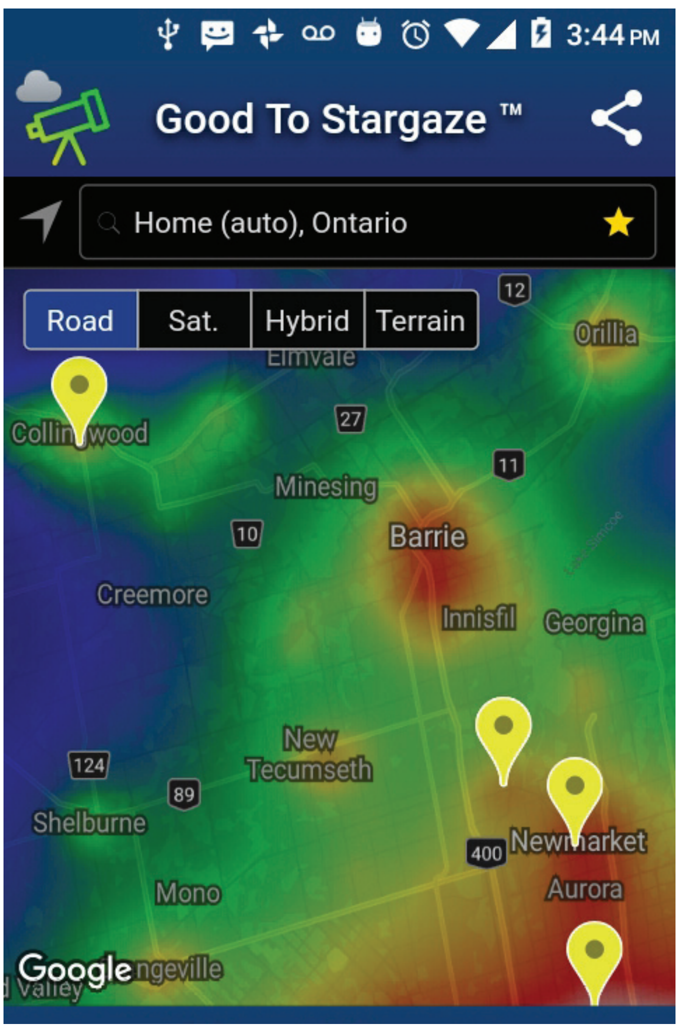



*Figure 4 — Favourite locations marked on GTS map with light pollution overlay.*

grant those rights). The location bar prompts to enter a "postal code, city, or address." None of those worked for my home and neither did obscure locations. I had no trouble using the names of major cities. This is not a big deal, but I won't be able to lock in some specific sites on my phone until I can get there and read the global positioning satellites hovering overhead.

Curiously, I did not experience a problem searching for Bradford West Gwillimbury on the website. That said, the Use My Location button in the browser resulted in a continuously spinning icon. One way or another I had to help GTS with my location information.

There does not appear to be a way to save favourite locations on the website. I found a note that said, "coming soon."

GTS shows your light pollution for your location. It says my backyard sky is Bortle class 6 or has an SQM value of 19.9. That's pretty close to readings I took with a portable Unihedron device.

## Hobbyist Subscription

Some features in GTS are unlocked when you buy an annual subscription.

You receive an instantaneous report. Both on the webpage and in the app, you will see the Current Conditions report with immediate readings for the current time in a one-row table above the Forecast tables.

You also receive Forecast reports beyond one day—a full week's worth. Obviously, there's a diminishing return but it at least lets you make plans a few days out or for a precious weekend.

A subscription allows your web settings to be preserved and locations to be saved on the mobile app.

There are no advertisements with the paid service, and the annual fee of USD $23 is not insignificant.

## Other GTS Notes

A number of the features don't work in the mobile app without an active data connection.

The first time I accessed the Help screen, lots of information was displayed. The second time I switched to Help mode the screen went blank. After another attempt all was fine. You will note hyperlinks to other apps by the developer, an FAQ for the app, and a reference to the privacy policy.

From my phone, I tried the sharing button. This offers a screen shot and/or reference to the app in the sharing note. I see that this could be handy for recording the current conditions.

Data is fed into GTS from the **forecast.io** source aka **darksky.net**, a weather forecasting and visualisation company based in Cambridge, Massachusetts. This organization draws data from weather resources worldwide, including the Canadian Meteorological Centre (CMC) ensemble model.

GTS lacks a proper red mode. Remember, if you put a red film over your screen, everything green will go black.

I reached out to the author, Matthew Lloyd, on a couple of occasions and he replied promptly. He provided me with a complimentary annual pass for evaluation purposes. Mr. Lloyd keeps tabs on feedback in the app stores and encourages people to let him know of issues and ideas through his support email address. It has a 4/5 rating at Google Play and 4.9/5 at the Apple store.

So, try Good to Stargaze for free on the web and on your mobile device. You'll have to cough up for an annual subscription if you want 7-day forecasts, an instantaneous report, and no ads. Visit www.goodtostargaze.com today and set up the criteria for your favourite location.

## Bits and Bytes

Update: SETI is winding down volunteer data processing. If you're using BOINC (which I reviewed April 2017), you can monitor your final SETI jobs. ✶

*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.*

# Great Images

*by James Edgar*

*The Moon was rising over the trees of the ball diamond in Melville, so I snapped a few frames as I watched the Moon climb higher. The sky was covered by forest-fire smoke, thus the orange hue to our Luna. Shooting details: Canon 70D camera with a 18-250 zoom Sigma lens set at 250 mm for 1/15th of a sec, f/6.3, and ISO 200.*

# Dish on the Cosmos

## Tatoine and Binary Star Systems

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

As a nerd of a certain age, one of my favourite movies is the first *Star Wars*. Early in the movie, the film shows Luke Skywalker contemplating a double sunset from the deserts of the hypothetical planet of Tatooine. *Star Wars* is not well known for its accurate physics: things on Tatooine should cast two shadows. However, the science-fiction idea does raise the question of whether there are planets around binary-star systems and whether a planet like Tatooine could exist in our own galaxy. A recent paper by a team of scientists used the Atacama Large Millimetre/submillimetre Array (ALMA) to make observations of young binary stars. The scientists found remnant gas disks that are the legacy of planet formation. Using the excellent resolution of ALMA and its ability to detect gas motions, they were able to infer the orientations of the gas disks relative to the orbit of the binary stars. This relative orientation is the key ingredient that determines whether the planetary system could last billions of years, like our own Solar System.

Binary and multiple star systems are common. Of the stars visible in the sky, half of the lights we see are made up of at least two stars and even triple systems like Alpha Centauri are relatively common. Binary stars are so frequent for the same reasons that planets are thought to be numerous: the need to shed angular momentum during star formation. As stellar systems form, they need a place to deposit the angular momentum of the gas from which they are forming. For single-star systems, this is thought to go into the orbital motion of a disk of gas around the star, and planets naturally form in that disk. Binary stars also likely form from a gas disk, but the mutual orbit of the stars around the common centre of mass becomes the reservoir for the angular momentum of the forming system. Since the orbit of the binary stars can account for the angular momentum, there is not a clear need for planets as there is in a single-star system. Nonetheless, planets could form in binary systems, since both of the forming stars would be fed by a gas disk.

The other big question in planetary systems around binary stars is whether they would be stable over the billions of years that it takes for medium-mass stars to evolve. The theory of gravitation only predicts stable orbits for two bodies in orbit around each other. Thus, the only truly stable planetary systems would consist of one planet and one star, or two stars in orbit around each other. In the study of orbital mechanics, there is no simple solution to the orbits of three bodies in the same system because there are more unknown variables that need to be solved for than there are equations in the problem. This lack of a simple solution is called the "three-body problem," which has been shown to have no general solution, and that the motions in three-body systems do not repeat each other. The harder problem of the tens of thousands of bodies (planets, asteroids, comets) that we see in our own Solar System has no hope for a general physics solution. However, there is a question of whether our Solar System is stable: is it likely to remain in roughly the same configuration over time with the planets remaining roughly in the same orbits relative to each other? Since the Solar System has been around for some 4.6 billion years, nearly half the expected lifespan of the Sun, it must be fairly stable. The analysis of the many-body problem in our Solar System finds that it is stable. However, the motions of the planets are "chaotic," meaning we cannot predict where planets will be over a long term though their orbital locations are roughly stable. This is analogous to the patterns of weather vs climate: we have no hope of predicting the exact weather a year from now, but the average conditions are likely to fall in a narrow range.

There are several key ingredients to the relative stability of our Solar System. First, the Sun is far more massive than all other objects in the Solar System, comprising some 99.7% of the Solar System's mass. Of the other objects in the Solar System, the planets are all on nearly circular orbits. Finally, all of the planets are found in nearly the same orbital plane, and that plane is aligned with the rotational axis of the Sun. These factors are all thought to be the result of how our Solar System formed, out of a single, flat gas disk. If the Solar System were perturbed by, for example, a close encounter with a nearby star, then the stability of the system would be jeopardized.

Binary stars lack these ingredients: the binary stars orbiting around each other create a time-varying gravitational force that makes it difficult for orbiting planets to find a stable orbit. In general, there are two possible scenarios where the analysis of orbits says that planets have any hope of remaining in the system for more than a few million years. In one case, the binary stars could be far apart, and the planets would be close enough to one of the stars that their orbital motion is dominated by just one star. The unconfirmed detection of a planet around Alpha Centauri B would be this kind of planet. Alternatively, the stars could be close together and the planets would be sufficiently far away that the two stars appeared close enough to being one star that the orbits could be stable. Tatooine would be one of this kind of system.

The planet-hunting mission *Kepler* found thousands of planets by watching a field of stars for "transits," the small drops in brightness toward stars when the planet passes between the star and the *Kepler* satellite. While most of the planets found are around single stars, there have been approximately

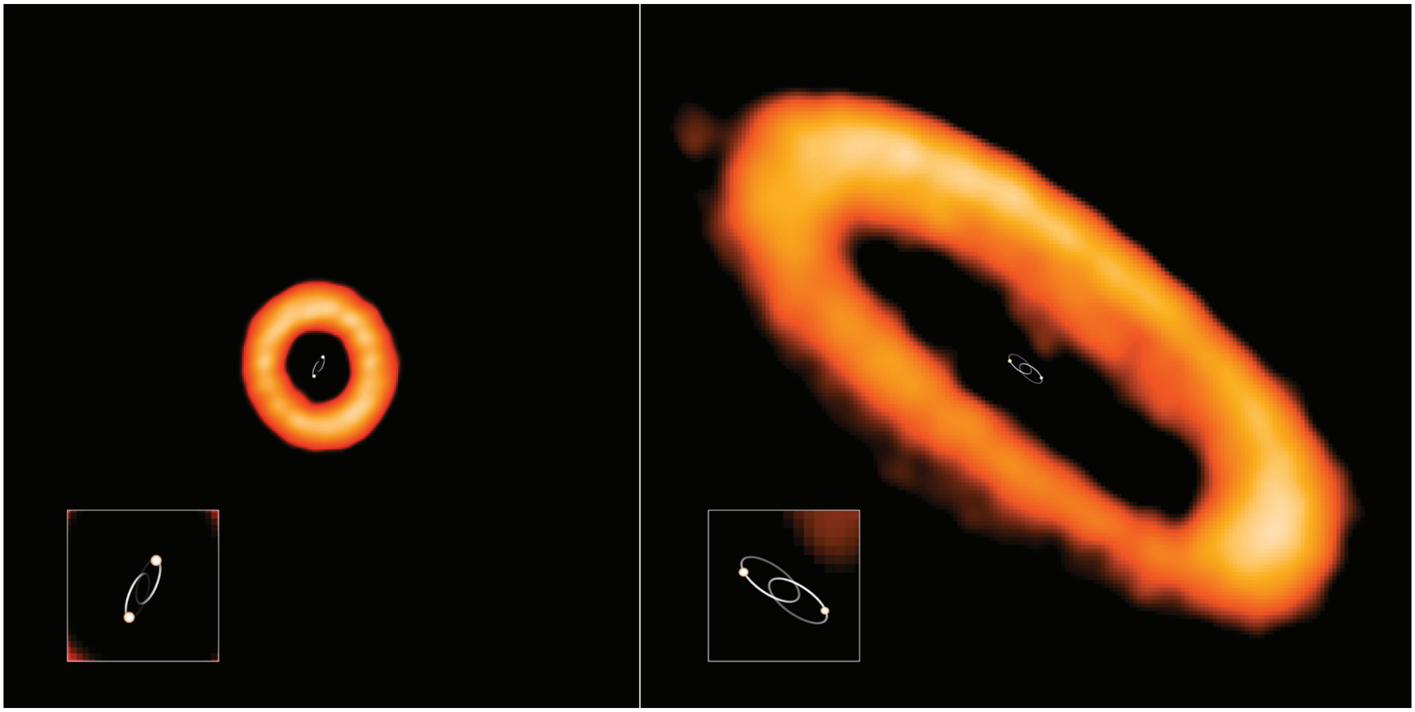


Figure 1 — Two examples of circumbinary disks where the orientations of the disks have been revealed with ALMA. (Left) The HD 98800 B system is a long-period binary where ALMA observations reveal a circumbinary disk that is perpendicular to the orbital plane of the two stars. (Right) In the AK Sco system, an aligned gas disk orbits around a short-period binary system. Image Credit: ALMA (ESO/NAOJ/NRAO), I. Czekala and G. Kennedy; NRAO/AUI/NSF, S. Dagnello

20 planets found in orbit around binary-star systems. These systems are all "circumbinary" meaning the planets are orbiting both stars, like the Tatooine case. *Kepler*, thus, showed that planets can exist around the stars. The structure of these systems was less clear, and astronomers could only deduce a little about how the orbits of the planets relate to those of the binary.

The new ALMA telescope observations provided this insight into the shapes of the orbits. ALMA cannot observe planets directly. Instead, astronomers focused the telescope on young binary-star systems that still host the remnant gas from their formation. ALMA has excellent angular resolution, making it possible to measure both the geometry of gas disks and their motion. These observations can then be used as a proxy for where planets could be forming, giving insight into the long-term stability of these systems.

A team of astronomers used the ALMA facility to make new observations of the gas in the binary-star systems and combine these observations with observations from the telescope archive. Figure 1 shows two examples of the results found in this study, showing the locations of gas disks relative to the orbit of the binary-star systems. The gas disks are excellent ways of finding where the orbits of planets would be found. The gas is also an excellent tracer because the astronomers could use the Doppler effect to study its motion and get a clear measurement of the orientation of the disk. For some cases, the observing team found that some gas disks were misaligned (Figure 1, left) showing a gas disk that was perpendicular to the orbits of the binaries. Planets forming in these systems would not be stable over a long period of time. In contrast, other systems were found where the gas disk is in the plane of the binary orbit (Figure 1, right). Planets formed in these systems would be more Tatooine-like and stand a better chance of being stable over the long term.

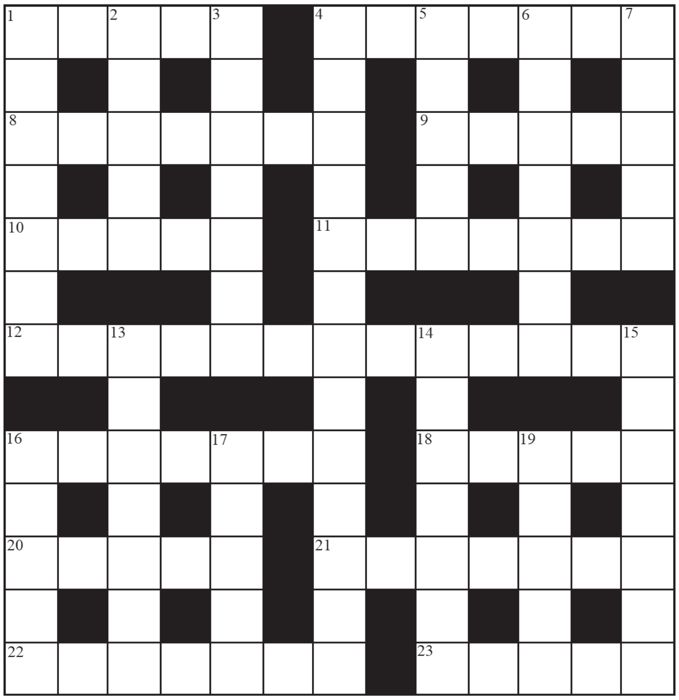
The research team also cited evidence for an intriguing correlation: whether a disk was aligned or misaligned depended on how close the binary stars were to each other. Stars close to each other have short orbital periods, just as planets close to their stars go around the star in less time. Stars with short orbital periods tended to have aligned disks. Stars with long orbital periods had misaligned disks, which points to how the slower orbits and separated stars lead to an instability in the orbital motion and the misaligned gas disks.

While the filmmakers likely thought Tatooine should have two suns to make it seem exotic to moviegoers, this recent work shows that Tatooine-like planets do exist and, when the stars are close to each other, the systems can be stable over a long period. While I know that *Star Wars* is filled with breaches of physical laws, I remain happy that at least some of its worlds could be found here, not just in a galaxy far, far away. ✶

*Erik Rosolowsky is a professor of astronomy at the University of Alberta where he researches how star formation infuences 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. Small organization turns up a moving one in Ursa Major (5)
4. Writer's award is easy to part with (7)
8. Crows wing over a dizzy gal or sailor (7)
9. Saw how the age of the earth was determined (5)
10. Mount not level is in a strange configuration (5)
11. Yukon and New Brunswick are two with a bad secret about the north (7)
12. River's head and all streams compose timely section of the Handbook (7,6)
16. A li'l man with a bright belt buckle (7)
18. Troubled company placed first equipment ad in magazine covers (5)
20. Earth plays backstop in France (5)
21. Bank of England gets the dish on space news (7)
22. Canada's space captain has rent arrangement (7)
23. Beneath your feet is where things drain out in space (5)

## DOWN

1. Gas swirls around one AU right to Dragon's End (7)
2. Groan about the Heart of Charles (5)
3. For Spanish, a lunar fissure that stars in Virgo (7)
4. Bayer's LMC could be mean, jocular, confused (8,5)
5. No dew forms on the day named for him (5)
6. Where to find our office of confused oration in this country (7)
7. Dobs slewed around east to northern galaxy (5)
13. Mesopotamian Saturn deity took wrong turn in a field (7)
14. Englishman instrumental in Mars rotation study (7)
15. Age-related population where all rest uneasily (7)
16. Proofreader sat back, at first, with the Journal (5)
17. Discover how Spock's portrayer initially swallowed an ear (5)
19. Great comet discoverer seen about and around Belgium (5)

### Answers to April's puzzle

**ACROSS**: **1** aten (anag); **3** trumpler (t(ru(mp)le)r); **9** regulus (regul-ar+us); **10** norma (norma-l); **11** kreep (hom); **12** athena (2 def); **14** tempel (temp+el); **16** Mirzam (mir+zam); **19** aspect (hid); **21** hamal (ham+al); **24** laika (2 def); **25** Edasich (anag); **26** mean time (me+anag); **27** vega (anag)

**DOWN**: **1** arrokoth (2 def); **2** eagle (2 def); **4** rascal (hid); **5** month (mo(n)th); **6** Lorentz (lo+rent+z); **7** read (2 def); **8** elapse (anag); **13** amalthea (2 def); **15** Muscida (anag+da); **17** ishtar (anag); **18** stream (anag); **20** epact (e+pact); **22** Maize (hom); 23 ylem (hid)

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

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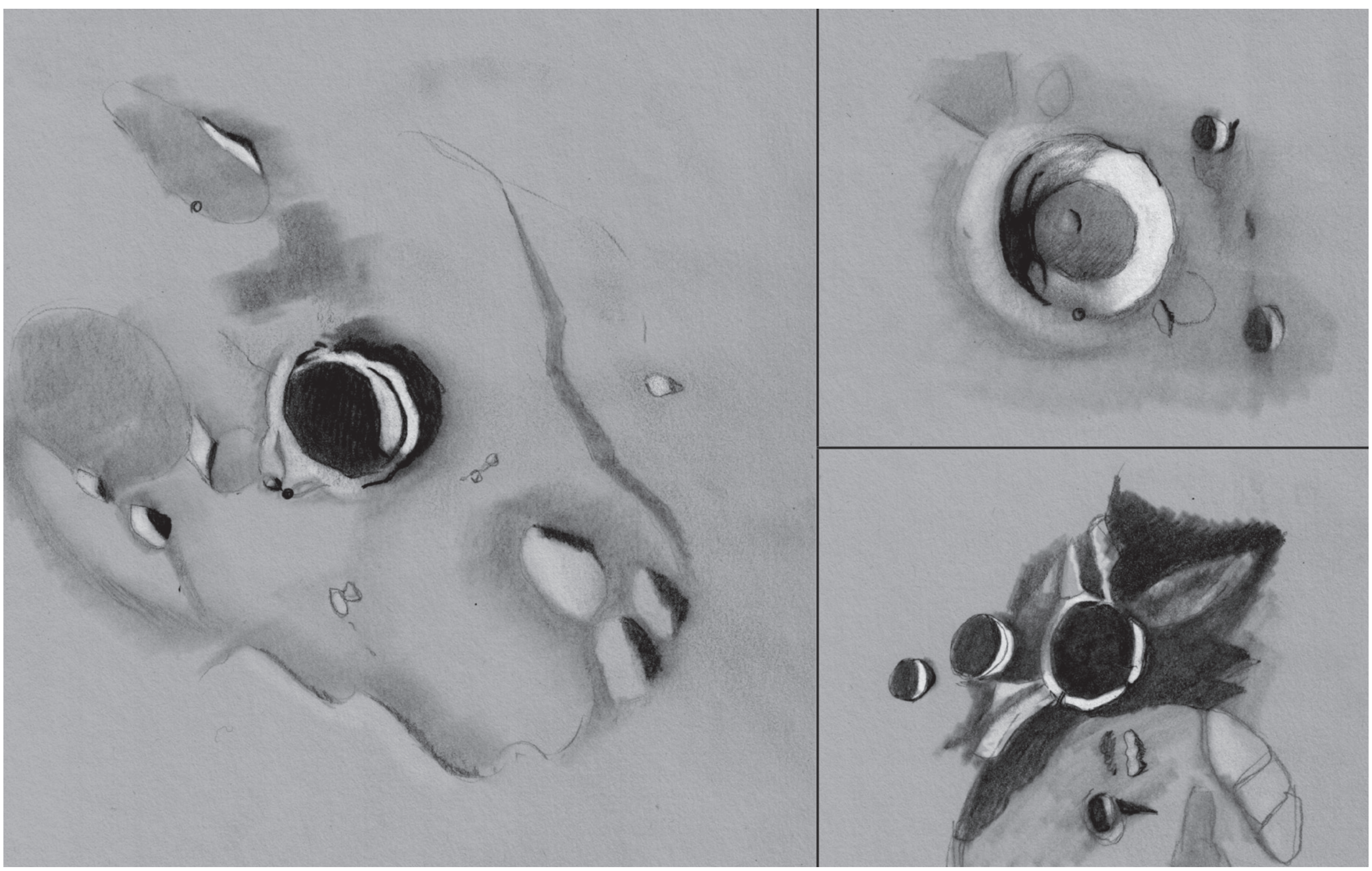
### *Values*

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

# Great Images

*by Michael Gatto*



*Moon sketches; craters Manilius (left), Delambre (top right), and Halley (bottom right). At least social distancing doesn't interfere with some backyard astronomy. Sketched at the eyepiece (a 13-mm Hyperion) of an 8″ ƒ/7.5 Newtonian on a Dobsonian Mount, from Dartmouth, Nova Scotia, 2020 April 29. Drawn in pencil, scanned and coloured in Photoshop. Seeing was average and there were some high clouds from time to time. These craters are targets in the RASC's Explore the Moon certificate program.*

# Journal

*Ron Brecher imaged the Silver Needle Galaxy—"not to be confused with the Needle Galaxy (NGC 4565)," he says. It lies about 14 million light-years away in Canes Venatici. He captured the colour data with a one-shot colour camera on his Takahashi 4" refractor and acquired luminance data with his mono camera on his 6" Sky-Watcher Esprit refractor from his SkyShed in Guelph, Ontario. Both telescopes were mounted on a single Paramount MX mount. Acquisition, focusing, guiding, and control done on a Paramount MX mount with TheSkyX. All pre-processing and processing done in PixInsight. Data acquired 2020 March 21–23, for a total of 21 hours and 13 minutes.*