The Journal of The Royal Astronomical Society of Canada

Journal

Le Journal de la Société royale d'astronomie du Canada

PROMOTING ASTRONOMY IN CANADA

April/Avril 2022
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Inside this issue:

Staring into the Iris

The Best of Monochrome

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

Andre Paquette NGC 1499

It was taken on 2019 Dec 7—just that night. There are 11 × 20-minute exposures. The filter used was a ~3nm Astrodon Hα filter. This was with my Planewave CDK 12.5 on a Celestron CGE Pro mount. Guiding was done via OAG with a Celestron Skyris 274M camera. Most of the low-level processing is my own software, but I also make use of Maxim/DL and Photoshop.

Journal

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Royal Astronomical Society of Canada

Société Royale d'Astronomie du Canada

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Stefan Jackson captured data of the Iris Nebula over the summer of 2021, and Shelley Jackson recently processed the data. The images were captured using a Stellarview 105-mm CF apochromatic triplet, a 50-mm guide scope and 120-mm mono guide cam, together with an Atik 314L CCD mono cam cooled to 0 °C, and an Atik EFW using LRGB and Hα filters. Lum: 129 × 120 sec; R: 99 × 180 sec; G: 95 × 180 sec; B: 94 × 180 sec; Hα: 83 × 240. Stacked and processed with 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.

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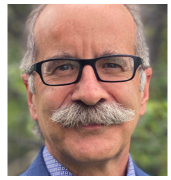
President's Corner



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

As readers of this *Journal*, most of you are familiar with the International Astronomical Union. Within that august organization is the Working Group for Small Bodies Nomenclature (WGSBN) which publishes the *WGSBN Bulletin*. This is the arm of the IAU tasked with renaming small bodies in our Solar System and recognizing the efforts of extraordinary humans around the globe.

Past President Peter Jedicke crafted a plan in 2018 and with RASC Board of Directors approval, solicited nominations from Centres of the RASC and submitted names and citations from across our Society and across our country.

The latest volume, that being Volume 2, #2, published 2022 February 7, represents the final installment of renamed asteroids in honour of RASC members nominated in Peter's almost four-year-old project.

The fruits of Peter's efforts were first realized in Volume 1, #8 on 2021 September 20, where the following RASC members were recognized:

(10052) Nason = 1987 SM12
Curt Nason (b. 1953) New Brunswick Centre.

(10053) Noeldetilly = 1987 SR12
Rolland Noël de Tilly (1906–1983) Centre de Montréal.

(10058) Ikwilliamson = 1988 DD5
Isabel K. Williamson (1908–2000) Centre de Montréal.

And then again, in Volume 1, #10 on 2021 October 15, three more RASC members were honoured:

(10045) Dorarussell = 1985 RJ3
Dora Russell (1913–1986) St. John's Centre.

(10047) Davidchapman = 1986 QK2
David Chapman (b. 1953) Halifax Centre.

(10059) McCullough = 1988 FS2
Brian McCullough (b. 1953) Ottawa Centre.

In Volume 1, #11 published on 2021 November 8, five more extraordinary members were recognized:

(10062) Kimhay = 1988 RV4
Kimberley Dawn Hay (b. 1959) Kingston Centre

(10065) Greglisk = 1988 XK
Greg Lisk (b. 1963) Belleville Centre.

(10066) Pihack = 1988 XV2
Brian Pihack (b.1956) Niagara Centre.

(10073) Peterhiscocks = 1989 GJ2
Peter Hiscocks (1945–2018) Toronto Centre.

(10076) Rogerhill = 1989 PK
Roger Hill (b. 1955) Hamilton Centre.

In Volume 1, #12 published 2021 November 29, we see added:

(10077) Raykoenig = 1989 UL1
Raymond (Ray) Koenig (1930–2007) Kitchener-Waterloo Centre.

And then, Volume 1, #13 on 2021 December 20, has seven more RASC members honoured:

(10080) Macevans = 1990 OF1
William MacDonald "Mac" Evans (b. 1942) Sarnia Centre.

(10081) Dantaylor = 1990 OW1
Daniel Taylor (b. 1958) Windsor Centre.

(10082) Bronson = 1990 OF2
Ted Arthur Bronson (b. 1952) Thunder Bay Centre.

(10083) Gordonanderson = 1990 QE2
Gordon "Jay" Anderson (b. 1947) Winnipeg Centre.

(10084) Rossparker = 1990 QC5
Ross Parker (b. 1959) Regina Centre.

(10085) Jekennedy = 1990 QF5
John Edward Kennedy (1916–1999) Canadian Astronomical Society.

(10086) McCurdy = 1990 SZ
Bruce Jefferson McCurdy (b. 1955) Edmonton Centre.

And finally, the latest edition, Volume 2, #2 published 2022 February 7, recognizes the final four in this round of nominees:

(10087) Dechesne = 1990 SG3
Roland George Dechesne (b. 1960) Calgary Centre.

(10096) Colleenohare = 1991 RK5
Colleen O'Hare (b. 1955) Okanagan Centre.

(10097) Humbroncos = 1991 RV16
honours the memory of sixteen persons, including ten members of the **Humboldt Broncos**, nominated by the Prince George Centre.

(10098) Jaymiematthews = 1991 SC1
Jaymie Mark Matthews (b. 1958).

(10109) Sidhu = 1992 KQ
Jaskarn Singh "Sid" Sidhu (b. 1938) Victoria Centre.

Complete citations can be found here, www.iau.org/publications/iau/wgsbn-bulletins/ referencing the appropriate Volume.

As you can well imagine, it is an understatement to say that these honourees were thrilled to be recognized in such a manner. On behalf of the Society, its members, and these recipients, please join me in thanking Peter Jedicke for his work towards this extraordinary honour and to the IAU Working Group for Small Bodies Nomenclature for their consideration.

Congratulations to all. ✶

News Notes / En manchette

Compiled by Jay Anderson

Twelve for dinner: The Milky Way's feeding habits shine a light on dark matter

It is a tenet of galactic evolution theory that the Milky Way was formed by the breakup and accretion of smaller stellar systems, such as dwarf galaxies and globular clusters. Over a period of time, evidence of these events gradually fades from view as the stars and other material are assimilated into the larger bulk of our galaxy. More recent events, not yet completely absorbed, leave a trail behind in the form of elongated streams of stars orbiting the Milky Way; these streams have become a popular subject for study, especially after the survey results from the *Gaia* spacecraft became available, which allowed their positions and movements to be determined to an unprecedented accuracy.

Spectroscopic study of such streams gives clues about the composition of stars in the early history of our galaxy and positional measurements define their orbits, revealing the fine-scale gravitational structure of the Milky Way that might reveal the presence of smaller accumulations of dark matter. A new study, involving Canadian, American, and Australian astronomers, has examined 12 of the 60 or so streams that have been identified as part of the Milky Way family, providing the largest, homogeneous sample of stream physiology.

Understanding these star streams is very important for astronomers. As well as revealing the dark matter that holds the stars in their orbits, they also tell us about the formation history of the Milky Way, revealing that the Milky Way has steadily grown over billions of years by shredding and consuming smaller stellar systems.

"We are seeing these streams being disrupted by the Milky Way's gravitational pull, and eventually becoming part of the Milky Way. This study gives us a snapshot of the Milky Way's feeding habits, such as what kinds of smaller stellar systems it 'eats.' As our galaxy is getting older, it is getting fatter." said University of Toronto Professor Ting Li, the lead author of the paper.

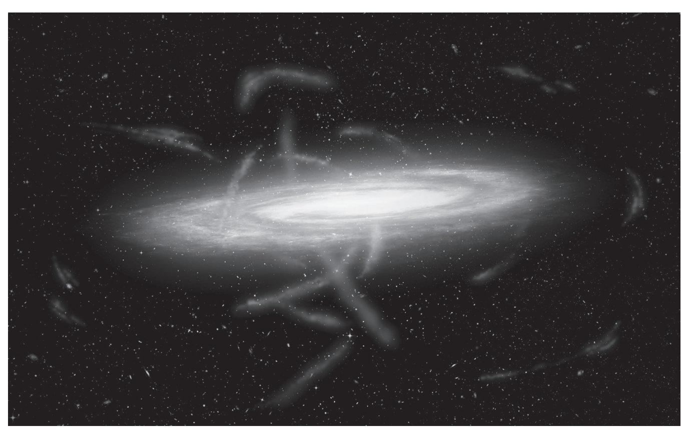


Figure 1 — Artist's representation of the Milky Way Galaxy surrounded by dozens of stellar streams (Credit: James Josephides; S5 Collaboration).

Professor Li and her international team of collaborators initiated a dedicated program—the Southern Stellar Stream Spectroscopic Survey (S5)—to measure the properties of stellar streams: the shredded remains of neighbouring small galaxies and star clusters that are being torn apart by our own Milky Way.

Li and her team are the first group of scientists to study such a rich collection of stellar streams, measuring the speeds of stars using the Anglo-Australian Telescope (AAT), a four-metre optical telescope in Australia. Li and her team used the Doppler shift of light to find out how fast individual stars are moving. Unlike previous studies that have focused on one stream at a time, "S5 is dedicated to measuring as many streams as possible, which we can do very efficiently with the unique capabilities of the AAT," comments co-author Professor Daniel Zucker of Macquarie University.

The properties of stellar streams reveal the presence of the invisible dark matter of the Milky Way. "Think of a Christmas tree," says co-author Professor Geraint F. Lewis of the University of Sydney. "On a dark night, we see the Christmas lights, but not the tree they are wrapped around. But the shape of the lights reveals the shape of the tree. It is the same with stellar streams—their orbits reveal the dark matter."

A crucial ingredient for the success of S5 was observations from the European *Gaia* space mission. "*Gaia* provided us with exquisite measurements of positions and motions of stars, essential for identifying members of the stellar streams," says Dr. Sergey Koposov, reader in observational astronomy at the University of Edinburgh and a co-author of the study.

As well as measuring their speeds, the astronomers can use these observations to work out the chemical compositions of the stars, telling us where they were born. "Stellar streams can come either from disrupting galaxies or star clusters," says Professor Alex Ji at the University of Chicago, a co-author on the study. "These two types of streams provide different insights into the nature of dark matter."

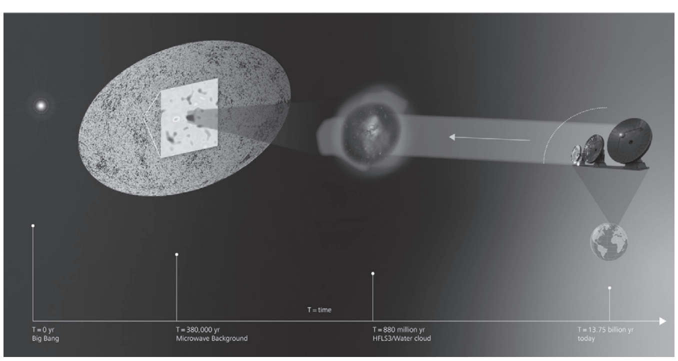


Figure 2 — The Cosmic Microwave Background (left) was released 380,000 years after the Big Bang, and it acts as a background to all galaxies in the Universe. The starburst galaxy HFLS3 is embedded in a large cloud of cold water vapour (middle, indicated in blue), and is observed 880 million years after the Big Bang. Credit: ESA and the Planck collaboration; zoom-in panel: Dominik Riechers, University of Cologne; image composition: Martina Markus, University of Cologne.

Half of the members in the study turned out to be streams derived from globular clusters, the others from dwarf galaxies. At least three of the globular clusters are still extant, gradually shedding stars to the galaxy and their associated streams.

According to Professor Li, these new observations are essential for determining how our Milky Way arose from the featureless Universe after the Big Bang.

"For me, this is one of the most intriguing questions, a question about our ultimate origins," Li said. "It is the reason why we founded S5 and built an international collaboration to address this."

Li and her team plan to produce more measurements on stellar streams in the Milky Way. In the meantime, she is pleased with these results as a starting point. "Over the next decade, there will be a lot of dedicated studies looking at stellar streams," Li says. "We are trail-blazers and pathfinders on this journey. It is going to be very exciting!"

Compiled in part with material provided by the Dunlap Institute for Astronomy and Astrophysics at the University of Toronto.

Water vapour cloud reveals early Universe temperature

Using a 12-dish movable microwave telescope array situated at 2500 metres in the French Alps, an international group of astrophysicists has discovered a new method to estimate the cosmic microwave background (CMB) temperature of the young Universe only 880 million years after the Big Bang. It is the first time that the temperature of the cosmic microwave background radiation—a relic of the energy released by the Big Bang—has been measured at such an early epoch of the Universe.

Since its beginning 13.8 billion years ago as an extremely hot and dense plasma, the Universe has been expanding and, as a consequence, its temperature has been falling. Those initial moments are not visible to our telescopes, and it wasn't until the Universe passed its 380,000th birthday that it had cooled enough for light photons to spread freely. Today's photons from that cosmic background radiation (CBR) have an energy that fits a temperature of 2.3K.

Current models of the Universe's expansion describe how the cooling process should proceed, but so far it has only been directly confirmed for relatively recent cosmic times. This new discovery not only sets a very early milestone in the development of the cosmic background temperature, but could also have implications for the enigmatic dark energy.

The scientists used the NOEMA (Northern Extended Millimeter Array) observatory in the French Alps, the most powerful radio telescope in the Northern Hemisphere, to observe HFLS3, a massive starburst galaxy. Such galaxies get their name from their high rate of new star formation and this particular one contains a large amount of water vapour. NOEMA telescopes were used to map the microwave spectrum of the galaxy, revealing a broad range of emission dominated by carbon monoxide and water vapour. Among the forest of emission lines was a single deep absorption line, at 3.95 mm.

Numerical modelling of the processes that cause the 3.95 mm line show that the absorption of photons from the CMB excites electrons in the water molecule from their ground state to a slightly higher energy level. From this level, the electrons are then further excited by the intense infrared radiation of the galaxy, leading to an eventual collapse back to the ground state. This population and depopulation of the upper energy levels has the effect of cooling the water vapour cloud to a temperature below that of the CMB, creating a shadow on the microwave background. From their observations, the astronomers deduce that the CMB at that time must have had a temperature between 16.4 and 30.2 K, a value that fits well with the 20 K temperature calculated from Big Bang modelling.

Because of its low temperature, the water casts a dark shadow on the microwave background corresponding to a contrast about 10,000 times stronger than intrinsic CMB fluctuations of only 0.001% (light/dark spots).

"Besides proof of cooling, this discovery also shows us that the Universe in its infancy had some quite specific physical characteristics that no longer exist today," said lead author Professor Dr. Dominik Riechers from the University of Cologne's Institute of Astrophysics. "Quite early, about 1.5 billion years after the Big Bang, the cosmic microwave background was already too cold for this effect to be observable. We have therefore a unique observing window that opens up to a very young Universe only," he continued. In other words, if a galaxy with otherwise identical properties as HFLS3 were to exist today, the water shadow would not be observable because the required contrast in temperatures would no longer exist.

"This important milestone not only confirms the expected cooling trend for a much earlier epoch than has previously been possible to measure, but could also have direct implications for the nature of the elusive dark energy," said co-author Dr. Axel Weiss from the Max Planck Institute for Radio Astronomy (MPIfR) in Bonn. Dark energy is thought to be responsible for the accelerated expansion of the Universe over the past few billion years, but its properties remain poorly understood because it cannot be directly observed with the currently available facilities and instruments. However, its properties influence the evolution of cosmic expansion, and hence the cooling rate of the Universe over cosmic time. Based on this experiment, the properties of dark energy remain—for now—consistent with those of Einstein's cosmological constant. "That is to say, an expanding Universe in which the density of dark energy does not change," explained Weiss.

Having discovered one such cold-water cloud in a starburst galaxy in the early Universe, the team is now setting out to find many more across the sky. Their aim is to map out the cooling of the Big Bang echo within the first 1.5 billion years of cosmic history. "This new technique provides important new insights into the evolution of the Universe, which are very difficult to constrain otherwise at such early epochs," Riechers said.

"Our team is already following this up with NOEMA by studying the surroundings of other galaxies," said co-author and NOEMA project scientist Dr. Roberto Neri. "With the expected improvements in precision from studies of larger samples of water clouds, it remains to be seen if our current, basic understanding of the expansion of the Universe holds."

Compiled in part with material provided by the Max Planck Institute for Astronomy.

Another destination to search for life?

A Southwest Research Institute scientist set out to prove that the tiny, innermost moon of Saturn was a frozen inert satellite and instead discovered compelling evidence that Mimas has a liquid internal ocean. In the waning days of NASA's *Cassini* mission, the spacecraft identified a curious libration, or oscillation, in the moon's rotation, which often points to a geologically active body able to support an internal ocean.

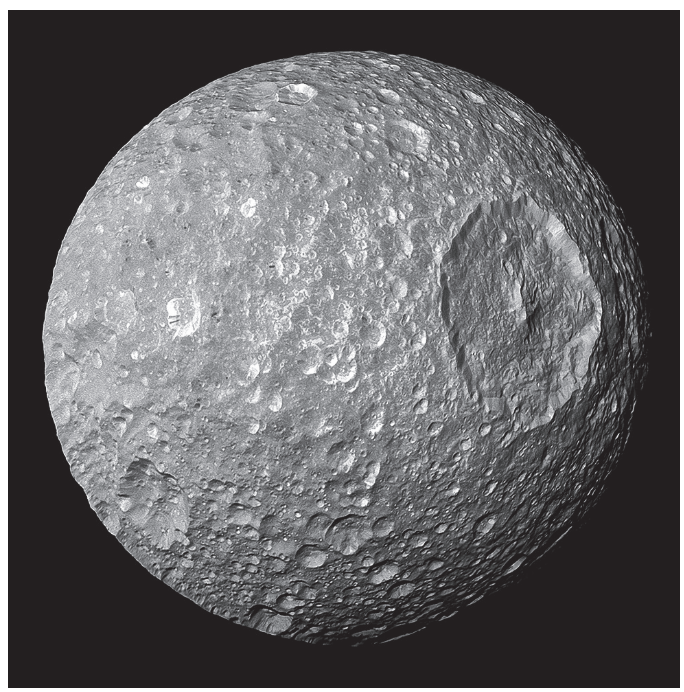


Figure 3 — Mimas with its large crater Herschel. *Other bright-walled craters include* Ban *just left of centre near top, and* Percivale *two thirds of the way left of Herschel. NASA image.*

"If Mimas has an ocean, it represents a new class of small, 'stealth' ocean worlds with surfaces that do not betray the ocean's existence," said SwRI's Dr. Alyssa Rhoden, a specialist in the geophysics of icy satellites, particularly those containing oceans, and the evolution of giant planet satellites systems.

One of the most profound discoveries in planetary science over the past 25 years is that worlds with oceans beneath layers of rock and ice are common in our Solar System. Such worlds include the icy satellites of the giant planets, such as Europa, Titan, and Enceladus, as well as distant planets like Pluto. Worlds like Earth with surface oceans must reside within a narrow range of distances from their stars to maintain the temperatures that support liquid oceans. Interior water ocean worlds (IWOWs), however, are found over a much wider range of distances, greatly expanding the number of habitable worlds likely to exist across the galaxy.

"Because the surface of Mimas is heavily cratered, we thought it was just a frozen block of ice," Rhoden said. "IWOWs, such as Enceladus and Europa, tend to be fractured and show other signs of geologic activity. Turns out, Mimas's surface was tricking us, and our new understanding has greatly expanded the definition of a potentially habitable world in our Solar System and beyond."

Tidal processes dissipate orbital and rotational energy as heat in a satellite. To match the interior structure inferred from Mimas's libration, tidal heating within the moon must be large enough to keep the ocean from freezing out but small enough to maintain a thick icy shell. Using tidal-heating models, the team developed numerical methods to create the most plausible explanation for a steady-state ice shell between 22 and 32 km thick over a liquid ocean.

"Most of the time when we create these models, we have to fine tune them to produce what we observe," Rhoden said. "This time, evidence for an internal ocean just popped out of the most realistic ice-shell stability scenarios and observed librations."

The team also found that the heat flow from the surface was very sensitive to the thickness of the ice shell, something a spacecraft could verify. For instance, the *Juno* spacecraft is scheduled to fly by Europa and use its microwave radiometer to measure heat flows in this Jovian moon.

This data will allow scientists to understand how heat flow affects the icy shells of ocean worlds such as Mimas, which are particularly interesting as NASA's *Europa Clipper* approaches its 2024 launch.

"Although our results support a present-day ocean within Mimas, it is challenging to reconcile the moon's orbital and geologic characteristics with our current understanding of its thermal-orbital evolution," Rhoden said.

"Evaluating Mimas's status as an ocean moon would benchmark models of its formation and evolution. This would help us better understand Saturn's rings and mid-sized moons, as well as the prevalence of potentially habitable ocean moons, particularly at Uranus. Mimas is a compelling target for continued investigation."

Compiled with material provided by the Southwest Research Institute.

The Sun has a gentle soul

Armed with a new statistical analysis of stellar flares on hundreds of M-dwarf stars, scientists are beginning to understand the likelihood that remote "exoplanets" might sustain life in our galaxy, research at the University of Colorado Boulder suggests.

The most-intense flares, which are more complex than previously observed, could have implications for the viability of life on nearby planets. Ward Howard, a postdoctoral researcher who led the study, and Meredith MacGregor, assistant professor of astrophysical and planetary sciences at CU Boulder, conducted the first large-scale analysis of solar-flare data collected at 20-second intervals from NASA's TESS mission. Their findings are soon to be published in *The Astrophysical Journal*. TESS—the *Transiting Exoplanet Survey Satellite*—was launched in 2018 to search for planets outside our Solar System, including those that could support life.

The satellite detects those planets when they periodically block part of the light as they pass in front of their host stars, events called "transits." The stars in question are M dwarf stars, which compose about 70% of the stars in our galaxy. Those stars are cooler and dimmer than Earth's Sun but are prone to explosive superflares—10 to 1000 times larger than flares from our Sun. Superflares could destroy a nearby planet's atmosphere, particularly because exoplanets in the "habitable zone" of these stars can be 20 times closer to their stars than we are to the Sun.

"The Sun is very well behaved," Howard said. "Many of these red-dwarf stars can emit flares 1000 times larger than those from the Sun, and you can only imagine what that might do to a planet or to life on the surface."

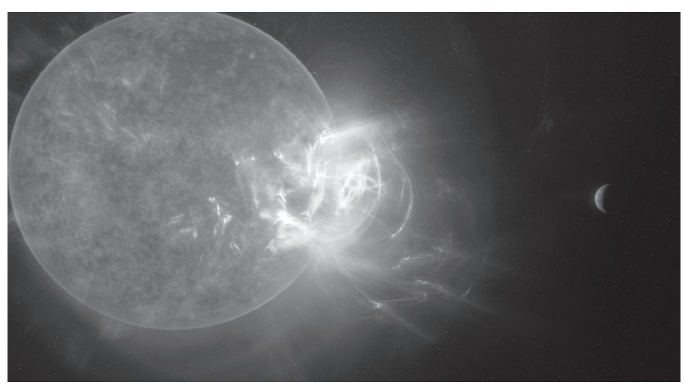


Figure 4 — Artist's concept of the largest flare ever seen from Proxima Centauri, the closest star to our Sun. Proxima is a red-dwarf star, the sort of star known to produce flares. But this flare was 100 times more powerful than any similar flare seen from our Sun. Image NRAO/ S. Dagnello.

By analyzing data from 440 large stellar flares (on 226 stars) from TESS, scientists are starting to "pull back the curtain" on questions of which exoplanets might have atmospheres that are conducive to life, and which would be "dead rocks," Howard said. The 20-second TESS data reveal the building blocks of the flare emission and informs how much radiation reaches the planets during the brief peaks of the flares. Nearly half of the flares had significant substructure in the new high-resolution data; some had quasi-periodic eruptions.

Additionally, the new analysis of the flares shows the flares to be "super complicated," MacGregor said. "They have all sorts of weird structure in the light curves, which indicates that some of them are bursting multiple times." Solar and stellar flares result from entangled magnetic fields, and they release huge bursts of radiation and charged particles.

"We have historically had a very simple picture of stellar activity, where one [magnetic] loop breaks and we have one outburst of energy, and then it slowly dies away, and then we think about the frequency of that," she continued. "That's the model that's been fed into everything we think about stars and their impact on planets, and it's clearly just flat-out wrong."

Although TESS's primary mission is to detect exoplanets, the fact that TESS stares at certain parts of the sky for a month at a time also allows the instrument to detect stellar flares, which are rare and random events.

"Our Sun does this, and we can get beautiful images where you see these loops of emission protruding out of the surface of the Sun, and then they break and stream out into space," MacGregor said.

When those particles and radiation hit the Earth's upper atmosphere, they can dissociate atmospheric molecules, causing the aurora borealis in northern latitudes and aurora australis in the southern.

"So we see beautiful, lovely green lights," MacGregor said. "What we're actually observing is the effect of our Sun splitting apart molecules in our atmosphere and then the release of energy from that splitting of things like ozone and water."

As originally deployed, TESS captured data every two minutes, a frequency sufficient to detect exoplanets but insufficient to gather detailed data on the incidence of stellar flares affecting those planets.

"It allows us to kind of have a statistical understanding of how often certain things occur," Howard said, adding that scientists have never before been able to determine how much radiation reaches planets during the peak of the superflares and how much complexity the flares have.

"This field of astrobiology and exoplanet research is changing so quickly right now, that it makes it a really exciting area to work in," MacGregor said. ✶

Compiled from material provided by the University of Colorado.

Featured Articles / Articles de fond

The Apollo 11 Astronauts Visit Canada

by Christopher Gainor, Victoria Centre

Introduction

The flight of Apollo 11 was an unparalleled achievement for the U.S. space program that generated worldwide interest. As part of the celebrations to mark humanity's first steps on another celestial body, the crew of Apollo 11 undertook the first world tour by U.S. astronauts, a tour that concluded with two stops in Canada.

Neil Armstrong, Edwin E. "Buzz" Aldrin, and Michael Collins were named as the commander, lunar module pilot, and command module pilot of Apollo 11 on 1969 January 9, when they began training for their historic flight from 1969 July 16 to 24 that took Armstrong and Aldrin to the surface of the Moon, while Collins remained in lunar orbit. After their return, the three astronauts were placed in quarantine until August 10, and two days later they began a round of public activities with a press conference, followed by parades, dinners, and ceremonies around the U.S.A.

Giantstep World Tour

On 1969 September 29, Armstrong, Aldrin, and Collins set off from Ellington Air Force Base near Houston with their wives Jan Armstrong, Joan Aldrin, and Patricia Collins on a tour that took them to 23 different countries over the next few weeks. President Richard Nixon provided the use of one of his presidential Boeing 707 aircraft for what became known as the Giantstep World Tour.

The astronauts and their wives were accompanied by staff from the National Aeronautics and Space Administration, the White House, the U.S. Information Agency, and the U.S. Department of State. A notable member of their entourage was the NASA doctor who accompanied the crew through their quarantine starting with their recovery, Dr. William R. Carpentier. The physician was born in Edmonton, Alberta, raised there and on Vancouver Island, and after studies at the University of British Columbia and Ohio State, he joined NASA and served as flight surgeon to the astronauts in the Gemini and Apollo programs.

The Giantstep Apollo 11 World Tour marked the first time that U.S. astronauts had been sent on a world tour. The administration of President Richard Nixon was anxious to reinforce the goodwill around the world created by Apollo 11's historic flight to the Moon. In this case, the astronauts and their entourage flew to Mexico, then on to Columbia, Argentina, Brazil, and then across the Atlantic Ocean to Spain, France, the Netherlands, Belgium, Norway, Germany, England, Italy, Yugoslavia, Turkey, the Democratic Republic of the Congo, Iran, India, Pakistan, Thailand, Australia, South Korea, and Japan. On November 5, the astronauts and their wives were welcomed back to Washington by President Nixon and they spent a night in the White House.

The five-week, round-the-world trip was "an incredible experience," Dr. Carpentier later recalled. "We had the president's airplane, the president's crew. Everywhere we went, we met heads of state, royalty. We stayed in the best hotels the cities we were visiting had to offer. I always had a car at my disposal with a chauffeur and a motorcycle escort, if I needed it. It was pretty heady stuff."[1]

Large crowds met the astronauts everywhere they went, and while Armstrong and Collins were at ease speaking before crowds, Aldrin had more difficulty with these duties, and he was starting to develop a problem with drinking.[2]

The Final Stops of Giantstep

Nearly four weeks after the Apollo 11 astronauts and their wives visited the White House at the end of their round-the-world trip, they returned to Washington to make one more international trip, this one to Canada. Besides being America's next-door neighbour and largest trading partner, Canada played a special role in Apollo.

A decade before Apollo 11, the Canadian government cancelled a jet interceptor aircraft, the CF-105 Avro Arrow. NASA hired 32 of Avro Canada's top engineers, and many of them played important roles in the Mercury, Gemini, and Apollo programs. As well, the struts in the landing gear for Apollo's lunar modules were manufactured in Canada, including those for *Eagle*, which brought Armstrong and Aldrin to the lunar surface before returning them to their mother ship, the *Columbia* command and service module that was piloted by Collins.[3]

The timing of the Apollo 11 crew's separate trip to Ottawa, Ontario, and Montréal, Québec, was a matter of controversy among the organizers of the trip. When discussions began in August about the world tour, State Department officials suggested that Canada be the first stop on the tour, when weather in Canada would be better than it would be in December, which would affect opportunities for the astronauts to be seen by crowds in the outdoors. U.S. Ambassador to Canada Adolph W. Schmidt later commented that the timing meant that "we treated our closest neighbour and our best customer as an after-thought." As well, the exact timing of the Canadian visit wasn't established until two weeks before it actually happened and involved days that were inconvenient for the Canadian government leaders. Schmidt commented about the "good grace with which the [U.S.] ultimatum was accepted and the unfailing cooperation that followed are evidence of Canadian good manners." [4] NASA protocol official Geneva Barnes later said of the separate trip to Canada: "Apparently, these stops couldn't logistically fit into either the beginning or the end of the world trip." [5] The flight of *Apollo 12* to the Moon took place in November between the world trip and the trip to Canada, and the Apollo 11 crew members were on hand at the control centre in Houston to assist during that flight.

Accompanied by their Giantstep tour staff, including Dr. Carpentier, the astronauts and their wives departed Andrews Air Force Base for the 80-minute flight to Ottawa on the morning of Tuesday, 1969 December 2. The astronauts and their party no doubt had read a briefing note on Canada prepared by the State Department that started by stating that, despite the similarities between Canadians and Americans, "Canada is a foreign country." The note highlighted policy differences between the two countries, notably Canada's "more accommodating" attitude to Communist and developing countries, and also Canada's role as America's biggest trading partner. The briefing note contained biographies of the dignitaries the astronauts would meet, including Prime Minister Pierre Elliott Trudeau, and a discussion of "internal strains" over separatism in the province of Québec. It urged that no comments be made on the matter. [6]

At the time, Canadian space programs were organized under several departments, most prominently the National Research Council of Canada (NRC), since the Canadian Space Agency was not formed until 1989. The Apollo 11 astronaut visit to Canada was organized under the aegis of the NRC.

Ottawa, December 2

After their 707 arrived at Hangar 11 at Ottawa's International Airport at about 11:30 a.m., the astronauts' party was met by Charles M. (Bud) Drury, the President of the Treasury Board, U.S. Ambassador Schmidt, and Dr. William G. Schneider, President of the NRC, and their wives. Their motorcade took the main route from the airport along Riverside Drive and Colonel By Drive to the Parliament Buildings in the centre of Ottawa. [7]

In front of a large, young, and exuberant crowd of about 1 000 people at the foot of the Peace Tower, Prime Minister Trudeau greeted the astronauts, saying they were "very, very welcome in our country." Armstrong then introduced Collins, who said: "This is my first trip to Canada, official or otherwise. I certainly hope it's not my last. I'm told it's 20 degrees but I can't really believe it. Your welcome makes me feel at least up in the 60s." Both Collins and Aldrin spoke about Canadian scientists analyzing the rocks they brought back from the Moon, and Aldrin added: "We are also grateful to the men and women who helped make sure that we could bring them back. When the Eagle landed at Tranquility Base, it landed on Canadian legs. They may not have been as shapely as some of the legs here on Earth, but when Neil and I stepped out on the lunar surface, they were indeed beautiful legs to us." [8]

A news report stated that the three astronauts "cast envious glances" at the fur coat Trudeau wore, which was more suitable for the weather than their own lighter coats. Aldrin later wrote that Ottawa was the coldest stop of their entire world tour, colder even than Seoul, whose chilly fall and winter weather he already knew from his service in the U.S. Air Force during the Korean War. Armstrong presented Trudeau with a replica of the small silicon disk he and Aldrin left on the lunar surface on 1969 July 20. The disk contained microfilmed greetings from 73 world leaders, including Trudeau, whose greeting read: "Man has reached out and touched the tranquil moon. Puisse ce haut fait permettre a l'homme de redecouvrir la terre et d'y trouver la paix." [9]

Figure 1 — Prime Minister Pierre Elliott Trudeau (foreground) greets the Apollo 11 astronauts and their wives in front of the Centre Block in Ottawa, 1969 December 3. Left to right: Edwin E. "Buzz" Aldrin, Michael Collins, Patricia Collins, Joan Aldrin, Janet Armstrong, and Neil Armstrong. Image: NASA.

The astronauts' party then was driven to the Prime Minister's official residence at 24 Sussex Drive for lunch with Trudeau, where the Prime Minister presented prints to the astronauts by Inuit artist Alashua Aningmiuq and maple leaf pins and art books to their wives. The astronauts gave Trudeau a replica of the plaque they left on the Moon marking their lunar landing, along with framed photographs taken on the Sea of Tranquility.

After lunch, they returned to the Parliament Buildings for a session of the Canadian House of Commons at 2:00 p.m. When the well-attended sitting began, the astronauts and their wives were seated in the Speaker's Gallery overlooking the chamber, where they received a 55-second ovation, with some of the applause coming from the galleries, where any noise is normally prohibited. In welcoming the "courageous" astronauts and their "equally brave wives," Trudeau said: "The venture of these three brave men into the unknown stirred the imagination and the pride of all Canadians. This country is not so old nor so well explored that either the experience of the frontier or the taste of adventure is forgotten. We are close in time and in space to wilderness. In our blood—or perhaps just in our secret desires—is found the spirit of such as Hudson and Cartier, Palliser and Steffanson. The exploits of our visitors today proved that the age of exploration is not over and we are glad. They proved too that there is new meaning in the heavens, and we are better for it."

The leaders of the other three parties in the House also spoke. Opposition Leader Robert Stanfield, Leader of the Progressive Conservative Party, said: "It will of course be many years before the full significance of this exploit is realized. In 1492 it was difficult for contemporaries to visualize all the consequences of the discovery by Columbus. It is a sobering thought that we today are one of those consequences and that an equally significant development may follow from the exploration of these men." Tommy Douglas, leader of the New Democratic Party, said: "The astronauts whom we honour here today represent a challenge to the governments and legislators of the world to match their achievement in landing on the Moon with similar advances on Earth." Real Caouette, leader of the Ralliement Créditiste spoke in French about the work done in Montréal on the *Eagle*'s landing gear.

A prominent member of the house who didn't speak but was present for the astronauts' appearance was former prime minister John Diefenbaker, who had decided in 1959 to cancel the Avro Arrow, a decision that helped make Apollo 11 possible, as previously noted. A few minutes after the astronauts were welcomed, Diefenbaker was on his feet asking about the distribution of boxcars used to bring Canadian wheat to market. [10]

The astronauts and their party followed this appearance with a break at the Chateau Laurier Hotel up the street from Parliament. The astronauts then appeared at a press conference in the auditorium at the NRC headquarters on Sussex Drive that began with them showing a 19-minute movie about their flight. Their wives remained at the hotel and held their own press conference.

At the astronaut press conference, Armstrong was asked what he thought of the world tour the astronauts had undertaken. "You wouldn't accept a million dollars to have the experience taken away from you, but you might not take a million dollars to do it again," Armstrong replied. He and Aldrin spoke about what they saw as growing prospects for cooperative ventures in space with other countries, including the Soviet Union. A more controversial subject was raised by a reporter who asked about revelations in November concerning the massacre by U.S. troops of South Vietnamese villagers at My Lai the year before. Some people booed the question, and Collins said the allegations were "tragic if true." [11]

Following the press conference, the astronauts and their wives attended a reception at Rideau Hall with Governor General Roland Michener and his wife, Norah, along with other dignitaries. That evening, the astronauts and their wives joined government leaders for a formal dinner at the Chateau Laurier, where the astronauts' party stayed for the night. Aldrin later wrote about the favourable impression Trudeau left with the crew. "Trudeau was the most informal of all the heads of state we had met and he handily accomplished the difficult chore of treating us as though he had known us all our lives." [12]

Montréal, December 3

The astronauts and their party arrived at Dorval Airport in Montréal at 10:00 a.m. after a 45-minute flight from Ottawa Airport Uplands, and they were greeted by the Mayor of Montréal, Jean Drapeau, along with driving snow and colder temperatures than those felt the day before in Ottawa. The astronauts were driven to the CBC studios on Dorchester Boulevard while their wives were driven to the Queen Elizabeth II Hotel, also on Dorchester. [13]

The wives held a press conference at the hotel after a brief shopping trip to a nearby department store, where they told reporters the snowfall they were experiencing that day was their first in 15 years. Janet Armstrong spoke about how their world tour gave them "unforgettable" memories of the impact Apollo 11 had on the world, and Patricia Collins, who had lived in France for two years, spoke in French to the journalists and said she had visited Montréal before while living in Boston. [14]

Armstrong, Aldrin, Collins, and Dr. Carpentier took part in a nationally televised panel discussion from CBC Studio 42 broadcast in both English and French. Among the journalists in the panel were Lloyd Robertson and Bob Evans of the Canadian Broadcasting Corporation, and Harvey Kirck and Peter Kent of CTV. The event was shown live across Canada that day and repeated that evening during prime time. [15]

A motorcade took the astronauts back to the Queen Elizabeth Hotel, where they were rejoined by their wives. The stop at the hotel was also advertised as the best place to see the astronauts and an estimated 1 500 people greeted them on Dorchester. Due to the size of the crowd, the astronauts had to wave to the onlookers from next to their car and could not reach a microphone set up for them. [16]

From the Queen Elizabeth Hotel, the motorcade took the astronauts and their party for the final stop of the Giantstep world tour, the Restaurant Hélène-de-Champlain on Ile Ste Hélène, the park where Expo 67 had taken place two years before and which was then known as Man and His World or Terre des Hommes. The luncheon was attended by the astronauts' party, local dignitaries, and workers from Héroux Machine Parts Ltd., located in the nearby suburb of Longueuil, where the struts for Apollo lunar modules were milled to high-precision standards.

All three astronauts spoke, including Aldrin, who spoke in part in French, and complimented Montréal: "We all saw Expo 67 as a symbol of international will and cooperation. In many ways it was similar to accomplishment of Apollo 11 and spoke for the validity of man's will."

Armstrong got a standing ovation from the Héroux workers when he said: "Many are interested in seeing the first feet to touch the Moon—but the first feet weren't American, they were Canadian. Well, at least we can say Apollo 11 reached the Moon with strong Canadian support … and we thank you for that."

Mayor Drapeau struck an unintended comic note when he tried to present the astronauts with a flag representing Man and His World, but instead produced a flag for the province of Québec. While Drapeau showed his embarrassment and the audience laughed out loud, Armstrong said: "This only shows that man and his world is not perfect!" Drapeau said that he had earlier hoped to have the Man and His World Flag erected on the Moon by the astronauts. After the mayor presented the flags and ceramic plates and the astronauts reciprocated with a signed photo, the astronauts were free to return to their motorcade for the ride up the Bonaventure Autoroute to Dorval Airport and the plane back to Washington, which departed more than an hour late at 3:45 p.m. after nearly six hours in Montréal. [17]

Conclusion

Aldrin later wrote that both he and his wife Joan "instantly liked" Montréal. "As for the three of us and our wives, one and all we fell back into the protocol business as though we were old hands at it. In fact, we were old hands, it just didn't occur to us until we went to Canada." [18]

In his report to the Department of State, Ambassador Schmidt called the Apollo 11 astronauts and their wives "exemplary Ambassadors" who "showed extraordinary control and generosity" when faced with requests for autographs and the other demands celebrities must deal with. He said the Canadian government "provided all-out support to their visit" and handled every problem, notably the timing of the visit, with good humour and patience. In his view, the Giantstep visit to Canada "was a resounding success" [19]

The astronauts' return home from Montreal marked the end of their crew activities that had begun in January that year. Collins departed NASA in 1970 for a job at the State Department and later became director of the National Air and Space Museum in Washington. Armstrong and Aldrin left NASA in 1971, Armstrong to teach in Ohio and Aldrin to return to the U.S. Air Force. The three crew members, who were never close personally, met only for occasional award presentations and reunions over the years until Armstrong died in 2012 and Collins in 2021. Armstrong is known to have visited Vancouver in 1977, and Aldrin has visited Canada on several occasions.[20] After helping with the recovery operations for Apollo 14 and 15 in 1971, Dr. Carpentier left NASA and pursued a career in nuclear medicine in Texas. Before the Apollo program ended with Apollo 17 in December 1972, the crews of the last three Apollo missions visited Canada for geological training in preparation for their missions.[21] ✶

Figure 2 — Apollo 11 astronauts Michael Collins, Neil Armstrong, and Edwin E. "Buzz" Aldrin converse with former Québec Premier Jean Lesage (l) at a luncheon in Montréal. Image: Archives de la Ville de Montréal.

Christopher Gainor is a historian of technology specializing in space exploration and aeronautics. He has written six books on the history of space exploration and on the Avro Canada CF-105 Arrow, a jet interceptor aircraft cancelled by the Canadian government in 1959. He is the Past President of the RASC and has served in many positions on National Council and on the Board of Directors.

Endnotes

1 Dr. William R. Carpentier, Oral History Interview by author, 1995 November 16, p. 11.

2 Carpentier interview, pp. 11–12. More details on the tour are included in Teasel Muir-Harmony, *Operation Moonglow: A Political History of Project Apollo* (New York: Basic Books, 2020) pp. 245–272; and Glen Swanson's Oral History Interview with Generva B. Barnes in Glen Swanson, ed., *"Before this decade is out…" Personal Reflections on the Apollo Program* (Washington, D.C.: National Aeronautics and Space Administration, 1999), NASA SP-4223, pp. 223–243; and Col. Edwin E. "Buzz" Aldrin Jr., with Wayne Warga, *Return to Earth* (New York: Random House, 1973) pp. 53–86; and "50 Years Ago: Apollo 11 Astronauts Return from Around the World Goodwill Tour," NASA History website, 2009 November 5, https://www.nasa.gov/feature/50-years-ago-apollo-11-astronauts-return-from-around-the-world-goodwill-tour. See also John M. Logsdon, *After Apollo? Richard Nixon and the American Space Program* (New York: Palgrave Macmillan, 2015) pp. 27–30; and Steve Wolfe, "Moonglow: Space Diplomacy in the Nixon Administration," *Quest: The History of Spaceflight Quarterly*, Vol. 18, no. 2 (2011), pp. 39–51.

3 Although the engineers from Avro Canada were often called the "NASA Canadians," 19 of them originally came from the United Kingdom. The story of these engineers is told in Chris Gainor, *Arrows to the Moon: Avro's Engineers and the Space Race* (Burlington, ON: Apogee Books, 2001).

4 U.S. Ambassador to Canada Adolph W. Schmidt, U.S. Department of State Airgram, "Report on Apollo XI Visit to Canada," 1969 December 31; National Archives and Records Administration, RG 306 (US Information Agency) Entry P243, Box 21, Folder "Canada Visit." The report recounted how a U.S. government official rejected an invitation from the Mayor of Ottawa to the Apollo 11 crew to visit even as the trip was being planned. The well-briefed astronauts apologized personally to the mayor during their visit.

5 Swanson, "*Before this decade is out*," pp. 239–240.

6 U.S. State Department briefing note, "CANADA," undated; National Archives and Records Administration, RG 306 (US Information Agency) Entry P243, Box 21, Folder "Canada Visit."

7 Many of the details of the trip in this article are taken from the itinerary for the visit distributed to the media, contained in a press kit produced by the NRC. Author's collection.

8 These remarks were transcribed from a CBC film clip of the astronauts with Trudeau at the Parliament Buildings. See CBC video and story, "When the Apollo 11 astronauts landed in Ottawa in 1969." www.cbc.ca/archives/when-the-apollo-11-astronauts-landed-in-ottawa-in-1969-1.5212294 Posted 2019 July 18, accessed 2022 January 30. Temperatures are given in Fahrenheit.

9 "Touring Moon Men Get Cheer in Ottawa," the *Vancouver Sun*, 1969 December 2, p. 20; Aldrin and Warga, *Return to Earth*, p. 250; John Burns, "Apollo XI crew gets ovation in Commons as astronauts end world tour in Canada," *The Globe and Mail*, Toronto, 1969 December 3. The second sentence of Trudeau's statement translates as: "May that high accomplishment allow man to rediscover the Earth and find peace." Details on the disk can be found in Tahir Rahman, *We Came In Peace for All Mankind: The Untold Story of the Apollo 11 Silicon Disc* (Overland Park, KS: Leathers Publishing, 2008).

10 Debates (Hansard) House of Commons, Canada, 1969 December 2 (28:2) pp. 1475–1480; "Commons welcomes Apollo 11 moonmen," *The Gazette*, Montréal, 1969 December 3, p. 2. Diefenbaker served as prime minister at the head of a Progressive Conservative administration from 1957 to 1963. Trudeau was leader of the Liberal Party.

11 Burns, "Apollo XI crew gets ovation;" "Astronauts predict crews from many nations," *The Globe and Mail*, Toronto, 1969 December 3. In his speech, Trudeau referred to French explorer Jacques Cartier (1491–1557), explorer of the prairies John Palliser (1817–1887), and arctic explorer Vilhjalmur Stefansson (1879–1962).

12 Aldrin and Warga, *Return to Earth*, pp. 250–251.

13 Walter Poronovich, "Apollo 11 astronauts end tour," *The Montreal Star*," 1969 December 4. The Dorval airport was renamed in 2004 after Pierre Trudeau. In 1987, Dorchester Boulevard was renamed after the late Québec premier, René Lévesque. Earlier in the year, from 1969 May 26 to June 1, the Queen E hosted John Lennon and Yoko Ono for one of their famous bed-in protests where they recorded the song "Give Peace A Chance."

14 Lily Tasso, "Le tour du monde vaute bien un voyage á la lune," *La Presse*, Montréal, 1969 December 4; Huguette Laprise, "Il est merveilleux d'être les femmes de tels hommes," *Journal de Montréal*, 1969 December 4.

15 Schmidt, "Report on Apollo XI visit."

16 George Radwanski, "Only the quick to see crew," *The Gazette,* Montréal, 1969 December 3, p. 2. See photo, *The Gazette*, Montréal, 1969 December 4, p. 1; "Moonmen End Canadian Visit," *Moose Jaw Times-Herald*, 1969 December 4. Robertson became famous years later working for CTV, and Kent later worked at Global TV before entering politics as a Conservative MP and cabinet minister.

17 Brian Stewart, "Astronauts bid graceful adieu as Mayor Drapeau goes Oops!" *The Gazette*, Montréal, 1969 December 4, p. 3; "Apollo XI crew nearly given wrong flag by Montreal," *The Globe and Mail*, Toronto, 1969 December 4; Claude Gendron, "L'espace abolit les frontiers terrestres! – Edwin Aldrin," *La Presse*, Montréal, 1969 December 4. Héroux is now known as Héroux-Devtek. Despite Armstrong's words, the landing pads for the lunar modules were made in the United States.

18 See Burns, "Apollo XI crew gets ovation;" "Apollo XI crew nearly given wrong flag," 1969 December 4; Aldrin and Warga, *Return to Earth*, pp. 250–251.

19 Schmidt, "Report on Apollo XI Visit." The Ambassador also praised Dr. Carpentier for his work during the visit to Canada.

20 Armstrong visited Vancouver on 1977 August 13, when he was hired to open a revolving restaurant atop the Harbour Centre in downtown Vancouver. The author encountered Aldrin in 1994 at a meeting of the National Space Society and the Canadian Space Society at the Regal Constellation Hotel near Toronto Airport, and in Victoria, B.C., during a book tour in 2000.

21 See Christopher Gainor, "Apollo Geological Training in Canada, 1970–1972," *JRASC*, February 2022, pp. 9–15.

Why is there Often Cloud Near the Horizon?

by Alister Ling, Edmonton Centre

This question was posed to me and Reg Dunkley, both retired meteorologists, by Victoria Centre member David Lee during an astro café. Like many avid skywatchers in the mid-latitudes, he was frustrated at the seemingly high frequency of cloud in the twilight arch.

The one-word answer is "foreshortening," but I suspect that many readers would prefer some diagrams and explanation to help them really grasp the phenomenon.

The ideal situation shown in Figure 3 depicts how the gaps in regularly spaced cloud streets can appear large overhead but compress toward the horizon.

Thankfully we do not live on a flat planet: the inevitable distant cloud would always stripe the lowest part of the sky. I find it instructive to examine the geometry to scale. Readers can access Figure 5 at www.desmos.com/calculator/vxdlpyod8h and adjust the values to see changes in real time. Clicking on a line will pop up the X and Y values (in km). For simplicity, cirrus cloud is taken to lie 10 km up.

Despite the astronomer's knowledge of the size and scale of the Earth and sky, their animal instinct and tactile experience of nearby nature can lead them to misjudge angles and distances of farther objects. For example, while standing on a hilltop you might figure you can see 30 or 40 km (assuming no prominent mountain ranges), and subconsciously put distant clouds at that range. On occasion we see public reports of UFOs post-sunset because their bright orange vapour trails have no visible craft at their leading edge. As the diagram shows, objects near the horizon and 10 km high are actually 300 km away!

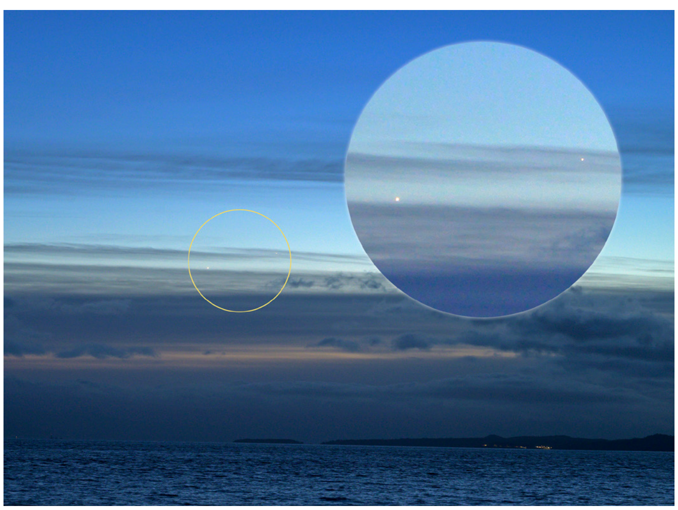


Figure 1 — Pairing of Venus and Jupiter 01:10 UT 2019 November 26, taken from Ogden Point, Victoria, B.C., by David Lee. Venus is about 4.8° altitude.

Figure 2 — A foreshortening example familiar to all readers. The spacing between the poles is constant, but the apparent gaps become shorter as our forward-viewing angle decreases.

How does the angular size of the gaps change with altitude? Figure 5 shows strips of cloud and gaps 28 km wide, a ¼-degree spacing as seen from the centre of the Earth.

Distance (km)	Altitude	Spread
0 km	90.0	deg
27.8	19.6	70.4
55.7	9.9	9.7
83.5	6.5	3.4
111.4	4.6	1.9
139.2	3.5	1.1
167.0	2.7	0.8
194.8	2.1	0.6
222.7	1.6	0.5
250.5	1.2	0.4
278.3	0.8	0.4
306.1	0.5	0.3
334.0	0.2	0.3
361.8	-0.04	0.2

Table 1 — Horizontal distance, altitude above horizon, and angular spread of regularly spaced 28-km strips at a height of 10 km, ignoring refraction.

The gaps near the horizon subtend angles barely larger than half a lunar diameter. Compounding the problem, increasing refraction at lower altitudes through the greater path length of air "pulls up" objects from beyond the geometric horizon.

The very lowest part of the sky can contain cloud from 400 km away.

For the photographer, what does this 400 km distance mean? When interpreting a satellite image, wondering anxiously if the advancing cloud will scuttle the celestial display, it helps to know that one degree of latitude is about 111 km. At 50°N, this is 1.6° of longitude. Quick, approximate math

Figure 3 — This schematic (half real, half modified) turns Figure 2 on its side, and paints alternating gaps with cloud and clear.

means that, if a deck of cirrus cloud is less than 4° of latitude or 6° of longitude away, it will show up.

Despite the cloud, take heart! Decades of experience have shown us that the leading edge of a cirrus shield can suddenly thin, dissipate, or form gaps just as often as jet vapour trails (contrails) make things worse. If we are lucky, then just a touch of cloud adds "atmosphere" to the scene. The relevant truism here is that in the end, the most persistent skywatchers are the ones most rewarded.

In summary, foreshortening and (to a lesser extent) refraction visually compress hundreds of kilometres of distance into the lowest 4° of sky. Compared to large gaps seen overhead, the horizon is indeed more likely to be obscured by clouds.

Additional information:

[Intro] page 48, column 2: ¼-degree strips. 6381 km, means 28 km wide s = r * theta (radians)

2019 Nov. 26, 01:10Z—conveniently, at 100% on my laptop screen, David's image puts Venus at 100 mm above the water horizon. First gap is 47–57 mm up, with top of the next deck at 85 mm ignoring the thinner cirrus. Venus is 4.8°, so first gap is 2.4° up, roughly 180 km distant.

Top of the higher band is 4.1° or 120 km.

AB–BC border is lon 120; YT–AK border is 140 ✶

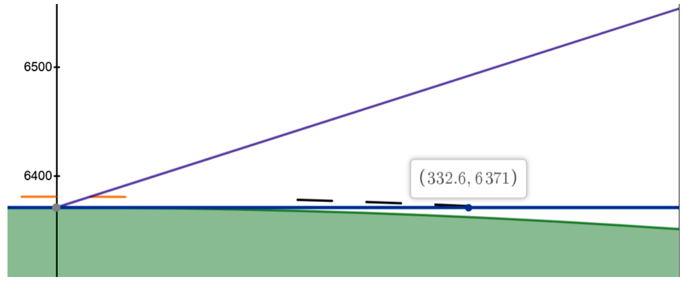


Figure 5 — A schematic of the geometry, where the lower green section is the solid Earth (radius 6371 km); horizontal blue line is the horizon; diagonal purple line is a user-changeable way to measure the altitude; the orange and black segments are ¼-degree arcs placed 10 km above the surface. Note that the word "altitude" in this article refers to the angle above the horizon in degrees.

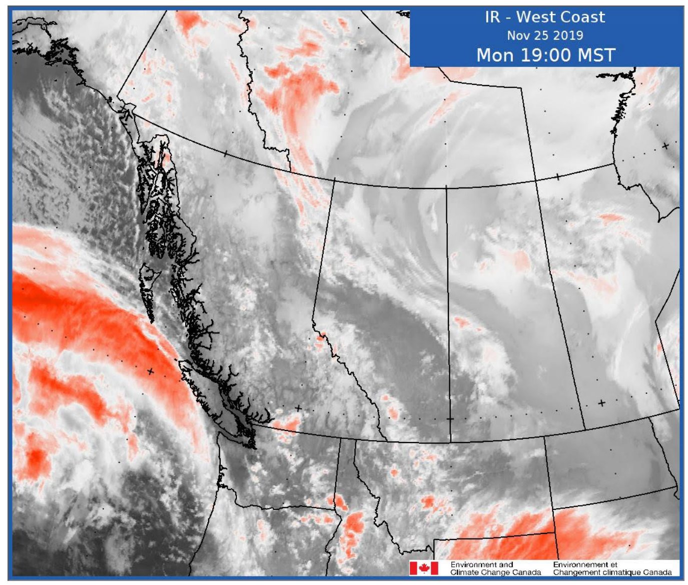


Figure 6 — GOES-W Satellite image at 02 UTC, 20191126, with thanks to Michael Skarupa at Environment Canada for retrieving it. This is 1 hour after David Lee's image from Figure 1, so the two cannot be exactly compared. The main gap below Venus is about 2.4° altitude, a linear distance of about 180 km or 1.5° of latitude. Allowing for some eastward motion of the cloud between the two times, this corresponds to the orange edge in the satellite image, just west of Vancouver Island.

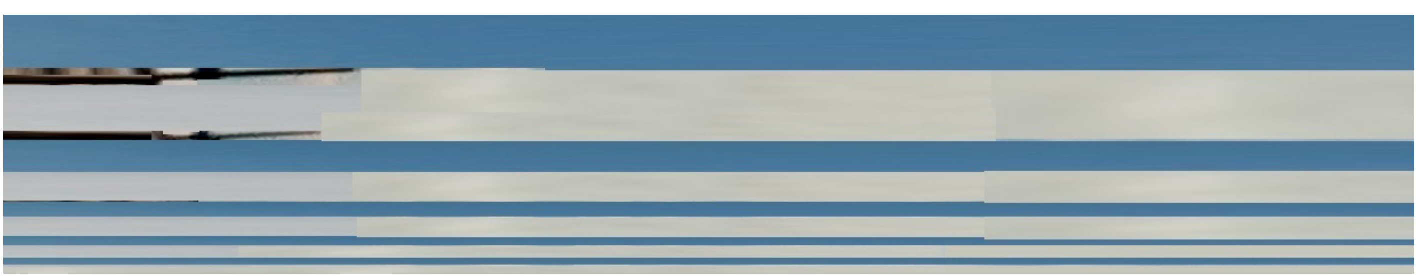


Figure 4 — The lowest section of Figure 3 zoomed in shows how clouds seem to take up an increasing amount of sky closer to the horizon.

AAVSO

Your Monthly Guide to Variable Stars – Series Two

by Jim Fox, AAVSO

March – U Monocerotis (U Mon)

U Monocerotis was first reported as a variable star by the German astronomer Ernst Hartwig in 1918. Harlow Shapely originally listed it as a Cepheid. Hartwig later came to fame when he discovered a supernova in the Andromeda Galaxy, the first ever seen outside our own Milky Way.

Today, U Mon is the second brightest of the 100 or so known RV Tauri-type variables. These are yellow super giants, thought to be evolving from a red-giant toward a white-dwarf phase. This phase of stellar evolution has a rather short period, lasting only a few thousand years. This may explain the small number of known T Tauri-type stars. The light curve of an RV Tauri star shows a pattern of alternating deep and shallow minima. This shape is similar to an eclipsing binary except the curve is flat at both maximum and minimum light, and the dimming is steeper than the brightening.

U Mon fluctuates between visual magnitude 5.1 and 7 with a period of 92 days between deep minima. In addition, the mean magnitude shows a slow fluctuation over a period of 2475 days (about 6.8 years). The amplitude of the short-term variation is smaller when the long-term variation is near minimum. What's happening?

The short-term variation seems to be due to radial pulsations of the supergiant star, perhaps a combination of primary and first overtone pulses. The long-term variation is probably caused by a dim companion star in an eccentric orbit and with a dusty disk or torus enclosing the entire system. This is quite a complex system, and the true mechanism may be something simpler. As with most variable stars, more observations are needed.

U Mon is easy to find at 7h 30m 47s, –09°46′37″. About 2.5° west of Alpha Monocerotis (SAO 134986) and 39′ northeast of SAO 152491, shown as the 5.7-magnitude (57) star on this chart. Figure 1 is not inverted with north up and east left. U Mon is the highlighted open circle. Chart courtesy AAVSO.

April – U Geminorum (U Gem)

Another variable star discovered by asteroid hunter John Russell Hind who thought it was a nova in 1855, U Geminorum is a member of a class known as "Cataclysmic Variables," or "CVs." This particular CV is a dwarf nova (so Hind was partly correct). U Gem stars are double systems with a hot, white-dwarf primary and a secondary normal (main-sequence) cooler star in close orbit, moving at very high speeds. The stars of U Gem orbit each other in just over 4 hours.

The pair orbit so closely that the white dwarf primary pulls material from the outer atmosphere of the secondary. The material accumulates in a disk, called an "accretion disk" around the primary. Every hundred days or so, instabilities in the disk cause it to flare, brightening the system from a quiescent magnitude of 14.5 to as bright as 8.2. The interval between outbursts is quite irregular, varying from 62 to 250 days, so it cannot really be called a "period."

But wait, there's more. The U Gem system also behaves like an eclipsing binary between nova-like flares. The dimmer secondary eclipses the primary (and its accretion disk) every 4 h 11 min. During the 20 minutes of eclipse, the system brightness drops from visual magnitude 14.2 to 15.1. You probably need dark skies and at least a 10″ aperture to see this eclipse visually.

You can find U Gem off the southeast shoulder of Pollux at 07h 55m 05s, +22°00′05″, 2 degrees north of the 5.4-magnitude star 85 Gem (SAO 79799). Figure 2 is not inverted with north up and east left. U Gem is the highlighted open circle. Chart courtesy AAVSO. A similar star that southern observers can monitor is VW Hydri (VW Hya) at 08h 33m 26s –14°43′22″, about 2.3° northwest of 9 Hya. VW Hya erupts from visual magnitude 14.1 to magnitude 9 every 27 days.✶

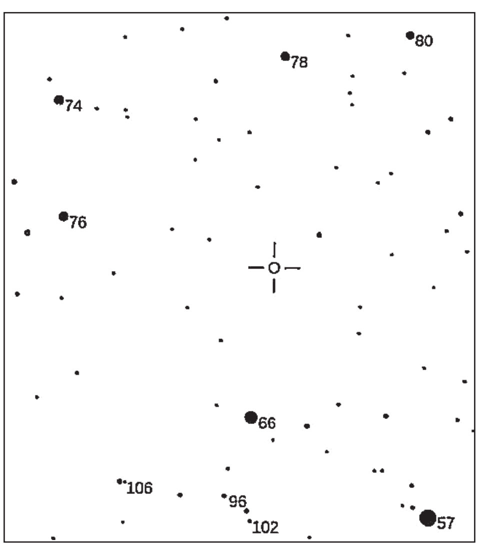


Figure 1 — U Monocerotis (U Mon)

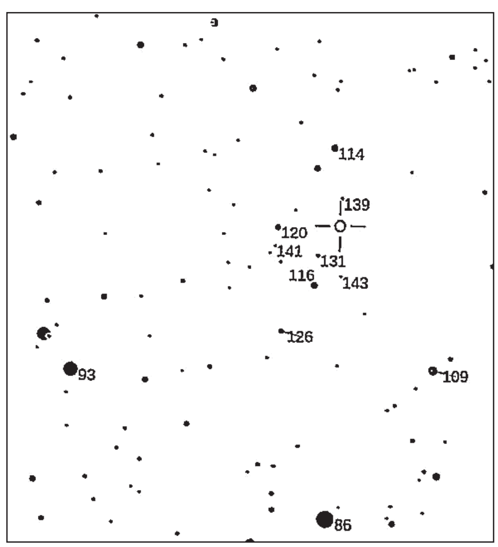


Figure 2 — U Geminorum (U Gem)

Jim Fox has owned many telescopes in his astronomical journey—he's even ground a few mirrors for his own. Jim has been a long-standing Astronomical League member and served as President from 1990–1994, as well as serving on the Board of the Astronomical Society of the Pacific. He was awarded the Leslie C. Peltier Award by the Astronomical League in 2014 and he has served several years as the AAVSO Photoelectric Photometry Coordinator. The IAU named asteroid 2000 EN138 "(50717) Jimfox" to honour his many achievements.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Observing

Podcasting as Outreach During a Pandemic

by Chris Beckett and Shane Ludtke

Conversations in the time of COVID-19

In March 2020, just before pandemic restrictions were put in place, my long-time observing friend Shane Ludtke was a guest speaker at what would be my last in-person astronomy class. Shane and I had a podcast several years prior but it floundered after a handful of episodes. This was mostly on me and my ideas around building content outside of the arduous job of just recording and publishing a podcast.

During the class break, Shane shared some thoughts on starting a new and improved podcast, the idea he pitched was to keep it simple, no complicated webpages for each episode, no attempts at themes or gimmicks, just a conversation between two amateur astronomers on what we are actually doing any given week, mixed with topical episodes focused on visual astronomy. While many astronomy centred podcasts exist, few provide content directly aimed at the amateur visual observer, as many of those podcasts are by experts, either in the field of astronomy, broadcasting, hosting, or all three. So we would declare ourselves as amateurs and position ourselves alongside the listener under the stars by offering advice to those just getting started, and a platform for everyone to share their own observations and equipment adventures. If all else failed, we would at least be able to maintain our social connectedness during a pandemic, which we thought might possibly last for a few months. I was excited, as attempting another astronomy podcast had been kicking around in my mind for a while but I could never seem to find the time to pull some ideas together.

The Actual Astronomy Podcast

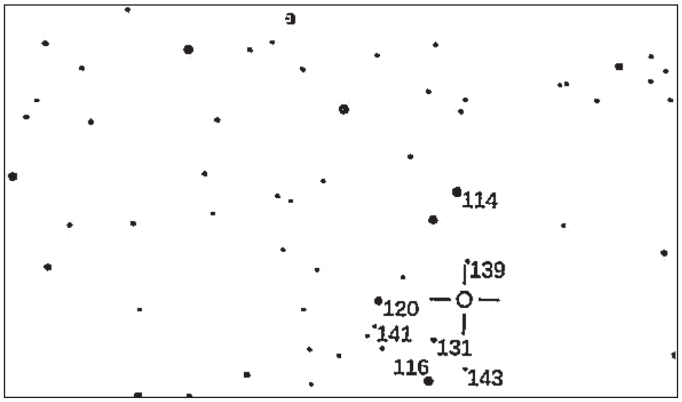
With working from home underway, we ramped up what might have been an otherwise fleeting idea and our now vacant social schedules quickly filled with show planning, software, and hosting set-ups. I also received notification that my astronomy class was on hold due to declining pre-pandemic numbers, while star parties and all other astronomy outreach was cancelled for 2020, so the podcast quickly shifted from just a conversation to having a public outreach component as well.

We decided to record several test episodes to work out sound and other issues and to create a backlog so we could stick to regular release dates while we got up to speed. The last thing we needed was a name for the podcast, and keeping to our simplistic approach, we agreed to go with the first good name that popped to mind and *The Actual Astronomy* Podcast was

born. As we began to form up regular topics, we put out an episode titled "Objects to Observe in the May 2020 Night Sky" and quickly saw our subscribers and listener numbers skyrocket…into double digits :). We built upon this success by including listener observations with our own reports mixed together with equipment information and reviews. We quickly found our inbox filling up with other visual astronomers eager to join in the conversation with what they were observing, sketching, imaging, or even throwing on the BBQ. Two years later, and with new episodes each Monday and Thursday, that means that as I write this in February, we are now working on our 200th episode.

A Pandemic Podcast

Few could have foreseen the pandemic's length and impact as more people sought out activities they could safely pursue in solitude, and as their typically busy evenings cleared out many people turned to astronomy. A Google search for "Astronomy during Pandemic" yields millions of results, and in 2020, *Sky & Telescope* reported sales for some retailers had surged 400% over pre-pandemic levels. By August 2020, my astronomy class was relaunched online using Zoom but with a higher number of attendees and many first-time stargazers from all over Western Canada. People have mentioned everything from stress relief, to get their mind off things, and non-COVID / non-screen time distractions, combined with the idea of connecting to something external from their immediate surroundings. Additionally many families have pursued astronomy as a bonding activity, while solo observers sought community by connecting with others and a mutual interest in the stars.



Building on our modest success, we reached out to the *365 Days of Astronomy* podcast, which is part of CosmoQuest and is a well-known astronomy podcasting hub with over 5,000 daily listeners. This is a science outreach division of the Planetary Science Institute, which states "CosmoQuest has built a thriving community of citizen scientists, astronomers, communicators, and friends." We put together a few shows for the *365 Days of Astronomy* and worked on our format and quality. When they put a call out for new regular podcasters, we happily made it through the review process and were granted two slots per month, plus regular options to contribute special episodes. Being part of the *365 Days of Astronomy* podcasters has been a great way to contribute to public science outreach through hands-on astronomy and has been a great way for people to find us. However, we do get periodically bumped from a time slot as NASA refuses to adjust their space-mission schedules, resulting in conflicts with our release dates over which they get priority. We have also been fortunate to have many friends who lent their voices as guests, while some visual astronomers, like YouTuber Marc Radice of *Refreshing Views* in the UK, have collaborated with us on visual-astronomy topics.

We have been happy to receive emails and sketches from many RASC members who enjoy hearing a podcast on visual observing with a Canadian take. There are also many international listeners from places like Brazil, Japan, Australia, and many from the UK who began tuning in after we were featured in their *Sky at Night* astronomy magazine. If you would like to hear an episode just say "Hey Google play *The Actual Astronomy* podcast" or subscribe via any podcasting software like iTunes or Podbean. ✶

Chris and Shane enjoy podcasting, technology, teaching astronomy classes, observing in dark places, and sharing the sky with other stargazers. They both live in Regina but do not share a microphone.

Skyward

Cheering on the *James Webb Space Telescope* and Enjoying the Real Night Sky

by David Levy, Kingston & Montréal Centres

We all got a special and thoroughly delightful present early on Christmas morning. Although I did not set my alarm, Wendee did get up around 5 a.m. I turned on our television set, and what I saw 15 minutes later was the most thrilling space view since 1969, when Armstrong and Aldrin walked on the Moon. It was the spectacular, flawless launch of the *James Webb Space Telescope*, the start of a mission so perfect and smooth that, if Webb could speak, it would have told us that it did not feel any motion whatsoever as it soared away. Even the countdown was unique: it was in French: "Dix, neuf, huit…" I did notice a possible hiccup. About ten minutes later, the metal covers designed to protect the telescope during launch fell away while the vehicle was still in powered flight. But a second later, I understood that this was not a hiccup; it was supposed to fall away. The telescope was already out of Earth's atmosphere, and with no air to bother it, the protective cover was no longer needed.

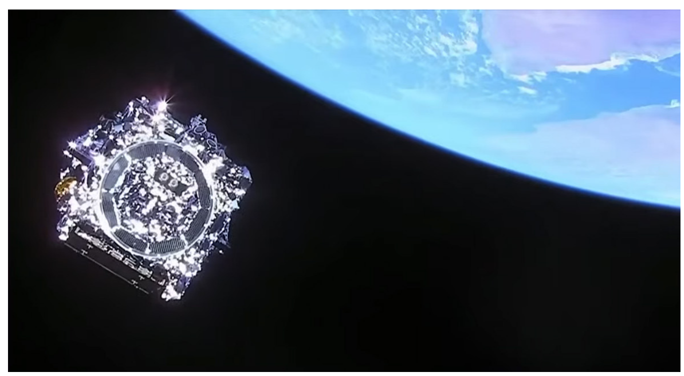


Figure 1 — The James Webb Space Telescope *is seen in orbit about the Earth just after launching from French Guiana on 2021 December 25. (NASA/ESA/CSA)*

As lovely as this experience was for me, the launch was not the most memorable part. That came an hour or so later, when NASA administrator Bill Nelson gave a speech in which he thanked the many people involved in the process of getting the telescope into space. At the end of his speech Nelson mentioned a young shepherd boy, sitting out under the stars, looking toward the night sky, and writing a poem about it. That shepherd boy, the Administrator went on, went on to become King of Israel.

The poem to which he referred is undoubtedly the 19th Psalm, the opening four lines of which I quote here, plus an additional one added by nova discoverer Peter Collins, an old friend.

The heavens declare the glory of God.

And the firmament showeth his handiwork.

Day unto day uttereth speech,

And night unto night revealeth knowledge,

So long as the sky is clear.

The telescope has now been fully deployed and is ready for its final adjustments. Unlike for the shepherd boy, and for all of us on Earth, the sky will always be clear and dark at the Lagrange 2 point (named after Italian mathematician Joseph-Louis Lagrange) in space where the telescope will live. The *James Webb Space Telescope* is there to teach us about the Universe of which we are a part, and I suspect that it will also inspire us to set aside the cares and the news of each day, head out into our backyards, and look up at the night sky.

Star Gazers

What crowd is this? What have we here? We must not pass it by;

A telescope upon its frame, and pointed to the sky…

— William Wordsworth, 1806

While I was working on my Master's degree at Queen's University in Canada some 42 years ago, I came across this poem, loved it, and decided to include it in my thesis. Norman MacKenzie, my thesis advisor, a scholar and a genius, pencilled one comment at the bottom of this poem: "Wordsworth wrote some wretched verse." Norman did not have much of a sense of humour, but I am still laughing at his written comment.

In his poem, Wordsworth complains about how many people who look through a telescope are disappointed in what they see. At no point in time is that idea more cogent than now. If a telescope we look through cannot offer us a view as good as a space telescope, then that telescope is a failure.

By the end of the poem, the crowd abandons the telescope:

"One after one they take their turns, nor have I one espied

That doth not slackly go away, as if dissatisfied."

For me, the night sky is far more than our imagined perceptions of what we can see through a telescope. Some of us can look at an internet photograph all day long, but not I. The beauty of the sky lies in its reality. The planets I see are real worlds. The constellations I point out to young observers contain real stars.

One evening I asked a group if they had seen the recent eclipse of the Moon. "Yes," answered one. "I saw it online."

No, he didn't. Eclipses are real only if you see them in the sky, while they are happening.

It is a given that a backyard telescope will never show us Jupiter as detailed or as colourful as a telescope out in space

*Figure 2 — Eureka, one of my telescopes, is probably a bit better than the one referred to in Wordsworth's 1806 poem "*Star Gazers*."*

will. What that telescope does show us is the genuine sky, a sky without artificial colour enhancement, a sky as it really exists on top of our heads on every clear night. It shows us a sky untarnished by the trivial events of the day, and unspoiled by petty concerns that are bothering us. Our own telescope truly shows us the Moon as it was a third of a second ago, a star as it appeared 34 years ago, or a galaxy as it appeared 12 million years in the past. Our backyard telescope shows us what is there and, unlike the crowd from 1806 that left dissatisfied, the people of today can understand that the sky they see is real. ✶

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* Science *channels. Among David's accomplishments are 23 comet discoveries, the most famous being Shoemaker-Levy 9 that collided with Jupiter in 1994, a few hundred shared asteroid discoveries, an Emmy for the documentary* Three Minutes to Impact, *five honorary doctorates in science, and a Ph.D. that combines astronomy and English Literature. Currently, he is the editor of the web magazine* Sky's Up!, *has a monthly column, "Skyward," in the local* Vail Voice *paper and in other publications. David continues to hunt for comets and asteroids, and he lectures worldwide. David was President of the National Sharing the Sky Foundation, which tries to inspire people young and old to enjoy the night sky.*

Binary Universe

In Search of an Almanac

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

Habitually, over the last few years, I have sought the *Sky & Telescope* magazine edition for the new year. I like to purchase the January issue with the annual Almanac.

The Almanac (for 40° or 50° north latitude) is that interesting graphical chart, hourglass-shaped, showing duration of night, movement of the planets over the year, Moon phases, noteworthy events for the upcoming months, etc. It takes a bit of noodling to read it, but it is a very useful planning tool.

For me, buying a magazine in Bradford West Gwillimbury, a town of 44,000, is difficult. While we lack a proper bookstore, my local drug/grocery/gift store has a large magazine stand. Just a short walk away, I'm proud to say they carry *SkyNews*.

But when I last checked in the final days of January, they *still* had the August issue of *S & T*! I asked for assistance some time ago and the store staff person replied, "We get what they send us." Ah. Corporate headquarters reading some dashboard sales report.

On 2021 December 30, I bemoaned my third-world problem on the RASC national forum. I asked for advice after visiting the online store: no January edition was listed but February showed? A few helpful members jumped into the fray, one noting the error on the website and another noting the Almanac sheet could be purchased separately, if you were willing to pay shipping fees more than the product itself. A generous member offered his magazine and Almanac.

A Do-It-Yourself Option

Then, Gaétan LaFlamme came to the rescue! He referred me to the COELIX software available at https://ngc7000.com saying the software was designed to help the amateur astronomer plan and prepare. He espoused the inexpensive tool describing it as "at the same time a sky mapping software, a generator of astronomical ephemeris, a virtual planetarium, and a telescope control software." Available in English or French, he assured me I would be able to print the Almanac for my specific location. Wow.

Then RASCal Hugues Lacombe gave his thumbs-up. He reminded us that COELIX is listed in the Recommended Reading, Atlases, and Software chapter of the RASC *Observer's Handbook*. Of course, I should have thought of that: "It's in the *Handbook*!"

Hugues went on to say, "I have been using COELIX for almost 20 years. Jean Vallières, [the] developer, is very accessible and helpful. All updates are free." Hey, he's in Canada too. Brilliant!

On arriving at the website, I was thrilled to spot both COELIX APEX and LITE. The LITE product is a lightweight and free version of the fully powered COELIX APEX. This allows a new user to evaluate and explore the software. I downloaded and installed the 64-bit LITE product version 1.124 to a Windows 10 laptop and dove in.

A Rich Feature Set

Whoa! This is big! Immediately I was impressed by all the options and features despite using the limited version.

I was looking at The Observer's Guide screen (see Figure 1) and saw that I could set up a location or station, show a world map like a GeoChron clock, determine what was visible tonight, and—woo hoo, there it was—the *All Year Phenomena* option to help me produce a graphical almanac.

And then I noticed the buttons in the top toolbar.
Holy Universe!

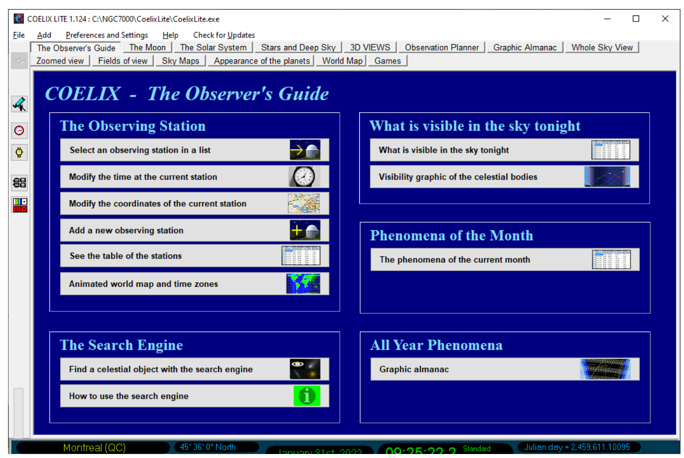


Figure 1 — The main screen of COELIX presenting The Observer's Guide.

If inclined, I could explore various matters with the Moon (Figure 2). The Solar System offers a plethora of tools including general ephemeris, elongation graphs for Jupiter's moons, and a table for meteor showers.

The Stars and Deep Sky screen offers catalogues and charts. Ah, Vallières is a double star observer! The 3D VIEWS screen offers realistic views in space of comets and asteroids.

The Observation Planner helps an observer prepare a list of targets and then view them in a good sequence at the best times. Smart planning features like SkyTools and AstroPlanner.

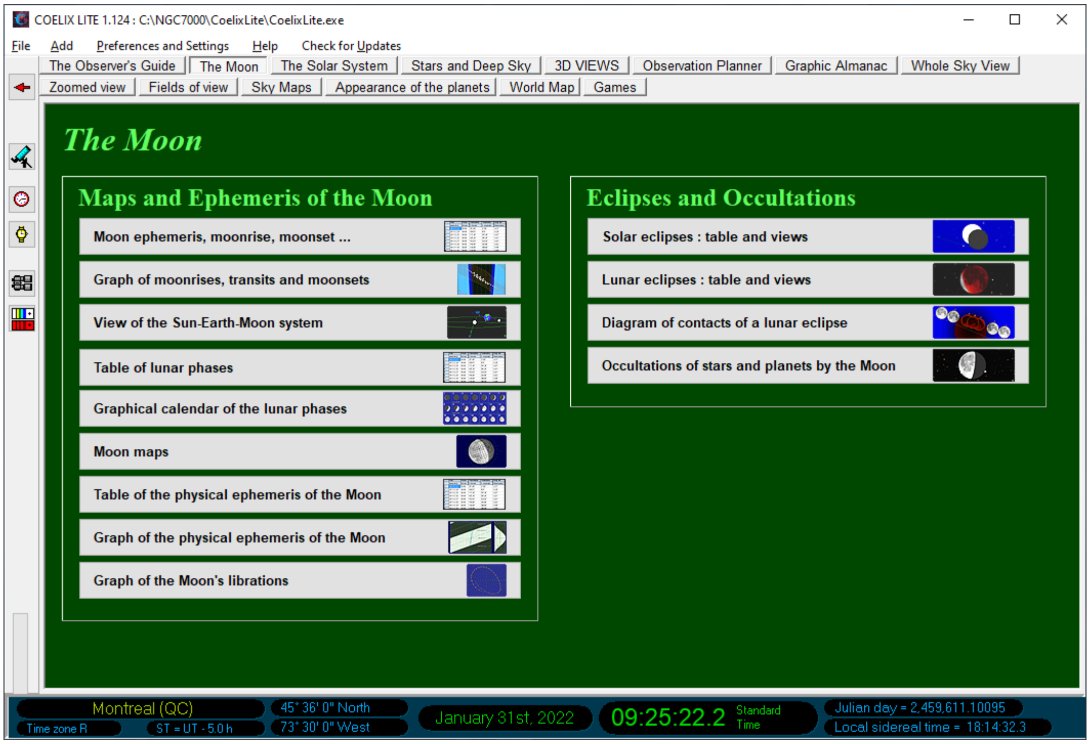


Figure 2 — The Moon screen in COELIX offering tables and charts for lunar phenomena.

The Whole Sky View (Figure 3) presents an attractive, rich colourful overhead chart of the night sky as good as any planetarium application.

The Zoomed View lets you simulate telescopic views in the ocular, accommodating for the number of reflections in your optical train. Similarly, the Fields of View lets you simulate framed fields with a DSLR or CCD camera. Sky Maps displays detailed black-on-white charts like paper atlases. The Appearance of the Planets screen shows the apparent size of Solar System bodies through the month with illumination hints for Mercury and Venus. Finally, there's a

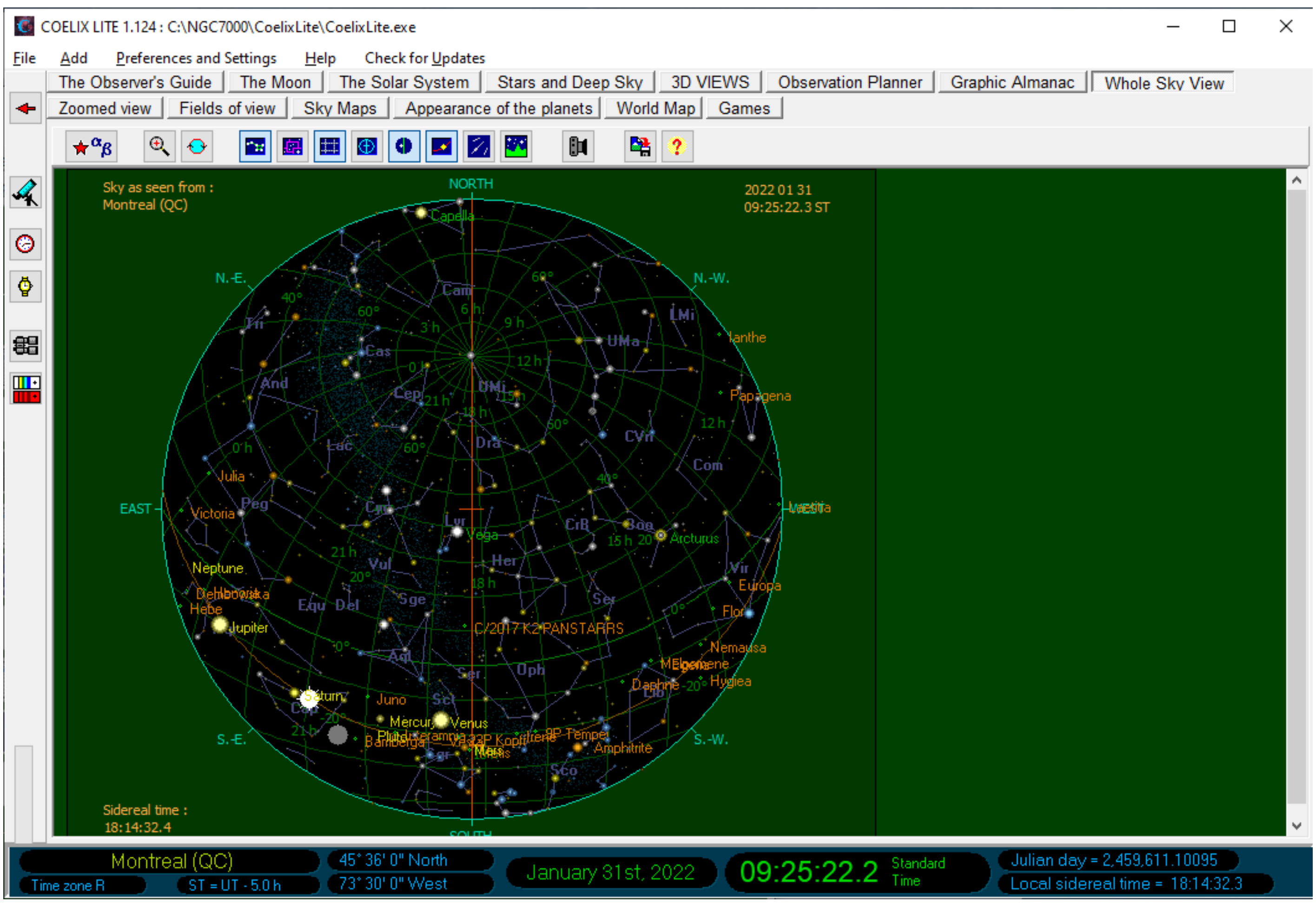


Figure 3 — A detailed, rich chart (zoomed out) showing the sky overhead with planets and stars.

game to help you learn the spelling of constellation names. Oh, yes, I almost forgot, COELIX can drive a variety of mounts via the ASCOM platform.

It would take me an entire *Journal* issue, cover to cover, to explore all the features. Suffice to say, there is something for everyone. Or perhaps, many options useful to every astronomer. Be sure to read the remarkable Features page on the website.

Making an Almanac Chart

My mission? To generate an almanac graphic for 2022 for my latitude. I accessed the Graphic Almanac screen, hit the New icon, reviewed by parameters, and clicked the Create button (Figure 4).

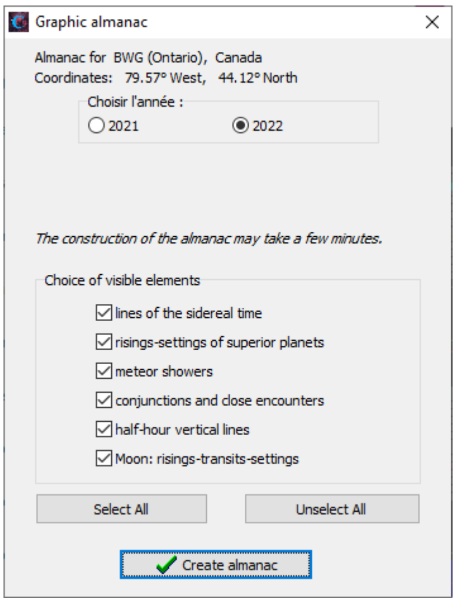


Figure 4 — The parameters dialogue box available ahead of generating a graphic almanac for the selected year.

After a couple of minutes, voila! A fantastic rich visual chart for my latitude, specifically my backyard. This graphical presentation (Figure 5) shows daylight, twilight transitions, the paths of the planets, the Moon phases, interesting appulses with the Moon, meteor showers, and the "speed" of the Sun. But wait, that's not all! The page includes a detailed list of phenomena for the calendar year including perigee and apogee dates, elongations and oppositions, and solstices. Exactly what I needed.

COELIX allows text annotations in the graphic and additions to the list of phenomena. The graph can be output in PostScript format or common image file types. I saved to PNG.

C'est magnifique!

Another Excellent Canadian Software

Try out COELIX LITE. It will take you a few days to explore all its excellent features and, if you're like me, you'll be able to generate your own visual almanac.

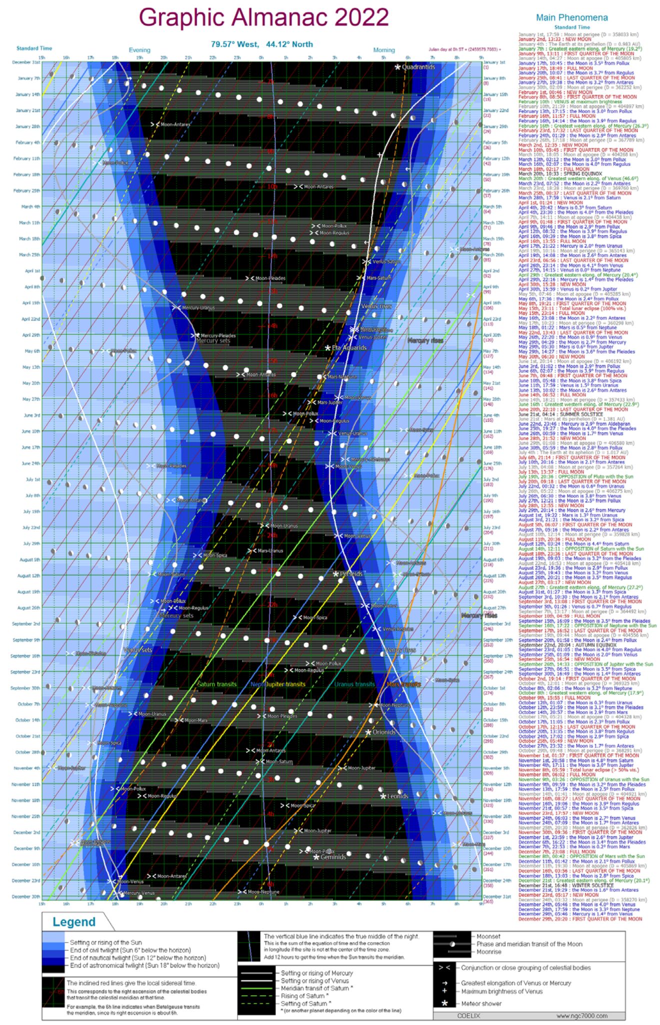


Figure 5 — The almanac chart produced by COELIX with planetary paths and list of astronomical phenomena.

Then if you like what you see and it makes your life better, consider the full APEX version. The Windows software is available for $35 CAD using PayPal. I intend to thank Vallières.

Bits and Bytes

The end-of-life notice for *SkyTools 3* was issued by the Skyhound developer. If you haven't already, download and apply the final update to version 3.2L which corrects an issue with downloading DSS images. Note the comets, minor planets, and novae data will not be updated in the future. It is sad on one hand, but the software launched in 2008 is long in the tooth and has been superseded by *SkyTools 4*. ✶

Blake's interest in astronomy waxed and waned for a number of years but joining the RASC in 2007 changed all that. He is a member of the national observing committee. In daylight, Blake works in the Information Technology industry.

Figure 1 – The Seagull Nebula takes flight in this beautiful image by Katelyn Beecroft. Katelyn acquired the image using her Sky-Watcher Evostar 72ED with 1.0 field flattener on a Sky-Watcher HEQ-5 mount, using a Canon T6i (modded) at ISO 1600. Guiding was done with a ZWO 30-mm ƒ/4 guidescope together with an ASI 120-mm mini-guide cam. The final image is a stack of 242 × 120 s subs. Processing was done with NINA, PHD2, Pixinsight, and Photoshop.

Figure 2 – Orion provides a wealth of targets for astrophotographers, including the stunning Messier 78 blue reflection nebula. Here you can see it surrounded by part of Barnard's Loop, taken by Andrea Girone. She used a Williams Optics RedCat 51 telescope (250 mm f/4.9) with an ASI533MCPRO camera, cooled to –10 °C on an iOptron CEM26 mount. The image was guided, calibrated, and stacked in Pixinsight and processed using Photoshop and Topaz DeNoise.

Figure 3 – Ed Mizzi imaged Messier 106 (NGC 4248) along with NGC 4217 in Canes Venatici, which is considered part of our Local Supercluster. Ed used a Sky-Watcher Esprit 100 mm APO ƒ/5.5 on a Sky-Watcher EQ6-R Pro mount and a ZWO AS183 Mono camera under Bortle 6 skies. He captured data in LRGB. R: 9.25 hours; B: 9.5 hours; G: 9.0 hours; L: 5.5 hours, for a total integration of 33.25 hours.

Figure 4 – Accomplished astrophotographer Ron Brecher imaged NGC 3184 from his SkyShed in Guelph, Ontario, on the nights of January 3 to 8. "Although it is a relatively small target for my focal length (1070 mm), it displays some nice detail and colour," he says. He did all acquisition, focusing, and control of his Paramount MX mount with N.I.N.A., TheSkyX, and PHD2. Focus with Optec DirectSync motor and controller. Equipment control with PrimaLuce Labs Eagle 4 Pro computer. All pre-processing and processing in PixInsight. He used his Sky-Watcher Esprit 150 ƒ/7 refractor and QHY600M camera with Optolong LRGB filters. Luminance: 36 × 10m; RGB: 5 × 10 m.

CFHT Chronicles

Charging into 2022

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

2022 brought CFHT a new director, a call for new proposals, new science news, and our 13th Users' Meeting. The year started off with exciting and long-awaited news; the announcement of our new executive director, Dr. Jean-Gabriel Cuby. Dr. Cuby is currently an astronomer at the Laboratoire d'Astrophysique de Marseille (LAM, Aix-Marseille University–AMU), where he served as director from 2012 to 2017. He anticipates starting in July of 2022.

"I look forward to leading the exceptional CFHT staff during this pivotal time. My goals are to keep CFHT at the forefront of astronomical research while working towards the future with the Maunakea Spectroscopic Explorer," said Cuby. "I look forward to becoming an active member of the community and learning more about my new home."

Dr. Cuby's long history with CFHT spans 25 years. He joined the French Time Allocation Committee in 1995, serving as committee chair in 1998, and subsequently served on the CFHT Science Advisory Committee and CFHT Board of Directors. He currently serves as one of the French agency representatives on the MSE Management Group.

Jean-Gabriel is very familiar with our instrumentation, specifically WIRCam. He and Chris Willott of the CADC were co-PI of our large programs from 2010-2012—the CFHQSIR survey (Canada France High-z Quasar survey in the Near Infrared). The survey followed up 171 fields from the CFH Legacy Survey Wide field. The survey aimed to search for high redshift (z – 7) quasars within previously observed 130sq degrees of the "Wide" field using the Y band.

Dr. Cuby began his career working at the European Southern Observatory, rising to the head of the VLT-VLTI instrument program at Paranal Observatory in Chile. He stayed engaged in the ESO community upon moving to LAM, serving on various ESO committees and instrument teams. While at LAM, he played an active role in the European Extremely Large Telescope project and in the *Euclid Space Mission*, led the AMU participation to the development of the DESI spectrographs, and led the LAM-CNES contribution to the Grism-Prism Data Processing System for the Roman Space Telescope. After leaving the director position at LAM, Dr. Cuby served as the chargé de mission to the deputy director, head of the Astronomy & Astrophysics division of the Centre National de la Recherche Scientifique (CNRS). In that role, Dr. Cuby represented CNRS and ultimately coordinated a European Commission program bringing together many optical and radio astronomical observatories and institutes (Opticon-RadioNet Pilot).

"I am very excited to welcome Jean-Gabriel as CFHT's Executive Director," said Laura Ferrarese, Canadian member agency representative on the CFHT Board of Directors. "Jean-Gabriel's exceptional skills, his familiarity with the Observatory, as well as his strong commitment to the Maunakea Spectroscopic Explorer, give me great confidence that he will usher in a new era for the Observatory and lead CFHT to new heights."

The CFHT Staff isExcited to Welcome Dr. Cuby to Hawaii!

I often write about our "large programs" at CFHT; a program that receives at least 50 nights of observing time on CFHT, spread out over multiple semesters. We issued a new call for large programs in January. The deadline for submission is March 31 with the announcement of projects receiving telescope time expected this summer. I am looking forward to the new and exciting science on the way from whichever programs are selected. Look for more information about each in a column later in the year.

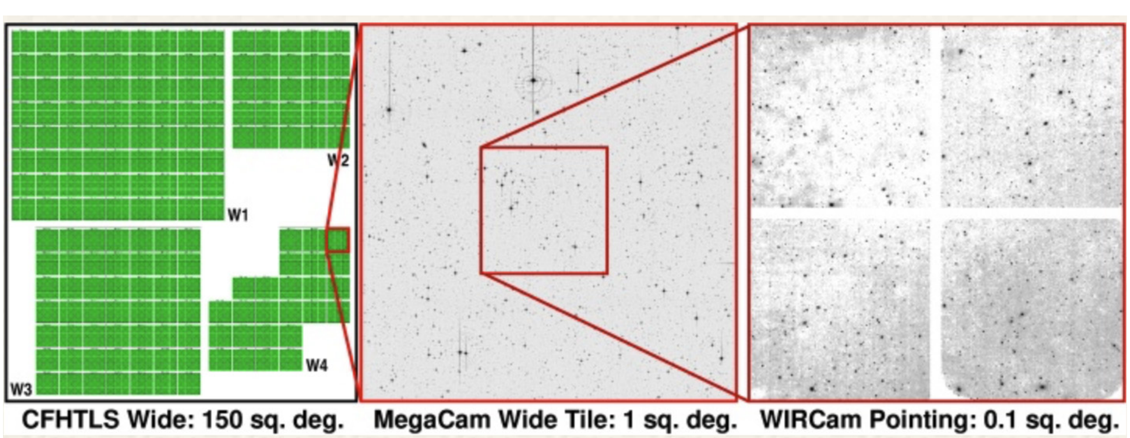


Image 1 — Comparison between the CFHTLS wide field, a MegaCam field, and CFHQSIR WIRCam field.

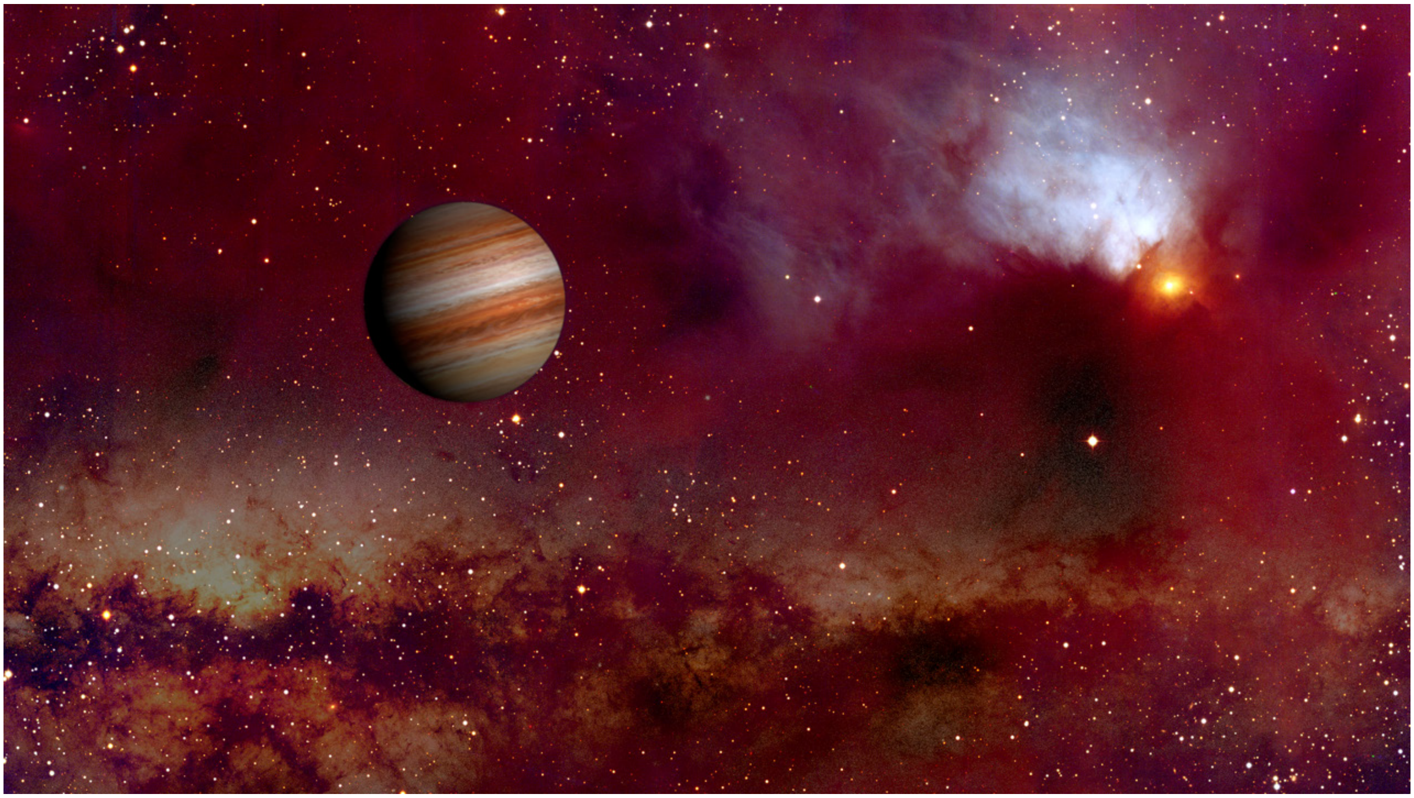


Image 2 — Artist's rendering of a rogue planet. Credit: COSMIC-DANCE Team/CFHT/Coelum/Gaia/DPAC

Largest Collection of Rogue Planets Discovered in our Milky Way

(note: much of this section comes from the news release—a collaborative effort between the team and CFHT)

Speaking of exciting science…. Our last news release of 2021 concerned rogue planets. A team of astronomers led by Dr. Núria Miret-Roig from the the Laboratoire d'Astrophysique de Bordeaux, France and the University of Vienna, Austria, announced 2021 December 22 in *Nature* the discovery of at least 70 new rogue planets in our galaxy, the largest group of rogue planets ever discovered, using data from telescopes around the world, including CFHT's suite of wide-field imaging cameras. The discovery of this collection of rogue planets is an important step toward understanding the origins and features of these mysterious galactic nomads.

While rogue planets or free-floating planets have masses comparable to the planets in our Solar System, they do not orbit a star. They roam freely, thus making them elusive cosmic objects that cannot be found using traditional planetary detection methods. Such planets are usually very difficult, almost impossible, to image directly. Prior to Miret-Roig's survey, most rogue planets were found via microlensing surveys, in which astronomers watch for a brief chance alignment between an exoplanet and a background star. However, microlensing events only happen once, meaning follow-up observations are impossible. Not many were known until now.

However, Miret-Roig and her team utilized the fact that, in the few million years after their formation, these planets are still hot enough to glow, making them directly detectable by sensitive cameras on large telescopes. To find these planets, Núria Miret-Roig used observations and archival data from a number of large observatories, including CFHT, facilities from NOIRLab, telescopes of the European Southern Observatory, and the Subaru Telescope, amounting to 80,000 wide-field images over 20 years of observations. used the 80,000 observations to measure the light of all the members of the association across a wide range of optical and near-infrared wavelengths and combined them with measurements of how they appear to move across the sky.

They found at least 70, and possibly as many as 170, new rogue planets with masses comparable to Jupiter's in a star-forming region in the expansive upper Scorpius and Ophiuchus constellations, just a few hundred light-years away. The exact number of rogue planets found by the team is difficult to determine because the observations don't allow the researchers to measure the masses of the probed objects. Objects with masses higher than about 13 times the mass of Jupiter are most likely not planets, so they cannot be included in the count. However, since the team didn't have values for the mass, they had to rely on studying the planets' brightness to provide an upper limit to the number of rogue planets observed.

The brightness is, in turn, related to the age of the planets themselves, as the older the planet, the longer it has been cooling down and reducing in brightness. If the studied region is old, then the brightest objects in the sample are likely above 13 Jupiter masses, and below if the region is on the younger side. Given the uncertainty in the age of the study region, the team's method gives a rogue planet count of between 70 and 170.

"We measured the tiny motions, the colours and luminosities of tens of millions of sources in a large area of the sky," explains Miret-Roig. "These measurements allowed us to securely identify the faintest objects in this region, the rogue planets."

The team also used data from the European Space Agency's *Gaia* satellite, marking a huge success for the collaboration of ground- and space-based telescopes in the exploration and understanding of our Universe. The study suggests there could be many more of these elusive, starless planets that we have yet to discover.

"There could be several billions of these free-floating giant planets roaming freely in the Milky Way without a host star," stated Hervé Bouy, astronomer at the Laboratoire d'Astrophysique de Bordeaux and project leader. "These objects are extremely faint and finding them is incredibly challenging with current telescopes."

By studying the newly found rogue planets, astronomers may find clues to how these mysterious objects form. Some scientists believe rogue planets can form from the collapse of a gas cloud that is too small to lead to the formation of a star, or that they could have been kicked out from their parent system. But which mechanism is more likely remains unknown.

Over the past two decades, CFHT turned its science focus to wide-field imaging and high-resolution spectroscopy. The team utilized the archives from all three of CFHT's wide-field imagers: MegaCam, WirCam, and the decommissioned 12K. The wide field of view, sensitivity in the near ultraviolet and near-infrared, and angular resolution of all three cameras proved critical to the team's success in detecting the newly discovered rogue planets.

"CFHT's suite of wide-field instrumentation enables astronomers to analyze archival data in creative ways like we did in this work" said Emmanuel Bertin, CFHT resident astronomer and co-author on the paper. "Throughout its time on the sky, MegaCam alone produced around 200TB of archival images which provide incredible opportunities for astronomers to use the data and make discoveries like this well outside the original science case."

Further advances in technology will be key to unlocking the mystery of these nomadic planets. The team hopes to continue to study them in greater detail with many of the next generation telescopes being planned and launched like the *James Webb Space Telescope*, the *Vera C. Rubin Observatory*, and others. ✶

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.

John Percy's Universe

Another Kind of Eclipsing Variable Star

by John R. Percy, FRASC
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You are probably familiar with "classical" eclipsing variable stars, like Algol, in which a pair of spherical stars revolve in an edge-on orbit, periodically eclipsing each other in a regular way. I now find that two or three lines of my own research are converging on a rather different kind of eclipsing variable star—one in which a dust-enshrouded companion orbits and eclipses a pulsating star.

1. RV Tauri (RV) Variables

This story goes back over a century. In 1905, the prolific but largely unknown Norwegian amateur astronomer Sigurd Enebo published a light curve—magnitude *versus* time—of a variable star, now named RV Tauri, with alternating deep and shallow minima (Figure 1). It's now known to be a pulsating star. The cause of the alternating minima is still unclear and is a separate story. Enebo suspected similar behaviour in other stars that he had observed and named them RV Tauri (RV) stars. The brightest RV star is R Sct, which varies between 4.2 and 8.6 mag. They are low-mass stars in their final stages of evolution, moving from the AGB to the white-dwarf state. I discussed this kind of star in a previous column (Percy 2021).

As more were discovered, it was found that some, including RV Tauri itself, had a "long secondary period" (LSP), an order of magnitude longer than the pulsation period. These stars are sub-classified as RVb. Part of the 1210-day LSP of RV

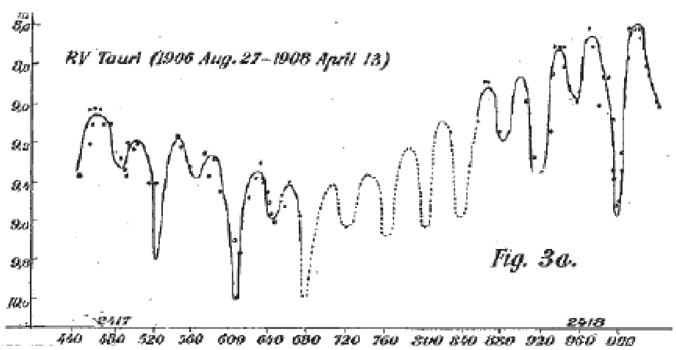

Figure 1 — The light curve of RV Tauri—magnitude versus *time —showing the pulsational variability with alternating deep and shallow minima, and part of the 1210-day-long secondary period. Source: observations by Sigurd Enebo.*

Tau is clearly visible in its light curve, shown in Figure 1. The pulsation period of RV Tau, from deep minimum to deep minimum, is 78.48 days. Other RV stars have (double) periods of 30–150 days.

This and other types of long-period variability was also studied by systematic photographic sky surveys, notably at the Harvard College Observatory which amassed over half a million images. Variability was and is also monitored by systematic visual observations made by skilled amateur astronomers, guided by organizations such as the American Association of Variable Star Observers (AAVSO: www.aavso.org). By 1990, AAVSO observations were digitized and decades-long light curves could quickly and easily be displayed. U Mon's LSP was particularly striking and, in 1993, I proposed that the minima in the LSP were due to eclipses. The "eclipses" were highly periodic, but the depth and shape of the minima varied, so the eclipser must include variable amounts of obscuring dust, presumably around a companion star.

In 1996, Karen Pollard and her colleagues in New Zealand published systematic photometric and spectroscopic observations, which showed that several RVb stars were indeed binaries. Andrei Fokin in Russia examined possible physical explanations for the LSPs, including pulsation and binarity, and showed that binarity was the most likely. Since then, Hans van Winckel, Laszlo Kiss and others have used a variety of techniques to build up the case for binarity. The latest word on the topic is by Laura Vega and collaborators (Vega et al. 2021) who obtained multi-wavelength observations of U Mon and showed that the yellow supergiant variable had a two-solar mass companion, and that the minima of the LSP were caused by a circum-binary disk of gas and dust. To quote the authors, "U Mon now becomes an archetype for the study of binary post-AGB stellar environment that represents an important evolutionary phase, which either sets the stage for sculpting the morphology and evolution of planetary nebulae or may represent systems that never become planetary nebulae at all, as the disc and stellar companion arrest its development."

Now you can appreciate why planetary nebulae look so varied and complex!

2. Yellow Semi-regular (SRd) Variables

My most recent project (Percy 2022) is to understand another type of yellow pulsating variables—the semi-regular (SRd) stars. Cepheid pulsating variables (like Delta Cephei) are highly regular; every pulsation cycle is the same. SRd variables are not, hence their name. Using data from the All-Sky Automated Survey for Supernovae (ASASS-SN; Percy 2020a), I have shown that these SRd stars can have one or more of—variable pulsation amplitudes, wandering periods, multiple pulsation modes—and LSPs. The latter is interesting and important, because previous studies (including by me) of AAVSO visual data had suggested that LSPs were rare or non-existent in SRd variables. I undertook a special search for LSPs in the SRd variables in the ASAS-SN catalogue—and found them to be very common. Indeed, many of the longer catalogue periods for these stars were actually the LSP, not the pulsation period.

I also found that there was considerable overlap between RV, SRd, and long-period low-mass Cepheids in the ASAS-SN catalogue. Known RV stars were often classified as SRd or CW and vice versa. In view of the great similarity between SRd and RV variables, it's safe to assume that the LSPs in SRd variables are also due to dusty binary companions. They deserve further study!

3. Red Giant (M, SR) Variables

Red giant stars all pulsate. The coolest, largest ones—the Mira stars—have periods of hundreds of days, and amplitudes of up to several magnitudes. Smaller red giants have shorter periods, smaller amplitudes, and semi-regular light curves, and are classified as red semi-regular (SR) variables. There are many among the naked-eye stars.

In 1954, the eminent Harvard astronomer Cecilia Payne-Gaposchkin pointed out that dozens of red giants had LSPs, as well as pulsation periods, based on long-term Harvard photographic photometry. Most of these stars were and are being monitored visually by the AAVSO. Red giants have been an important part of my research for many decades (Percy 2015). It began with using the systematic, sustained long-term AAVSO visual data. In the 1980s, it expanded to using *photoelectric* data from remote, robotic telescopes, and from skilled amateur astronomers in the AAVSO's new photoelectric photometry program. This was used to study smaller-amplitude SR variables. We found LSPs in many of them.

LSPs in red giants were re-discovered in the 1990s, by the hundreds, by astronomers including Peter Wood in Australia, using data from the massive automated MACHO sky survey. He raised the question: are they due to binarity, some form of pulsation, or something else? For the next two decades, Wood and many other astronomers (including me) attacked this question, either observationally or theoretically.

In 2021, the answer appeared. Igor Soszyński, and his Polish colleagues, published an elegant little paper (Soszyński et al. 2021) which presented strong evidence that the LSPs were caused by eclipses of the red giant by dust-enshrouded companions that were originally planets, but had accreted matter from the red giant's wind, and "grown" into brown dwarfs or low-mass stars. I and others have even found LSPs, in abundance, in the oldest red giants—those in globular star clusters. This would imply that planet formation was common, even in the oldest stars. Planets around other stars—exoplanets—are one of the most exciting and important topics in modern astronomy. Skilled amateur astronomers have contributed to their study indirectly, by observing LSPs in red giants!

4. Red Supergiant (Lc) Variables?

Here, things become more speculative. Whereas RV, SRd and SR variables are low-mass, sun-like stars near the end of their long lives, red supergiants are massive stars near the end of much shorter lives. But they too have LSPs. I and my student Hiromitsu Sato, and Laszlo Kiss in Hungary and his collaborators both found over two dozen red supergiants with LSPs. We used different techniques, but we both used decades of AAVSO visual data—the only dataset long enough for the purpose.

The two best-known red supergiants are Antares and Betelgeuse. Many of you will be familiar with the "great dimming" of Betelgeuse in February 2020, when it faded to magnitude +1.6. Reports tended to regard this as a one-off event but, in a previous column, I argued (Percy 2020b) that it was simply the conjunction of four periodic trends: at the time of the dimming, Betelgeuse`s pulsation period and LSP were both at minimum, and their variable amplitudes were both at maximum, producing the deepest possible minimum. AAVSO visual data showed that Betelgeuse had been almost as faint several times in the past, including in 1925–26 (Goldberg 1984).

But do Betelgeuse and Antares have companions? Yes! They are spectroscopic binaries with periods of 2110 and 2167 days, respectively (Goldberg 1984, Pugh and Gray 2013). Their LSPs are 2050 ± 460 days, and 1650 ± 640 days, respectively—values not significantly different from their binary periods. Furthermore: at the time of Betelgeuse's great dimming, a dust cloud was observed to be obscuring the visible face of the star. So, we could speculate that Betelgeuse and Antares are obscured by dust around their companions during the LSP minimum. But the dust could also have been ejected from the star's cool photosphere. This happens in the rare but spectacular R Coronae Borealis stars, which can fade by up to several magnitudes. In either case, Betelgeuse was eclipsed by dust, not just by another star.

I`m sure there is much more evidence in the literature, for and against this interesting hypothesis. Maybe that will be my next project. In the meantime, you can help by going out and measuring some of these interesting stars. The AAVSO can provide all the resources that you need. ✶

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Astronomical Art & Artifact

Technology Obscuring the Night: How Long Has Light Pollution Been Perceived as a Problem by Society Members?

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In homage to Rob Dick FRASC on retiring from the RASC's Light-Pollution Abatement (LPA) Committee.

Abstract

Light pollution has become the principal barrier to the night sky. Its documented growth charts a seemingly inexorable decline in simple, direct access to most astronomical phenomena. We tend to think of this as a problem of our time, possibly emerging as far back as the immediate post-World War II years. Is this true? When does an awareness that light pollution could be a problem for astronomy arise in the consciousness of RASC members?

Ruining the Night

Every astronomer knows the problem. Anthropogenic lighting is the single largest impediment to our experiencing the Universe from the surface of our planet. And it doesn't appear to be getting any better. We've all seen the series of maps using satellite data showing the artificially illuminated Earth at night, displaying light flux increasing from year to year (e.g. The Blue Marble; for a "snapshot" of the world in the mid-2010s, see Falchi 2016). These images are not unattractive, resembling the beguiling industrial landscapes of Edward Burtynsky. The comparison is not a frivolous one; the light of our manufactured landscapes block the Universe beyond.

In a memorandum to the Science and Technology Committee of the British House of Commons in 2003, the Astronomer Royal, Lord Rees of Ludlow, stated that:

> "Van Gogh painted his "Starry Night" in the same spirit as his portrayals of sunflowers and cornfields—the night sky is part of everyone's shared environment. Indeed it is a uniquely universal feature: it has been viewed and wondered at, essentially unchanged, by all cultures throughout human history. But unless we live in exceedingly isolated parts of the UK, we are now, deprived of this experience... it is an impoverishment if children grow up without ever seeing a "real" starry sky in the way earlier generations did: astronomy and space have a special appeal and an effective role in stimulating general interest in science." (House of Commons, *Light Pollution and Astronomy*, 227–228)[1]

In other words, access to the night sky is a cultural good. It is part of an endangered world heritage, increasingly moving beyond our reach. A similar point was made in the influential (but perhaps not influential enough) La Palma Declaration (Marín, & Jafari et al., 2007).[2] And UNESCO backs these concerns (Portal to the Heritage of Astronomy, Dark Skies Information).

Wherever there are astronomers, there are groups working to raise awareness about light pollution, in the evergreen hope that it will eventually spur real change. The RASC is no exception (www.rasc.ca/lpa). The earliest reference to any initiative in the Society seems to pinpoint the Toronto Centre as the place of origin, via its Observational Activities Committee (OAC). The first sign in print was a brace of pieces in the National Newsletter for 1974 December. Robert Pike, Chair of the OAC, began by inviting readers to take part in a "Study of the sky brightness in and around urban centres" (Pike 1974, L30), but this was a prelude to a fuller invitation from the person who was in effect the "principal investigator"[3] of the project, the highly capable Richard Berry (1974, L31). The project would provide members with plans to construct their own photometers for the investigation—harvesting quantitative data was important. (A third piece was a reprint of an article about a proposed new sports structure that might well corrode the quality of the skies at the David Dunlap Observatory; Anon. 1974, L28–L29).

The project was a success, and resulted in the inaugural Journal papers on the subject. Richard Berry's "Light Pollution in Southern Ontario" (1976) was a significant methodological treatment that is still cited in the literature (e.g., Falchi 2016, 15), and it was followed by Pike's explanation of his computer model that made Berry's work possible (Pike 1976). This was the start of the Society's organized efforts directed toward light-pollution abatement. In those efforts the dominant figure to date has been Robert Dick, FRASC (Ottawa Centre), and a crude measure of the weight of his contribution is to be found in the number of his papers on the subject that have appeared in the *Journal* over the last 47 years. Now and again working with colleagues, he is the prime architect of much of our current light-abatement policy, and many of our programs.[4]

His work has been substantial. Others, among whom are to be counted the late Peter D. Hiscocks (Toronto Centre) and Richard Huziak (Saskatoon Centre), have also made significant contributions to light-pollution abatement.[5]

The term "light pollution" to indicate an excessive and intrusive level of man-made artificial illumination became current in the early 1970s, having apparently been coined in the late 1960s (the term does occur earlier, but not to refer to an unwanted excess of electromagnetic radiation; rather, "light pollution" was used of any and all sorts of pollution—water contamination, soil contamination, radioactive contamination, what have you—in contradistinction to "heavy pollution"; light pollution. OED).

It is often claimed that the modern problem of runaway light pollution really commenced in the immediate post-WWII years (Walker et al. 2021, 16), an impression that many of us share. I have casually assumed that our astronomical forbears in the first half of the 20th century and earlier enjoyed quite good observing conditions from their city backyards, perhaps the equivalents of Bortle Class 3 skies or better, from nearly anywhere in Canada (Bortle 2001). If that was the case, light pollution was hardly a factor in their astronomical lives. It's worth asking whether that impression is accurate. When did Society members first become aware of what we now call "light pollution"? Was it when the current term was coined (1960s–1970s), or was it before, and if so, how much before? What are the earliest documentary traces of an awareness of light pollution, and what form did it take?

When did it Start?

> "In January of 1579 Queen Elizabeth decided that sea coal smoke had become a problem, and her solution was to jail over a dozen of London and Westminster's leading polluters" (Cavert 2016, 45).

This delightful and heartwarming approach to those responsible for the industrial degradation of the air by burning bituminous coal "during the Queen's majesty's abiding at Westminster" (47) alerts us to the chief factor potentially obscuring the night sky for astronomers before light pollution—smog.[6] One can well imagine that even conditions somewhat milder than pea-soup smog could seriously affect observations.[7]

This was not a new problem in Elizabeth I's day; it was centuries old by the 1570s. In the last quarter of the 13th century, Edward I attempted several times to prohibit the use of sea-coal (Brimblecomb 1975—its effect on the atmosphere in the city did provide him with a manufactured excuse to try to shirk an obligation there, and the requisite angry barons, in 1299; Prestwich 1997, 520).

Monarch succeeded monarch, as urban smog succeeded urban smog. John Evelyn, a founding member of The Royal Society of London for Improving Natural Knowledge, even wrote a tract against smog (1661). Evelyn's work, complete with proposed solutions to the environmental problem, was "Published by His Majesties Command." He clearly enjoyed some influence, but in the end his tract did not clear the "aer"—none of its measures were implemented.

The surprise here is that there appear to be few complaints from astronomers about the effects of smog on their observing. In the Royal Society, Evelyn was a colleague of astronomers Robert Hooke, the Royal Astronomer the Rev'd John Flamsteed, Isaac Newton, Edmund Halley, Sir Christopher Wren, and others, yet nowhere in his tract is there any reference to the smoke of London obscuring the night. Perhaps, like many botanists and horticulturalists of the 17th and 18th centuries, the astronomers at that time preferred passivity in the face of the problem (Brimblecomb 1987, 68, 75, 90; this passivity took the form of trying to grow smog-resistant plants in urban settings, rather than taking on the causes of the pollution directly). Or smog and associated conditions may not have limited their access to the night sky as much as our current levels of light pollution limit ours, although this seems a most unlikely explanation, given the blanketing toxicity reported of some of the historic smogs. Perhaps it was less constant. It would be interesting through modelling to compare the effects of smog and lesser contaminations in various places during the 16th to the early 20th centuries to the effects of light pollution in our time.

The son of the author of the *Cycle of Celestial Objects* (1844) certainly noticed the effect of smog on observing: "For [Charles] Piazzi Smyth the contrast between the clear skies he had experienced over the hills of South Africa and the smoky atmosphere of Edinburgh...was particularly striking" (Brück & Brück 1988, 27). Or, in Piazzi Smyth's own words:

> "For witness that our Observatories, instead of being built on the highest mountains in the clearest climates, have always been erected at the bottoms of the lowest valleys, hardly elevated in any sensible, certainly not in any useful degree, above the level of the sea; and that, worse still, they are generally immersed in the smoke of our largest towns" (Anon. [=Smyth, C.P.] 1853, 53).

An awareness of this problem was not confined to astronomers alone. Ernest Jones in his 1847 poem "The Factory Town," published in the Chartist *The Northern Star and National Trades' Journal*, observes that:

> "Even the very stars seemed troubled
> With the mingled fume and roar;
> The city like a cauldron bubbled
> With its poison boiling o'er" (Jarrige & Le Roux 2020, 134).

Some cities were doubtless worse than others, and some areas of some cities better than others. In 1862, Alvan Graham Clark with his father Alvan Clark Sr. discovered Sirius B, a challenging target, from the observatory at their works in Cambridgeport, Massachusetts, not far from Boston (Warner & Ariail 1996, 36–37). And it's curious that when Edward S. Holden, the first director of the Lick Observatory, wrote his survey of *Mountain Observatories in America and Europe* (1896), in the long wake of Piazzi Smyth's pioneering 1856 expedition (Smyth 1858), he didn't cite either smog, or encroaching city lights as motives for siting observatories on mountains. That was to change within the next half century.

Roger Hutchins, in charting the course of British university observatories from the late-18th century to the eve of the Second World War, noted environmental difficulties congregating from the 1890s to the 1930s. At the Solar Physics Observatory at South Kensington "...by 1888 the atmospheric pollution at the site was so bad that Lockyer constructed an outstation at his home in Westgate-on-Sea in Kent" (Hutchins 2008, 230). The Royal Observatory, Greenwich, was affected by "…atmospheric pollution…" ca. 1900–1930s (285–286). In the

1890s–early 1900s, the Horselethill Observatory of Glasgow University "...measured an annual deposition of more than one and a half tons of soot per acre per year at the observatory site" (395). At Durham Observatory in 1913 the "...atmosphere was reported as 'filthy', 'foggy', and 'sooty' in 1913" (420; 409). And the Observatory at London's Imperial College was "[c]losed in 1931 due to atmospheric conditions" (417). Sea-coal took its toll.

By the time it came to choose a site for the 200-inch telescope on Mount Palomar, protection from the possible encroachment of urban lights had become an issue (at least according to the entertaining, but unreliable, David O. Woodbury 1940, 28, 212).

When did Society Members Begin to Note the Unwanted Light?

The earliest notices in Society publications of anthropogenic pollution interfering with astronomical observations date from the organization's revival in the 1890s.

At a meeting of the Society on 1894 September 18, member Katherine Vale "…who had recently removed to Davenport, Iowa…," was "…requested to favour the Society with any items of interest pertaining to the advancement of science in her locality" (Vale 1895, 80). She happily complied with a description of the Chamberlin Observatory of the University of Denver. In remarking on the location of the observatory she noted that:

> "University Park is on a higher level than Denver; the ground rises gently into a rounded hill, upon the highest point of which the Observatory is built; it is more than four miles from town, and a longer distance from the large smelting works, so that the smoke of the city interferes very little with observation…" (Vale 1895, 80).

Her remarks reveal that, contemporary with the complaints over the degraded sky above British university observatories, an American university observatory was perceived as having been sited to avoid a similar problem.

A vivid public recognition that a country sky free from the atmospheric pollution of cities was better for stargazing was voiced by John A. Patterson on 1898 October 4. He speaks of it as a "revelation:"

> "Mr. John A. Paterson, who had just returned from a holiday trip, spoke enthusiastically of the serenity of the skies in the Muskoka district: —
>
> Last August I visited a pleasantly-sequestered nook in the Georgian Bay bearing the mellifluous name of Honey Harbour,[8] and there the summer evening sky was to me a revelation. We have been told of the murky Toronto sky and of the metropolitan smoke, which with the mists and vapours of Lake Ontario mars the glorious effulgence of the overarching firmament. But there the transparency of the air is such that the ordinary eye is as good as a telescopic eye of moderate power here, and seems about as strong as the "double-million magnifier with hextra power" of Mr. Samuel Weller.[9] I remember one occasion especially well when almost unconsciously I found I had an audience of some ladies and gentlemen who were hotel summer visitors. It was an enchanting twilight and "heaven's husbandry"[10] was not shown, for all her candles were growing aflame, and as the darkness stole round us
>
> "Silently one by one in the infinite meadows of heaven
> Blossomed the lovely stars, the forget-me-nots of the angels." [11]
>
> The day had been warm, although tempered by the cooling, bracing breezes of the Georgian Bay, and now, these "being up gathered like sleeping flowers," [12] in the Sun's shadow the firmament had put on her finest and bravest apparel. Looking to the east there Andromeda, the bride of Perseus, displayed her trembling jewels, and next her Cassiopeia, her mother, gracefully seated on her golden chair, seemed to beckon to her for forgiveness to atone the wrong she had done by boasting of her daughter's beauty. The great nebula [M31] of undigested world stuff (if such it be), held in the left hand of Andromeda, was too close to the edge of the horizon to be seen. Further to the east, close to the horizon, Pegasus seemed lifting himself with ponderous wings from the bosom of the lake.
>
> Along the line of the ecliptic low down, Aquarius, Capricornus, Sagittarius, Scorpio, Libra and Virgo, belted the sky. Antares, with its red flashing fires, beamed with remarkable brilliancy away to the south in the middle of the Scorpion's back. Just east of the meridian the Swan, with her flashing wings, the Dolphin and the Eagle, blazed so beautifully as if indeed these creatures, ancient dwellers in the ever circling menagerie of the old astronomers, had been brightened and whitened as they shook off the waters of the Georgian Bay. Altair, that first magnitude star, flamed on the neck of the Eagle like a blazing jewel. On the west of the meridian we saw Hercules the "kneeler," [13] the Northern Crown with its glittering circle, the Herdsman, with the flashing eye of Arcturus, like a diamond on his knee, watching Polaris and off to the north the Hunting Dogs bore on their necks Cor Caroli, far, far brighter than ever we see it here, and the Great Bear, with its pointers and tail-stars more dazzling, seemed mightier than before. But what shall we say of the Great Galaxy [ie, the Milky Way]? *We* never see that in Toronto unless we call a sort of slight hazy gleam that glorious circle; but there it was a thing to be set down and thought over; the white parts near Sagittarius and in Cygnus where it divides into two mighty arms as if lifted up in silent praise, were indeed in that calm and cloudless night a marvel, and eloquent with wondrous beauty. It seemed as if the glorious stars were gathered in the crowded sky and listened in breathless silence to the litany of the Universe led by the solemn uplift of the Great Galaxy. Venus and Jupiter hung like great globes over the western horizon, and as the silent footfall of the evening stole on and the darkness deepened, these silver-fair planets

seemed to chase each other to their rest. There we sat on the rocks and studied the great book of the firmament spread before us emblazoned with shining letters that shone the more brightly as the purple evening wore on and dark night followed. We in Toronto do not and cannot see the glories of the heavens as they look down on us, but there and in Muskoka the bosom of old night seems on fire and sparkles with as many coloured glories as the hilt of King Arthur's sword *Excalibur*, which "twinkled with diamond sparks, myriads of topaz lights and jacinth work of subtlest jewelry." [14] Should it ever come—and I trust the time is not far distant—that a first-class astronomical observatory be built in Ontario, I fear Toronto cannot claim it, as the power of a first-rate objective would be sadly crippled by the mist and the smoke that hang about it. [15] "Go west" is an advice often given to young men who pursue Hope's golden dream; "Go south" leads the invalid to strength and health; but "Go north" will lead my hearers where they may see God's sky without a telescope, and will show the astronomers where they may plant their instruments most effectively" (Patterson 1899, 90–92).

Smog may have been the principal anthropogenic contaminant affecting observations at the time, but it wasn't the only one. Other unwanted electromagnetic radiation could cause havoc to geophysical observations in the 19th and 20th centuries.[16] John A. Patterson in his 1896 presidential address to the Society noted that:

> "It is to be regretted that the Electric Railway system in Toronto makes it impossible to satisfactorily study Earth current changes at this observatory. At Greenwich, what promised to be a most valuable and interesting Earth current record, has within the past few years been ruined by the building of an electric railway in East London. This railway is not at any point nearer than one and a half miles to the Earth current wire, and yet the vibrations of the galvanometer magnet, caused by the passage of the trains, are greater than any ordinary Earth current changes" (Patterson 1897, 105).

Arthur Harvey returned to this theme in his presidential address three years later:

> "Mr. Stupart's name recalls many happy hours spent among the records of the Toronto magnetic and meteorological observatory, which with unvarying kindness and patience he has made available to me for my favourite study, the Sun and his connection with terrestrial magnetism. The installation of the electric street railway system interfered so much with the working of the magnets that no amount of care in applying corrections sufficed to make them tell their tale with accuracy. A new house for these delicate instruments has accordingly been built at Agincourt, nine miles distant to the north-eastward, where the trolleys cease from troubling and the restless bars are undisturbed by artificial attractions" (Harvey 1899, 129).

The period around 1900 is also when the first references in Society documents to light pollution occur.

At a meeting of 1898 April 14:

> "Some discussion arose regarding the visibility of the zodiacal light in this latitude. Mr. Lumsden had quite recently observed the phenomenon on a clear evening in the north-east part of the city. He stated that it was so marked as to be quite noticeable to other observers who saw it unexpectedly. Mr. Elvins remarked that he had never successfully observed the zodiacal light in Toronto, since the electric system of lighting had been established" (Lindsay 1899, 19).

Two years on, the same observation was made:

> Short papers of a popular character were read by Rev. Robert Atkinson, Mr. A. F. Miller, and Mr. Andrew Elvins upon "Mercury," "Venus," and the "Zodiacal Light" respectively…Speaking of the Zodiacal Light, Mr. Elvins described its appearance as seen in these latitudes, and regretted that owing to the introduction of electric arc-lamps, Toronto was no longer a good observing station" (Lindsay 1901, 7).

Beyond the interest due to their historical precedence, these reports are otherwise intriguing, in particular the disparate experiences presented in the first of them. Both Elvins (1823–1918) and Lumsden (1847–1903) were experienced observers (Lumsden may have been the better astronomical artist), but they were of different generations, so while Elvins's experience of observing conditions in Toronto was longer than Lumsden's, the 75-year old's vision may not have been as acute as that of his 51-year old friend. It is possible that the factor determining whether the phenomenon could be seen or not was the respective urban observing location of each. The significant thing here is that Elvins was ready to attribute the non-observability of the phenomenon to what we would now call light pollution. The lighting technology he specifies is one with which most of us are no longer familiar on a daily basis.

At the Society meeting after Elvins's second complaint about the electric arc-lamps, Dr. J.J. Wadsworth gave an imaginative talk about what it would be like to view the heavens from the surface of the Moon, free from terrestrial observing conditions:

> "Dr. Wadsworth said that he had stationed himself with his 12½-in. reflector upon the central hill in Triesnecker, a beautiful ring-plain, about fifteen miles in diameter, with a circular rampart. His first glance assured him that, compared with Triesnecker, Toronto was a poor place for observational astronomy. What we call fifth-magnitude stars seemed to him as bright as Capella usually does from the Earth, while "Sirius excelled any arc-lamp" on Toronto Island, as seen from Toronto" (Elvins 1901, 10).

That an arc-lamp was cited as a proportional comparison for the brightest star in the terrestrial sky gives some indication of the light pollution amateur astronomers of a century and a quarter ago were up against.

The Technology

Arc-lamps employ carbon (graphite) rods as electrodes, rheostats to control the resistance, and solenoids to control the spacing of the electrodes. When at rest, the carbon rods are in contact. To start the lamp the rods are separated, and a spark jumps between them (the regulated current circulating through the solenoids maintains a constant distance between the rods; Woodhead et al. 1984, 74-76). They were introduced to Toronto in 1879 in a lone but resplendent restaurant and expanded through private initiative soon afterwards (Turning on Toronto: Setting the Scene).

As intimated in the passage from Dr. Wadsworth quoted above, arc-lamps were bright. In fact, they were significantly brighter than the technologies previously in use (candle, oil, and gas light). They were found to be both novel, and unsettling. How bright were they? Many of the new LED streetlights that have recently been installed in cities across Canada have a colour brightness of 4,000K. The carbon arc-lamps of Elvins's day had a colour brightness between 3,600 and 5,000K. They were comparable to the LEDs that are causing such consternation among amateur astronomers now!

The average street fixture of 1900 was as far from full-cutoff as imaginable. But the average street fixture was far from the worst manifestation of this technology, for those desiring clear and unsullied skies. In some places, arc-lamps were mounted on inaptly named "Moon towers," 2.5-ton, 50-metre-tall iron towers with multiple arc-lamps, designed to illuminate whole city blocks. As far as I know, the Toronto skies were not subjected to such an indignity, but Victoria's were in the 1880s (Roy 1976–1977, 86, 88). "Moon towers" have now mostly departed cityscapes. A notable (perhaps notorious) exception is the city of Austin, Texas, which undertook a restoration project in the 1980s to restore their "Moon towers" as part of the city's heritage (Moore & Strand 1991). Preservable heritage is clearly in the eye of the beholder. Perhaps Austin's restored "Moon towers" can best serve as a salutary warning. The "Moon towers" resemble nothing so much as the Martian fighting machines (tripods) from H.G. Wells's *War of the Worlds* (1897), petrified to immobility, but still capable of malevolent mischief.

The Intractable Symbolism of Electric Illumination

The wonder is that it took so long for amateur astronomers to organize to try to do something about light pollution, given that there was some acknowledgment that it degraded skies well over a century ago. It may be that RASC members of that time preferred to model a passive response, like most of the English botanists and horticulturalists of the 17th century mentioned earlier. It may have been seen as more polite and culturally acceptable to flee to dark skies, rather than try to tackle the source of the pollution head-on at home. It can't be a coincidence that the RASC's light-pollution abatement efforts started in the mid-1970s, in the decade after Rachel Carson's *Silent Spring* (1962), and some well-publicized ecological disasters, and the use of Agent Orange in Vietnam, when more people were becoming aware of the environmental costs of modern industrialization, and direct action became more acceptable (although still not "polite").

The symbolism of electricity may also have played a part in holding back an active response to light pollution. Electricity had an aura about it dating back at least to the 18th century, born of its being perceived as technological magic, and a vector of material progress:

> "Few things could be more traditional than nightfall, which had always divided human experience into two quite-distinct periods. To break through the darkness with massive lighting displays erased this demarcation and declared human independence from the rhythms of nature. The illuminated city, with its bright boulevards, skyscrapers, and spectacular electric signs, seemed to exemplify progress, representing the triumphant light of civilization. Like the world's fairs, illuminated cities were widely understood to be dynamic utopian landscapes, while an unelectrified city was backward" (Nye 2018, 7).

The symbolism was further enhanced when artificially illuminating the night was presented as a crime-fighting measure. The latter happened even earlier than the "taming" of electricity:

> "According to the most familiar formula, dark streets bred crime and fear as well as signifying the gloomy past that was being transcended by technology. This became a simple, pervasive way in which historical progress was imagined. During George I's reign, argued the *Builder*, householders had been obliged to hang lights outside their homes until 11:00 P.M. only, after which "highwaymen continually rode into the streets…and perpetrated the most open outrages with impunity."" (Otter 2008, 193).

This symbolism was as potently active in Canada as elsewhere:

> "There is not time here to explore the rural reform movements of the 1910–1940 period, or the rural problems, protests and promise that played a role in discussions of rural electrification. But within a larger, and growing discussion about the importance of 'the modern rural' in Canada and the growing disparity between rural and urban standards of living, electrification was increasingly seen more widely as the panacea not only for all ills of rural society, but for Canadian society generally. Promotional campaigns reached deep into the countryside, promoting electricity as the overarching solution to the problems that Canada was encountering with crime, poverty and vice associated with increasing urban industrialisation" (Sandwell 2017, 192).

Society members and their astronomical colleagues elsewhere can be forgiven for being reluctant to fight light pollution a century and a quarter ago, or to even make much of it. The symbolism in favour of artificial lighting, and the power and wealth promoting the technology were formidable—more so than astronomers individually, or corporately. The problem remains to this day, because the symbolism is still so potent.

It is clear from this paper that light pollution, and earlier anthropogenic degradations of the night sky have been going on for much longer than is commonly thought. The technologies causing the pollution have changed since the 16th century, and will change still. The pollution expected to be caused by LEO-satellite mega-constellations affecting the collection of astronomical data is something novel, at least in scale (Walker et al. 2021, 120-157; astonishingly enough, something like this was predicted by Leslie Peltier 1965, 234).

Light-pollution abatement has seen some notable battles won, almost all at the local level, but even a casual glance at successive images and maps of the illuminated globe at night show that the war is being alost. None of that can be laid at the feet of those in the RASC and their colleagues elsewhere who have worked hard toward reducing light pollution. But by now it's evident that some other strategy is needed.

One of the problems in trying to motivate our fellow citizens, including the political and corporate classes, to effectively ameliorate light pollution is that so many other pollutions and problems seem more immediately dangerous. In comparison to geopolitical problems, world-wide pandemics, cancers, the climate crisis, and a multitude of inequalities, they may reason that light pollution is a problem that can be kicked down the road with fewer immediate consequences. Yet none of these problems, including light pollution, are wholly independent of the others. If I was given to optimism, I might hope that a solution to the climate crisis could also be a solution to light pollution. If I was given to optimism. ✶

Acknowledgements

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

Endnotes

1 The Common's Science and Technology Committee produced a thorough, incisive, and hard-hitting report. It is a shame that the Labour Government of the day, and regional authorities did not act on more of the Committee's recommendations. The report is also notable for how seriously it treats the amateur astronomical community in the UK in general, and specifically in its praise of the British Astronomical Association. Nothing even remotely comparable—process or report—has issued from the Canadian Parliament. One can live in hope…

2 The La Palma Declaration is a model of lugubriously laboured pseudo-legalistic expression—its stylistic shortcomings likely worked against its laudable aims.

3 The term was not then fashionable.

4 Perhaps he will forgive me when I note that he was a master at proving the old adage that "it is easier to seek forgiveness than permission," during his long leadership of the Society's light-pollution abatement portfolio.

5 The RASC was not the only game in town; Tom Bolton's successful work to limit light pollution near the David Dunlap Observatory was not done under the aegis of the RASC, although the Society morally supported his efforts, and, shifting to the world stage, one finds the International Dark-Sky Association (IDA, 1988–).

6 Unfortunately, the actions amounted to little besides the momentary discomfort of the brewers responsible. Charles I tried even more vigorously, but the Royal motivation across reigns was to improve the comfort of those at the top, rather than make breathing easier for the citizenry at large. In time, the Crown gave up; Cavert 2016, 43–60; Brimblecombe 1987, 30, 66.

7 This would be different from the slight haze recommended as advantageous for planetary observation: "Calm nights when there is a little haze and fog, making the stars look somewhat dim, frequently afford wonderfully good seeing" (Denning 1891, 64)

8 Approximately ca. 44° 52' 17.364" N, 79° 49' 12.792" W.

9 Weller is a colourful Cockney character from Dickens' Pickwick Papers. The actual quote is: "Yes, I have a pair of eyes," replied Sam, "and that's just it. If they wos a pair o' patent double million magnifyin' gas miscroscopes of hextra power, p'r'aps I might be able to see through a flight o' stairs and a deal door; but bein' only eyes, you see, my wision's limited" (Dickens 1838, 75).

10 A quote from Vaughan 1650, 83.

11 From Longfellow's *Evangeline* (1847, 51).

12 From Wordsworth's "The World is too Much With Us" (1807, 2, 122, poem 18 of Miscellaneous Sonnets).

13 The original name for the constellation Hercules in Greco-Roman antiquity (Eratosthenes, & Hyginus 2015, 26-31).

14 From Tennyson's *Idylls of the King* (1896, 382, "The Passing of King Arthur").

15 Yet that is exactly the plan the Society adopted in the early 1900s—the "Royal Astronomical Society of Canada Observatory" was to be erected in Trinity Bellwood's Park in downtown Toronto (Rosenfeld 2013)!

16 The term "observatory sciences" has been coined in 21st-century science studies to cover the range of scientific disciplines practiced within astronomical observatories in the 19th and early 20th centuries, but which are generally no longer included under astronomy's aegis (for the contours of science constantly evolve; Aubin et al. 2010; Aubin 2011). This can be seen in the range of activities pursued by the Dominion Observatory while it existed (Hodgson 1989, 1994). The Royal Astronomical Society still embraces astronomy, astrophysics, *and* geophysics, a heritage it has maintained from the 19th-century division of the sciences. And it should be noted that many present-day space agencies embrace an unusually wide range of disciplines, very much akin to 19th-century "observatory sciences"—astronomy, astrophysics, geophysics, meteorology, and other disciplines. And instruments working in the visual part of the electro-magnetic spectrum could be subject to disturbance by acoustic (and possibly infrasound) waves; this was the partial cause of the failure of the Monument to the Great Fire of London (1671-1677) as an enclosure for a zenith telescope (Zack 2015, 265).

17 For a recent excellent and sober review of the problem from a professional astronomical standpoint, fully alert to wider implications, and offering sensible proposals for action, see Green et al. 2022."

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Dish on the Cosmos

The Galactic Centre

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

At the dawn of radio astronomy, Karl Jansky detected the first radio waves from a source outside the Solar System: the centre of the Milky Way galaxy. The rise and fall of the signal strength tracked with the constellation Sagittarius in the sky. Jansky knew that the centre of the galaxy was off in this direction and the rise and fall tracked with sidereal rather than solar time. The timing and the direction led Jansky to conclude that the Galactic Centre (GC) was an emitter of bright radio waves.

The GC is one of the strongest radio signals in the sky, and as radio telescopes improved, a clearer picture of the galaxy's centre began to emerge. Because of the long wavelengths of radio waves, the signals from the GC pass through the dust that lies in the midplane of the galaxy and blocks out optical light. Radio waves are one of the best ways to study the extreme environments in the dense nuclear region of the Milky Way. As telescopes improved, these observations identified Sagittarius A*, a compact and bright radio source, as being at the exact centre of the Milky Way and further evidence pointed to the radio source hosting a massive, compact object. While some of the best dynamical measurements of the black hole at the GC are from infrared observations of stars, radio observations revealed the signatures of the anemic accretion onto the black hole.

On larger scales, the GC shows some of the intense environmental conditions in the whole galaxy. It is rich with the molecular gas that forms stars, but one of the abiding mysteries of this "Central Molecular Zone" is why the density of gas is so high, but the rate of star formation is correspondingly low. When stars do form, they can build up into the largest clusters forming in our galaxy today, offering some insights as to how ancient globular clusters may have come into being. This central region also shows signs of several past supernova explosions, intense turbulence, and strong magnetic fields. Observations of gamma rays, at the extreme opposite end of the electromagnetic spectrum, show a strange "haze" of high-energy processes. Are these the signs of a cluster of neutron stars or the tantalizing signal of dark-matter annihilation? We can only probe these extreme conditions in the highest densities of matter in the galaxy. Certainly, there are other places across the Universe where there are more extreme conditions, like the hearts of Active Galactic Nuclei. However, the relatively quiet Milky Way is nearby and affords us an unprecedented view of the small-scale details of these physical processes.

All these factors make the GC a favourite target for radio astronomers, and any telescope that can see this part of the sky invests effort at observing it. As telescopes have improved, so too has our understanding of the different physics playing out in this extreme region. The most recent addition to this field is the newly released observations from the MeerKAT telescope in South Africa, which has made a wide-area map of this entire region. MeerKAT is a modern radio interferometer that is being actively built and developed as a preliminary facility that will eventually lead to the construction of the Square Kilometre Array (SKA).

While this column has previously featured a preliminary image from MeerKAT, the recent release of the imaging data accompanied by a scientific analysis of the work has left the astronomical community amazed. The MeerKAT image is shown in Figure 1, which shows the brightness of the radio emission throughout the region. The amazing quality of the radio image showcases many of the strange phenomena playing out in the GC. There have been stacks of scientific papers aiming to tease apart these regions but there are a few objects that stand out particularly well in this image.

The high quality of this image fails to convey the additional data captured by the MeerKAT observations. MeerKAT observes at all the different frequencies from 850 MHz up to 1750 MHz and thus can measure how the brightness of the radio emission changes across this entire frequency band. Astronomers describe this change as the "spectral index," which is the exponent describing the mathematical relationship between the brightness of the spectrum and the observed frequency. Different spectral indices imply different mechanisms for the radio emission. If the spectral index is strongly negative (less than –0.4), this emission is likely from synchrotron radiation and is the result of electrons whipping around a magnetic field at relativistic speeds. In contrast, when the index is slightly negative or positive (more than –0.2), the radiation likely arises from a gentler process of electrons moving past protons in a warm plasma and is often called "thermal emission," because the technical term is from the original German—*bremsstrahlung*—and is a bit of a mouthful. Synchrotron emission is usually from high-energy explosions or intense magnetic fields, whereas the thermal radiation is usually associated with the warm plasma found near high-mass stars. The spectral index measured by MeerKAT gives us more evidence as to what these objects are.

One of the most striking features in the galactic centre is "The Mouse" and its associated supernova remnant SNR G359.1-0.5 (labelled based on its position in galactic coordinates). The Mouse is a neutron star that has been ejected from the supernova explosion and is moving supersonically through the plasma in the GC. The neutron star is a known pulsar and the emission around it is the pulsar wind nebula, which traces the interaction of the strong magnetic field around the

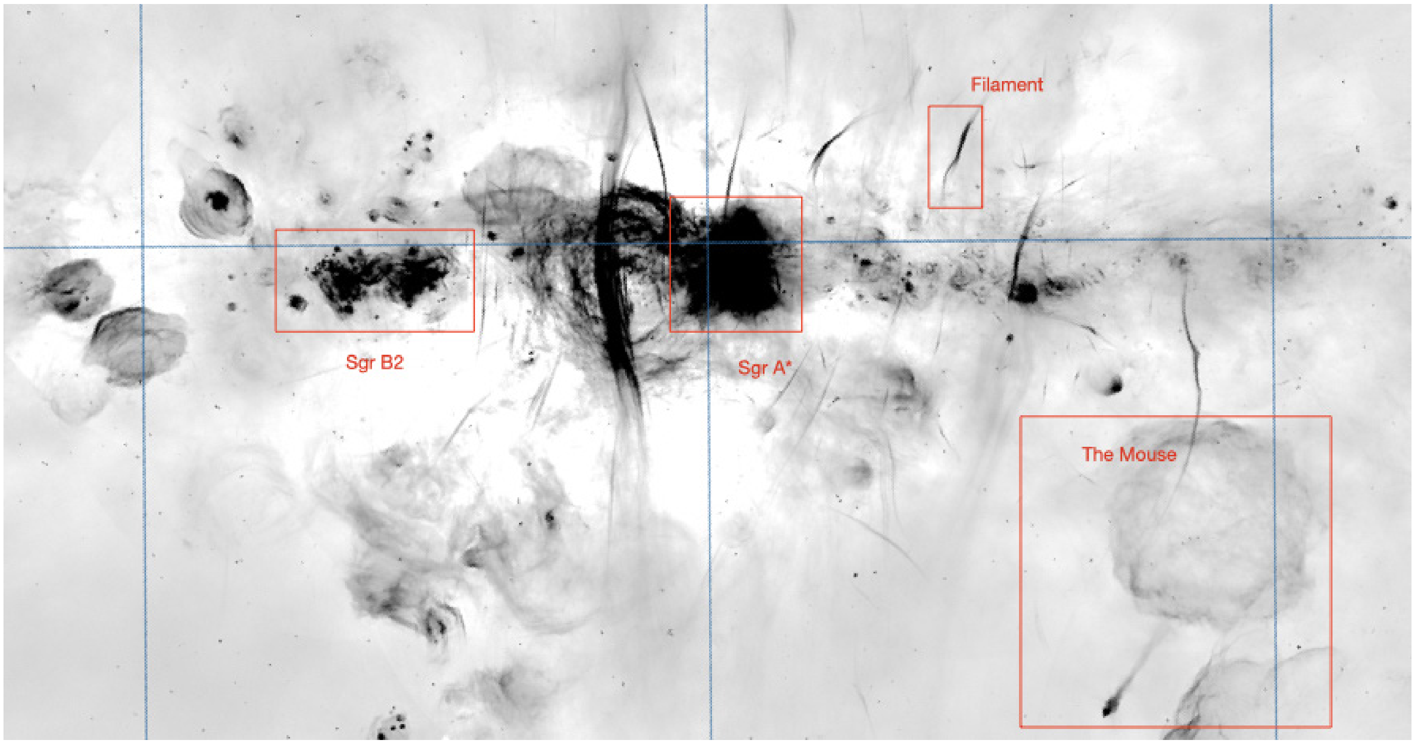

Figure 1 — The MeerKAT observations of the galactic centre as published in Heywood et al. (Astrophysical Journal, 2022, 925, *165). The new radio image is of unprecedented quality and depth and reveals the details of several features including the labelled Mouse, filaments, and Sgr B2.*

pulsar with the material around it. The neutron stars that are formed in supernova explosions can be given a strong "kick" during the explosion, propelling them through space. The high-quality MeerKAT image shows the connection of the Mouse back to its associated remnant. While the Mouse was previously known and studied, the MeerKAT image has dug up several faint supernova explosions around the area that were previously undetected.

Another striking feature in the image is the ubiquity of narrow, bright "filaments" of radio emission, which show spectral indices that are also associated with synchrotron emission. The reason that these filaments "light up" in the radio remains a mystery, but something is driving high-energy particles down narrow tubes of magnetic flux. The MeerKAT imaging shows some bright, already known filaments, but also finds a host of smaller, fainter filaments throughout the region. These filaments are rare in other systems, and MeerKAT offers a unique opportunity to characterize the filament population. The high-quality image also traces the filaments further along their lengths and suggests their connections back to bubbles, but future work will be needed to probe whether these structures all connect up. The details revealed by MeerKAT have lent some support to the theory that the cosmic rays lighting up these filaments are all driven up to high speeds in a series of clustered supernova explosions that detonated in the GC several million years ago.

A personal favourite of mine is the object Sgr B2, which is a bright radio feature right in the galactic midplane. The Sgr B2 object is a curious star-forming region since it is giving rise to some star formation, but the rate is much lower than it should be. In the MeerKAT data, several bright nebulae around high-mass stars pop out from the data, but the remainder of the cloud is devoid of significant star formation and shows the signature of synchrotron emission. While theories are starting to pick apart the reasons for the apparently low star formation, some scientists actually propose that the strange properties are an illusion, where two clouds are projected along the same line of sight, implying more extreme conditions than are actually taking place.

These are just a few of the details in the MeerKAT observations but full scientific understanding from this new treasure trove of data will be several years coming. The observations promise to improve as well: the SKA is under construction and will expand the MeerKAT telescope over the next decade. The mysteries of the Mouse, where the filaments connect back to, and what is happening with Sgr B2 will all become clearer with time. ✶

Read more at: https://arxiv.org/abs/2201.10541

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Imager's Corner

Two Nearly Identical Systems

by Blair MacDonald, Halifax Centre (b.macdonald@ns.sympatico.ca)

The idea for this edition's column came from a reader who was confused and frustrated by the answers they got to a simple question—what kind of astro-camera is better for RGB or colour imaging? I suspect this edition will earn me hate mail from at least one of the two camps, maybe both.

In this edition we will take a look at some of the theory surrounding this question, and courtesy of a fellow astroimager and RASC member, Jason Dain, we will look at an actual data set in addition to the theoretical discussion. Most times when you get into this discussion, it is very difficult to prove your argument as there are only a few cameras that come in one-shot colour (OSC) and monochrome versions. Both Jason and I have used a fantastic OSC camera made by ZWO, the ASI2600MC Pro and Jason is now the proud owner of a shiny new ASI2600MM Pro, a mono version of the OSC camera using the same sensor as the OSC version. This allowed Jason to capture side-by-side data on the same target, under similar conditions, using the same scope so we have an excellent data set to compare images from both cameras.

When you ask this question on groups such as Cloudy Nights you often get answers like—mono is better because it doesn't have missing pixels like the OSC Bayer matrix does, or the ever-favourite OSC is better because it is less work. Neither of these is correct, and neither is helpful to a novice trying to decide which camera to buy. There is really a whole discussion you need to have with someone that asks this question. At the top of the discussion points is what qualifies as better? Is it SNR (signal-to-noise ratio), is it time spent collecting data, is it ease of processing, is it resolution, the list of things needed to answer this simple question really depends on the interests and capabilities of the person asking it and on a good definition as to what qualifies as better. Jason and I discussed these questions for a while and concluded that resolution and SNR for the same data acquisition time would be a good way to rate the differences. Thinking a little more on the topic, we realized that resolution depends heavily on seeing and that our typical conditions would leave us seeing limited with both cameras. This left us with the SNR comparison, which is what we used for the purposes of this evaluation. In a previous edition of Imager's Corner, we explored signal-to-noise ratio and noise in general. If you remember, a 3 dB difference in SNR is about the minimum the human eye can perceive, so for the purposes of this experiment, if the SNR of two images varies by less than 3 dB we will claim they are effectively the same.

A little technical detail is required to get an understanding of what camera specifications are important to the discussion and dispel a couple of popular myths. The ASI2600MC version is a full OSC camera that uses the colour version of Sony's IMX571 APS-C format sensor with a RGGB Bayer mask for colour imaging. The ASI2600MM version of the camera is identical with two differences of note. First, this version of the camera uses the mono version of the IMX571 APS-C sensor. It is identical to the OSC sensor except it does not include a Bayer matrix. This means that we don't have to contend with trying to compare data from different sensors and do a lot of hand waving to explain why things vary from what was expected. The second difference between the two cameras is the type of optical window used to cover and protect the sensor. The OSC version uses a window that provides both a UV and IR cut-off suitable for full colour imaging using a refractor, while the mono version uses a simple clear window that has a broader passband than the OSC version. The optical transmission characteristics versus wavelength of both windows are shown below.

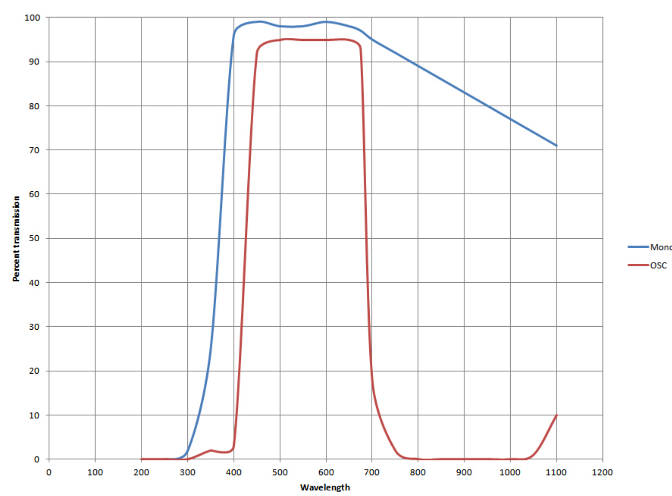


Figure 1 — Optical window transmission characteristics of both cameras. The ASI2600MC is shown in red while the ASI2600MM is in blue. In both cases the X axis is wavelength and the Y axis is the percentage of incident light transmitted by the window.

At wavelengths longer than 670 ηm, the mono version of the window has a significant transmission advantage. For informational purposes, the wavelength of Hα is 656 ηm and the SII emission line is located at 672 ηm. The passband transmission for both filters is similar, with the mono version passing 98 percent of the incident light, while the OSC version passes about 95 percent. At Hα wavelengths, the mono window passes about 98 percent of the incident light, while the OSC window passes about 94 percent. The situation tilts in favour of the mono unit at SII wavelengths with the mono window passing 97 percent, while the OSC window starts to roll off passing 80 percent. Although this seems like a large difference it only amounts to –1.7 dB, less than the 3 dB we would need to see to make a noticeable difference in SNR.

Next, let's take a look at camera quantum efficiency, the measure of how many incident photons are converted to electrons and detected by the sensor, but to do this we need to compare apples to apples. Many people simply look at the QE peaks for both cameras and attempt to draw conclusions. With manufacturer specifications for both cameras, we can see that the mono version peaks at greater than 90 percent and the OSC sensor peaks at greater than 80 percent. Since both cameras use the same back-illuminated sensor, it is a reasonable assumption that, other than sensor to sensor variations, the difference is due to losses occurring in the Bayer matrix filters. This makes the simple comparison of QE peaks misleading, since you will have to put red, green, blue, and probably luminance filters in the optical train of the mono camera to take a colour image. Now in the mono case these can be high-quality interference filters with very little loss, something that can't be easily done with the small micro-filters used in a Bayer matrix array. The filter response of the mono colour filters is shown below.

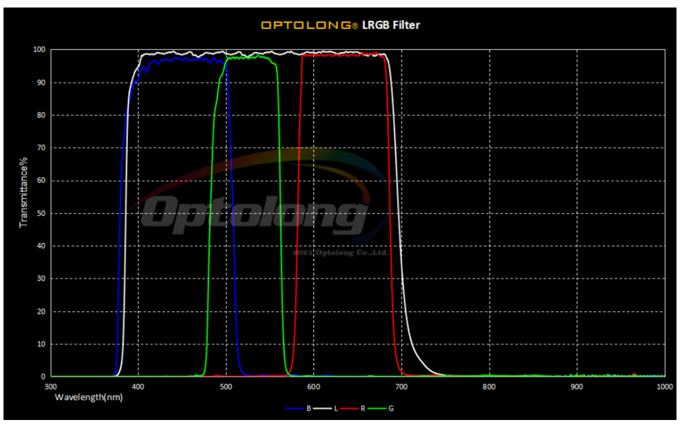


Figure 2 — Transmission characteristics of Optolong's LRGB filter set used in this experiment.

The transmission characteristics have to be combined with the QE plot of the mono sensor to compute overall quantum efficiency in order to compare it with the OSC camera.

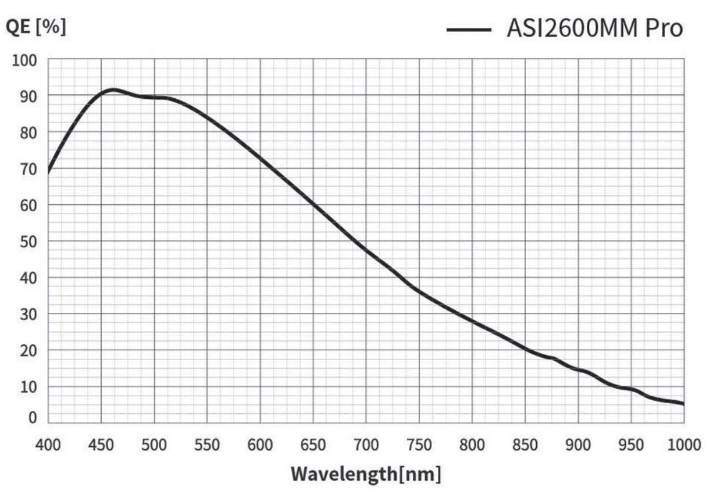


Figure 3 — Absolute quantum efficiency plot of the Sony IMX571 APS-C sensor.

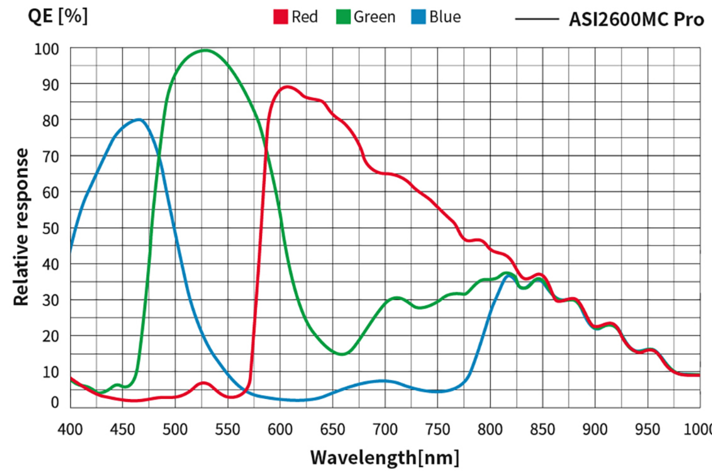


Figure 4 — Relative quantum efficiency plot for the colour version of Sony's IMX571 APS-C sensor.

To make matters even more confusing, manufacturers usually give relative quantum efficiency information for OSC sensors where the peak QE is scaled to 100 percent as shown below for the colour version of the same sensor.

In order to convert this to absolute quantum efficiency the plot must be multiplied by the absolute value for the peak (80 percent). Once we have the absolute quantum efficiency for both cameras, the OSC data needs to be scaled by the optical window response and the mono-camera data needs to be scaled by both the optical window response and the LRGB filter responses, giving the apples-to-apples comparison plot.

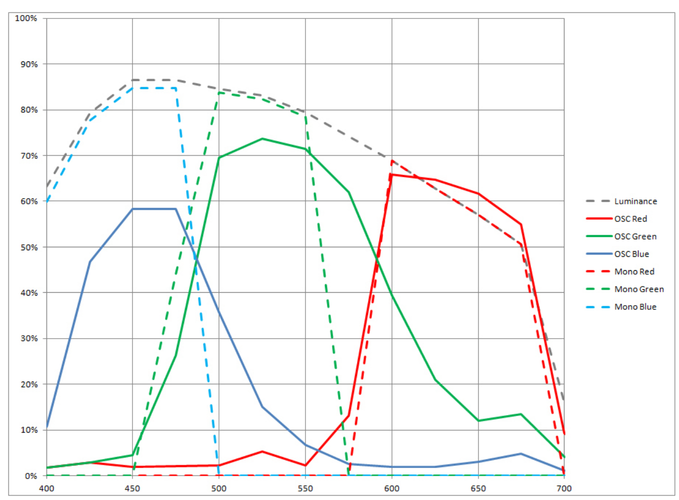


Figure 5 — Fully scaled QE plots including filter and optical-window effects for both the mono and OSC cameras.

As you can see there isn't much difference until you hit the blue end of the spectrum. Here the interference filters used with the mono camera are clearly superior with a 3.2 dB difference between the two systems in the band from 425 ηm to 475 ηm. For the rest of the visible band, both cameras are virtually the same with less than a 3 dB difference between them. There is certainly nothing in the specifications of these two systems, once the mono-filter transmission data is taken into account, to lead the reader to expect any better performance at Hα frequencies (where emission nebulae shine) from one camera over the other.

Eyepiece	**Red 650 ηm**	**Green 525 ηm**	**Blue 460 ηm**
Difference OSC relative to mono	0.7 dB	–0.9 dB	–3.3 dB

Table 1 — Difference in dB at the band centres (OSC relative mono)

Table 1 shows the difference in QE at the band centres in dB, calculated by $20*\log(QE_{OSC}/QE_{mono})$.

Finally, let's look at the effect on the image of those missing pixels due to the Bayer matrix. With the majority of the resolution of the OSC camera coming from the green channel, which has half the pixels, one would expect half the resolution of the mono camera when used with the same optical system. The question becomes what will seeing allow? Using my Esprit 120 and the ASI2600MC Pro, my calculated resolution is 0.92 arcseconds per pixel. Since the camera is an OSC device using a RGGB Bayer matrix, I'll get about half that resolution, so let's call it 1.84 arcseconds. This means that under ideal conditions, I should be able to resolve objects 1.84 arcseconds apart. Examine the image of Epsilon Lyrae taken with this setup.

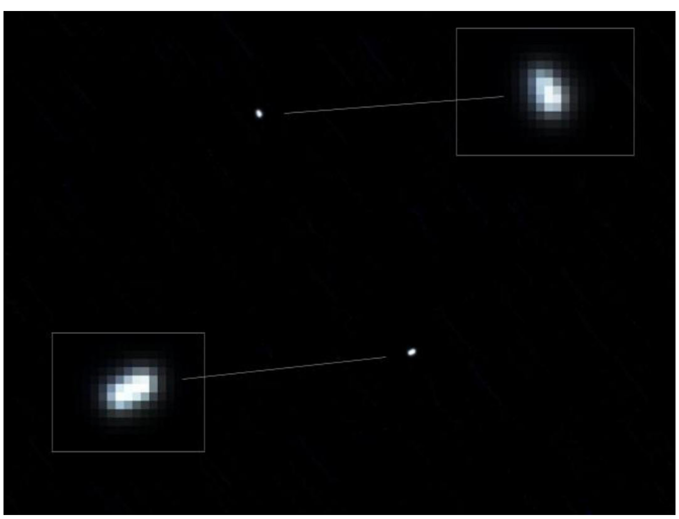


Figure 6 — Image of Epsilon Lyrae taken with a ZWO ASI2600MC Pro and an Esprit 120 APO refractor.

Now, I'm sure we can argue whether the individual stars are resolved, but I think we can agree that even at 2.3 arcseconds of separation, seeing is still limiting what can be achieved. This means that the resolution loss due to the Bayer matrix, under most observing conditions (at least here in the Maritimes), is swamped due to seeing. With seeing being the limiting factor, the mono camera will have about the same resolution as the OSC unit.

With the resolution question out of the way, the question becomes one of what the missing pixels do to the SNR. To answer this, we need a little background in sampling and interpolation. Consider a true image of an object, one that is band limited by seeing. The idea of band limiting means that the image is blurred such that the number of pixels we have can correctly sample a target with at least two pixels (preferably more) in any direction. This criterion means that we are, at least, critically or Nyquist sampled. Sampling with fewer pixels will produce alias artifacts that may or may not be noticeable. Now think of a mono sensor as an array of buckets collecting water during a rainstorm. If the rain is falling at a constant rate over the array of buckets, each one collects the same amount of water (lets use one litre for this analogy) over the course of the storm. Using the same analogy for an OSC sensor, for any one colour channel we would cover alternating buckets so they cannot collect any water. Now in any direction (X or Y), at the end of the storm, we would have a bucket with one litre followed by a bucket with no water followed by another bucket with one litre and so on. Interpolation is the method used to guess at how much water would have been in the covered buckets if they were left uncovered during the storm. In this case it is as simple as looking at each of the buckets surrounding the empty one and seeing that they have one litre in them.

It is a pretty safe bet that the empty bucket should have had one litre as well. Mathematically we could do this by linear interpolation. When the system has two dimensions, we use bilinear interpolation, which is a generalization of linear interpolation to two dimensions. Now let's think of what happens when the rate of rainfall is not constant over the array of buckets. In this case the covered bucket could have collected more or less water and we get an error from our interpolation. This is where the concept of band limiting comes into the equation. If we take a porous sheet and place it over the entire array of buckets and move it around randomly during the storm, it will act to average out the variations bucket to bucket, removing the rapid changes that occur over short distances during the storm and again our simple linear interpolation can give us a useable estimate of how much the covered buckets would have collected. This is what seeing does for our light collection; it blurs or averages out rapid pixel-to-pixel variations, and allows interpolation to produce an accurate estimate of the value for the missing pixels due to the Bayer matrix. There is a very slight error produced when the illumination changes direction from increasing brightness to decreasing brightness, and there are more complicated interpolation algorithms to handle this situation. There are whole rafts of algorithms, some locally adaptive and some not, that strive to produce a more accurate representation of the missing pixels, but either simple bilinear or bicubic interpolation does an excellent job, when the sampled signal is band limited. Seeing works so well, in most locations, to band limit that the error is reduced to where it can be ignored with virtually no impact on SNR. Generally speaking, an interpolator feeds the data through a low-pass filter (bilinear or bi-cubic) to fill in the missing data. This is an important point when seeing is the limiting factor; the interpolation process will improve SNR because of the effects of the interpolation filter and this may give the OSC devices a boost that helps to overcome the slight loss of sensitivity.

There are lots of mono to OSC camera comparisons available on a variety of websites, but many try to treat the OSC camera as if it were a mono system ignoring the requirement for interpolation. They usually do this by creating super pixels using binning and then compare the resultant number of pixels collected by this imaginary pixel to the result of binning the same number of pixels in a mono camera. This type of comparison doesn't work because it completely ignores the fact that if you have an evenly illuminated grey background, then the OSC pixels miss two thirds of the incident photons due to the Bayer filter removing those from two of the colour bands. If you find it necessary to compare an OSC sensor to the luminance of a mono camera you must create a luminance image from the interpolated colour channels for the result to be comparable. The requirement for interpolation is simply inherent in the way an OSC sensor was designed.

Well, enough of the theory, let's look at some real-world data to see what, if any, difference we can detect in the SNR of images taken with a mono and an OSC camera where all other aspects of the system are the same except for one sensor having a Bayer matrix. The data set Jason acquired over several nights consists of hours of exposure on M45 with both the OSC and mono versions of the camera using the same scope, an Esprit 100. In both cases, the sub-exposures were 180 seconds. Remembering our test criteria of best SNR for the same total exposure time, we started by analyzing a single calibrated frame from both cameras. Each frame was linearly stretched so as not to change the SNR by multiplying each pixel by a constant, so an area containing just background could be selected for measurement. The SNR was measured in a small 29-by-29-pixel window in several places around the image and the values presented here are the average of 8 readings. The signal is simply the average value of the pixels within the measurement window and the noise is the standard deviation. Table 2 and Table 3 summarize the results for both cameras.

The SNR of the OSC camera exceeded the mono camera by a statistically significant amount in the red and green channels, while the blue channel dropped below our 3 dB limit required to safely say there was any difference. These results are actually

Mono	Average	Deviation	SNR linear	SNR dB
R	3694	416	8.879808	18.96807
G	3205	366	8.756831	18.84694
B	4505	444	10.1464	20.12624

Table 2 - Single frame SNR data for the mono camera

OSC	Average	Deviation	SNR linear	SNR dB
R	4125	306	13.48039	22.59405
G	6951	462	15.04545	23.54811
B	4427	324	13.66358	22.71129

Table 3 - Single frame data for the OSC camera

expected as discussed in the text analyzing the camera and filter combinations at the start of this edition. The OSC image was debayered to produce the colour channels. As part of this process, interpolation is used to fill in the missing pixels and the interpolation filter (bicubic in this case) removed some of the higher spatial frequency noise producing a higher SNR value. The advantage in the blue channel is reduced by the higher system QE in the blue channel as shown in Figure 5 and the additional photons converted to electrons in the mono system just about cancel out the inherent advantage of the OSC interpolation. This trend continued for a stack of three images as well.

Mono	Average	Deviation	SNR linear	SNR dB
R	3680	186	19.78495	25.9267
G	3221	174	18.51149	25.34883
B	4507	205	21.98537	26.84267

Table 4 - Data from stack of three frames for each colour using the mono camera

Mono	Average	Deviation	SNR linear	SNR dB
R	4060	178	22.80899	27.16212
G	6804	228	29.84211	29.49659
B	4374	185	23.64324	27.47414

Table 5 — Data from stack of three frames for each colour using the OSC camera

Next, we looked at 1.5 hours of stacked data with very similar results, the OSC providing seeing-limited resolution with slightly better SNR.

The imaging time for the mono camera to achieve the same SNR as the OSC version, using simple RGB techniques is clearly longer, over three times longer in fact. The effect of the

Mono	Average	Deviation	SNR linear	SNR dB
R	9788	184	53.19565	34.51752
G	8175	164	49.84756	33.95288
B	11701	194	60.31443	35.60842
Lum	14408	130	110.8308	40.89321

Table 6 — 1.5 hours (30 subs @180 seconds per channel) of data from the mono camera

Mono	Average	Deviation	SNR linear	SNR dB
R	12086	187	64.63102	36.20882
G	19667	206	95.47087	39.59742
B	11561	176	65.6875	36.34965
Derived Lum	19609	182	107.7418	40.64768

Table 7 —1.5 hours (30 subs @180 seconds) of data from the OSC camera

Mono	Average	Deviation	SNR linear	SNR dB
R	4178	37	112.9189	41.05533
G	6808	42	162.0952	44.19541
B	3997	35	114.2	41.15332
Derived Lum	6808	42	162.0952	44.19541

Table 8 — 4.5 hours of OSC data

Mono	Average	Deviation	SNR linear	SNR dB
R	4505	41	109.878	40.81822
G	4350	38	114.4737	41.17411
B	4616	42	109.9048	40.82033
Lum	9228	84	109.8571	40.81657

Table 9 — 4.5 hours of LRGB data collected using the mono camera

interpolation filter improves the SNR enough in each OSC channel that the mono camera requires a longer exposure to approach the performance of the OSC device for any single channel. Of course, no one shoots simple RGB with a mono camera, usually the technique employed is LRGB imaging, where a longer luminance exposure is used for detail, and shorter colour frames are taken (possibly binned) to do a LRGB combine. We tested this method as well by restacking

Figure 7 — 4.5 hours of LRGB data taken with a mono camera

1.5 hours of the luminance data and an hour of each colour, comparing the result to 4.5 hours (the same total exposure time) of OSC data. Using this method, we finally achieved close to parity between the two cameras in all but the green channel, keeping in mind that the luminance channel for the OSC is derived from the three colour channels after the fact by my processing software.

From both the theoretical analysis and the measured data, we can see that the OSC camera actually has a slight advantage over an identical mono camera. There are a couple of caveats to this statement; first, the systems must be seeing limited, which negates the mono camera's inherent resolution advantage; second, the OSC camera image must be debayered to produce a full colour image before things are compared. Where the mono camera should really shine is in narrow-band imaging. Here the OSC camera suffers due to the losses from the colour filters employed in the Bayer matrix. For RGB imaging, the Bayer filters are matched by the colour filters required for the mono camera. But for narrow-band imaging, the Bayer filters represent a loss in addition to the narrow-band filters, while the mono unit only sees a loss from the narrow-band filters. Will this be enough to overcome the noise reduction inherent in interpolation? Maybe Jason and I will tackle this question in a future edition of this column

To give you an idea of the quality of Jason's data from both cameras, here are the processed mono and OSC images from 4.5-hour exposures. Jason processed the mono version while I processed the OSC data.

Most of the differences are due to processing styles with the OSC image showing more background dust and gas with smaller stars. The LRGB mono image is stretched a bit more, but as a result, it is slightly less detailed than the OSC version. The blue saturation is stronger in the mono version, no doubt due to the better blue response as shown in Figure 5.

I'd like to thank Jason for all his help with this edition. His high-quality data provided a great way to verify the theoretical analysis and shows just how far modern OSC CMOS cameras have come in their ability to capture clean, full-colour data.
To see more of Jason's fantastic images, as well as his terrific daytime wildlife photography, please take a few minutes and visit his Facebook page at www.facebook.com/profile.php?id=100010775255799.

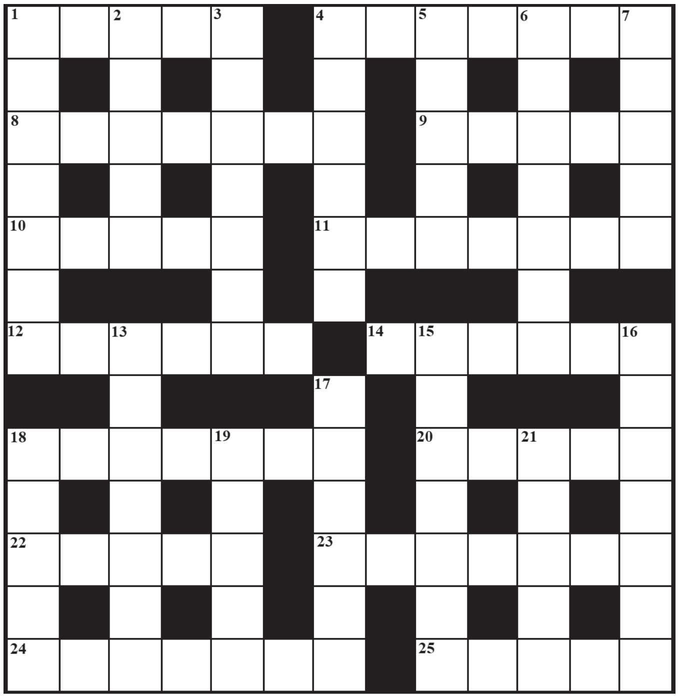
Remember, this column will be based on your questions so keep them coming. You can send them to me at b.macdonald@ns.sympatico.ca. Please put "IC" as the first two letters in the topic so my email filters will sort the questions. ✶

Blair MacDonald is an electrical technologist running a research group at an Atlantic Canadian company specializing in digital signal processing and electrical design. He's been an RASC member for 20 years, and has been interested in astrophotography and image processing for about 15 years.

Figure 8 — 4.5 hours of LRGB data taken with an OSC camera

Astrocryptic

by Curt Nason



ACROSS

1. German astronomer soundly came from France (5)
4. One nova recoils in a pulsating star initially, as in the peacock (7)
8. What met Schiller's Sagittarius? (7)
9. Schiller's Capricornus has much to say in a game (5)
10. Materials in a bolide always obey the gas law (5)
11. Chiron and Ophiuchus at work (7)
12. An elf turns about five in a solar wave (6)
14. A miss is amiss around east of Orion's head (6)
18. What NASA landers must be, or else space it (7)
20. Outreach activity on the horizon (5)
22. New space power on the table (5)
23. Telrad component for measuring in the southern sky (7)
24. Southern genius roils in the pit of Boötes (7)
25. Egyptian sun god's Earth crossers (5)

DOWN

1. Oddly, omega is not its designation in Canis Minor (7)
2. Volume of water used by a tiler, perhaps (5)
3. Hugged by the French woman, Guevara was grating on our nerves (7)
4. Supermassive black hole named around the first of winter, I hope (6)
5. She glows at the hearth and in the belt (5)
6. OT book of tasers (7)
7. Sun is up revealing iridium on the Moon (5)
13. She cleaned up in stellar classification (7)
15. Spread treacle in the bull's shoulder (7)
16. Disproven space media disturbed the ears (6)
17. Asteroid with hot wings (6)
18. Callisto's issue in polar cusp position (5)
19. Study about meteor remnant (5)
21. Frequent comet goes east at breakneck speed (5)

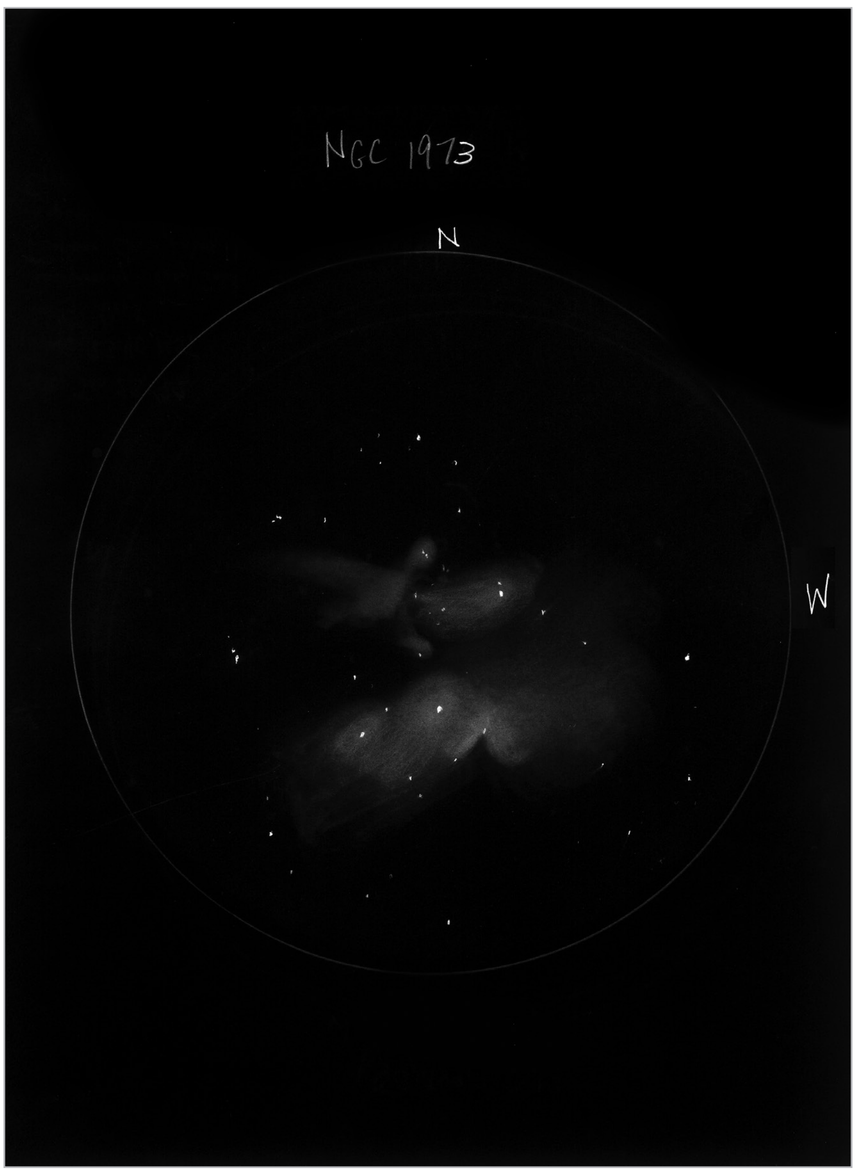
Answers to previous puzzle

Across: **1** ALGIEBA (anag); **5** STAUB (S(Tau)b); **8** ADLER (anag+r); **9** RESOLVE (2 def); **10** SETTING (2 def); **11** EARTH (anag); **12** PLANCK (hom); **14** ISHTAR (anag); **17** LYMAN (anag-e); **19** ALRAKIS (anag); **22** Red SPOT (anag); **23** PRIME (anag-e); **24** STARS (S(rev)S); **25** RUSSELL (hom)

Down: **1** ADAMS (anag); **2** GALATEA (gala+tea); **3** ERRAI (2 def); **4** AURIGA (Au+Riga); **5** SISTERS (2 def); **6** ALLER (hid rev); **7** BRECHER (hid); **12** POLARIS (polar+is); **13** CANOPUS (anag); **15** TEKTITE (Te(anag)Te); **16** CASTOR (anag); **18** MEDEA (anag); **20** RUPES (anag); **21** SHELL (2 def)

Great Images

by Eric Klaszus



"The Runner" was sketched 2022 January 23 at Chain Lakes Provincial Park, Alberta, using a 17.5-inch ƒ/5 'scope and a Tele Vue Panoptic 24-mm eyepiece (92× magnification). Temperature: –4 °C

Journal

Marc Richard took this amazing image of the Perseus molecular cloud. "The reflection nebula NGC 1333 at bottom left is an active region of star formation that is visible through backyard scopes from a dark sky. So are its dimmer neighbours Van den Bergh 12 top left and 13 top centre," he says. Marc integrated a total of 305 × 300 second LRGB exposures that he captured from his backyard in Sainte-Lucie-des-Laurentides, Québec, over nine clear, moonless nights in October and November 2021. He used a Takahashi FSQ 106 ED on a Takahashi NJP Temma-2 Mount, with a QSI 683WSG-8 camera. He used PixInsight, PHD2 Guiding, Astro Pixel Processor, and Sequence Generator Pro to process the image.