The Journal of The Royal Astronomical Society of Canada

Journal

Le Journal de la Société royale d'astronomie du Canada

PROMOTING
ASTRONOMY
IN CANADA

February/février 2021
Volume/volume 115
Number/numéro 1 [806]

Inside this issue:

Give a little bit of Heart and Soul

The Best of Monochrome.

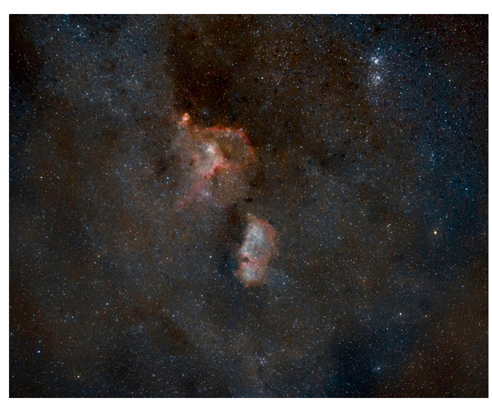
Drawings, images in black and white, or narrow-band photography.

Klaus Brasch rang in 2020 by taking this image of our constant companion, the Moon, with his AP-155 ƒ/7 refractor with a Canon 6D, combining an over-exposed Earthshine with properly exposed crescent, shooting in mono.

Journal
February / février 2021 | Vol. 115, No. 1 | Whole Number 806

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

contents / table des matières



Martin Gisborne captured what is a favourite of many astrophotographers: The Heart and Soul Nebulae. He shot the pair on 2020 November 8, from Maple Bay, Vancouver Island, B.C. He used a Nikon D850 and the Micro-Nikkor 105-mm ƒ/2.8 lens (at ƒ/5.6). The camera and lens were mounted on a Sky-Watcher Star Adventurer star tracker and a regular Manfrotto camera tripod. A total of 47 two-minute exposures were combined with dark, flat, and bias calibration frames. The image was processed in PixInsight with additional processing in Adobe Photoshop.

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.

The Journal of The Royal Astronomical Society of Canada is published at an annual subscription rate of $125 (plus Canadian tax), $140 USD for US subscriptions, $150 USD for International subscriptions. Membership, which includes the publications (for personal use), is open to anyone interested in astronomy. Applications for subscriptions to the *Journal* or membership in the RASC and information on how to acquire back issues of the *Journal* can be obtained from:

The Royal Astronomical Society of Canada
203 – 4920 Dundas St W
Toronto ON M9A 1B7, Canada

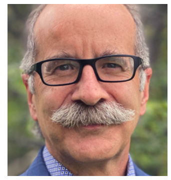
Email: nationaloffice@rasc.ca
Web site: www.rasc.ca
Telephone: 416-924-7973
Fax: 416-924-2911

Canadian Publications Mail Registration No. 09818
Canada Post: Send address changes to 203 – 4920 Dundas St W, Toronto ON M9A 1B7

Canada Post Publication Agreement No. 40069313

 ISSN 0035-872X

President's Corner



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

Our connected world is driving technology and business at a fast pace. As a veteran of 40 years in the industry, I help companies connect at higher speed and lower latency than ever before. We are building terrestrial networks today with 200 GB per wavelength. That's 19 TB per pair of fibre. With 10 GB fibre to the home and 5G promising 50 MB–1.8 GB over wireless, technology continues to provide high-speed internet to much of the world.

Of course, these terrestrial networks are not perfect, and they don't extend into low-density markets, hence the un-served and underserved marketplace. Today, we reach those users with smaller ISP's (Internet Service Providers) and satellite systems. The latest satellite internet in Canada is provided on the ViaSat-2, a geo-synchronous satellite in the Ka-band (25–40GHz) with 9 beams encompassing Canada and 63 beams covering the US. It offers up to 25 Mbps downloads but typically > 100ms–200ms.

What's new, and gaining a lot of attention, is the entrance into this space (pun intended) of SpaceX and likely others. SpaceX and its constellation of *Starlink* satellites, launching into low-Earth Orbit (LEO) promises to bring high-speed, low-latency internet to the entire planet. Everyone understands high-speed but latency may be a new term to many. Latency doesn't play a big role in internet surfing and similar tasks, but for voice over IP, video streaming, or gaming, latency is equally if not more important than speed. Early beta testers of the *Starlink* service are providing very positive feedback and they are expecting 50Mb–150Mb service and expected latency of 20ms–40ms; a game-changer for rural Canada. With monthly costs of $129.00 CAD and about $650.00 for the terminal, its cost is in line with other, mostly inferior services. While the promise of SpaceX and others sounds altruistic and of great benefit, don't lose sight that this is a business venture. Analysts predict $35B–$120B USD in revenues. If *Starlink* gets anywhere near this, others will certainly join in.

The technology is not without its challenges though. If we consider cellular networks, we have fixed cell towers that hand off our signals as we drive from the coverage of one cell to the next and we've all likely experienced the odd dropped call during hand-off. In the LEO constellation of satellites, the user is stationary and the cell site is moving, so every internet connection undergoes handoff as the cell zips by at 28,000 kph. Consider too that the volume of space needed to encompass the globe is huge. The approved number of *Starlink* satellites to garner this global footprint is 12,000 satellites. 12,000 satellites! Also, the bandwidth per satellite is limited and shared among users, so, as the number of users goes up, the actual bandwidth per user goes down. Signal degradation may decrease customer satisfaction too as *Starlink* is licenced in the 10–12 GHz band and is susceptible to rain fade.

For the astronomical community, *Starlink* has a lot of cons. For amateur astrophotographers, it's a nuisance at best. For professional astronomers, particularly those engaged in wide-field surveys and such, this introduces a challenge and an unwelcomed usurper into the field. For radio astronomers, this will have the greatest detrimental impact. Canada's Dominion Radio Astrophysical Observatory, like the Square Kilometre Array and others, resides in a radio-free zone. Even a simple cell phone in the vicinity of these purposefully sensitive instruments can compromise the data. With transmitting satellites in the important 5b band always in the sky, some research targets become unattainable.

There are more issues to consider too. The Kessler Syndrome defines the potential for catastrophic and cascading collisions from an overabundance of satellites. Think of the opening sequence of the movie *Gravity*! If *Starlink* is successful and others build their own networks, it's conceivable that there could be as many as 100,000 satellites in LEO. What risk does this pose to space exploration? Visits to the ISS, or to the Moon and Mars could become jeopardized by the possibility of collision. Launch windows become very narrow when the sky is full of dishwasher-sized objects travelling at 28,000 kph.

Another consideration is the potential detritus. It's nice to know that *Starlink* satellites have a life cycle and deorbit plan, but what are we bringing back into the atmosphere and our soil and lakes and streams? We all try to recycle our electronics in a conscious effort to protect the environment but that is impossible with a deorbiting piece of space junk. And what happens if the parent company of one of these constellations goes out of business? Who is left with the remains? In a CBC interview, I likened this to the dilemma we face with plastic bottles today; where we have a solution for one problem, that's created an even bigger problem for the planet.

There is some good arising out of this exercise though. What we are witnessing is a business venture tapping into an unregulated asset where they are addressing only their needs. The Silicon Valley approach to business, hitting it hard and fast, woke us all up to the reality that our orbital space is in need of global governance. Everyone with an interest in that orbital space, and everyone impacted by what goes up there, needs to have their voices heard. In that same interview with CBC, I pointed out that we all have a sense of pride in SpaceX's execution of these launches, where the launch is flawless, and the recovery of the booster is spectacular. What would our perspective be if this was China or Russia or North Korea launching the first such constellation of satellites?

Some great thought exercises for everyone to ponder. ✶

News Notes / En manchette

Compiled by Jay Anderson

Dusty atmosphere taxes Mars's water

The barren hillsides of Mars testify to a very dry and inhospitable climate, as it has an atmospheric water-vapour content that is 600 to 3000 times lower than the Earth's. Nevertheless, the presence of ice clouds in the upper atmosphere, sunrise fog banks, and morning frost deposits demonstrate that the atmosphere can reach saturation at the cold temperatures characteristic of the planet. Like the Earth, humidity varies with location. *In situ* measurements from the Mars Science Laboratory show surface relative humidities in Gale Crater that ranged from a few percent in the afternoon to 60 percent overnight.

In spite of these humidity values, one of the primary questions about the Red Planet is how it lost the vast bulk of its primordial water, which must have been present eons ago in order to create the fluvial landforms that demonstrate the large-scale presence of liquid water. One solution to the dilemma seems to lie in measurements from orbiting spacecraft that have shown water vapour at the top of the planet's atmosphere where it is exposed to the solar wind.

Past results from NASA's MAVEN (Mars Atmosphere and Volatile Evolution) have demonstrated that without a global magnetic field surrounding Mars, currents induced by the solar wind can form a direct electrical connection to the planet's upper atmosphere. The currents transform the energy of the solar wind into magnetic and electric fields that accelerate charged atmospheric particles, providing a mechanism that drives much of the atmospheric escape to space. Over billions of years, this process was blamed for a considerable loss of water vapour and the transformation of Mars from a warm and wet planet into a global cold desert.

Modelling the loss of water vapour over the eons is an exercise that is bedevilled with uncertainties: how dense was the atmosphere in the past; how active was the Sun; how much water was present at the start; how representative are MAVEN observations?

In the latest results from MAVEN, researchers say that they have uncovered the details of one of several mechanisms that has led Mars to lose a global ocean of water up to hundreds of metres deep over billions of years. Even today, Mars continues to lose water as vapour is transported to high altitudes after sublimating from the frozen polar caps during warmer seasons.

"We were all surprised to find water so high in the atmosphere," said Shane W. Stone, a doctoral student in planetary science at the University of Arizona's Lunar and Planetary Laboratory in Tucson. "The measurements we used could have only come from MAVEN as it soars through the atmosphere of Mars, high above the planet's surface." Stone

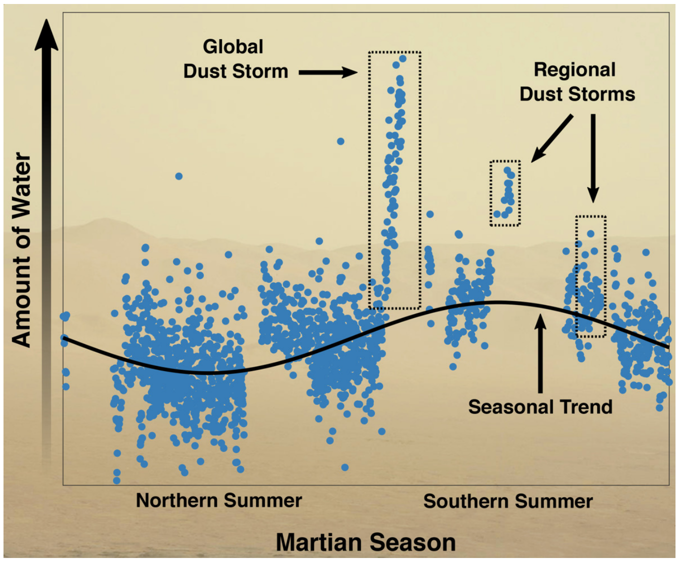


Figure 1 – This graph shows how the amount of water in the atmosphere of Mars varies depending on the season. During global and regional dust storms, which happen during southern spring and summer, the amount of water spikes. Image: University of Arizona/Shane Stone/NASA Goddard/Dan Gallagher

and his colleagues relied on data from MAVEN's Neutral Gas and Ion Mass Spectrometer (NGIMS), which inhales air and separates the ions that comprise it by their mass, allowing scientists to identify them.

Stone and his team tracked the abundance of water ions high over Mars for more than two Martian years. In doing so, they determined that the amount of water vapour near the top of the atmosphere at about 150 kilometres above the surface is highest during summer in the southern hemisphere when the planet is closest to the Sun, and thus warmer.

The warm temperatures of the southern summer bring dust storms and strong winds lofting water vapour into the uppermost parts of the atmosphere, where it can easily be broken into its constituent oxygen and hydrogen. The hydrogen and oxygen then escape to space. Previously, scientists had thought that water vapour was confined in the lower part of the atmosphere as it is on Earth, and only small amounts could rise to the edges of space. The research team measured 20 times more water than usual over two days in June 2018, when a severe global dust storm enveloped Mars. With the new measurements and modelling, Stone and his colleagues estimated Mars lost as much water in 45 days during the 2018 storm as it typically does throughout an entire Martian year (which lasts two Earth years). There are abundant ions in the upper atmosphere that can break apart water molecules 10 times faster than they're destroyed at lower levels.

"Everything that makes it up to the higher part of the atmosphere is destroyed, on Mars or on Earth," Stone said, "because this is the part of the atmosphere that is exposed to the full force of the Sun."

"We have shown that dust storms interrupt the water cycle on Mars and push water molecules higher in the atmosphere, where chemical reactions can release their hydrogen atoms, which are then lost to space," said Paul Mahaffy, director of the Solar System Exploration Division at NASA Goddard and principal investigator of NGIMS.

"What's unique about this discovery is that it provides us with a new pathway that we didn't think existed for water to escape the Martian environment," said Mehdi Benna, a Goddard planetary scientist and co-investigator of MAVEN's NGIMS instrument. "It will fundamentally change our estimates of how fast water is escaping today and how fast it escaped in the past."

Compiled with material provided by NASA.

See you on Mars...

The pandemic (and some lousy weather) has been keeping us all close to home, so perhaps it's time to do a little planetary exploration. This pandemic-eating educational game comes from Auroch Digital, the UK Space Agency, and the European Space Agency.

You're controlling your very own space agency at the dawn of the space age, with the ultimate goal of setting foot on the surface of Mars. Which technologies should you research? Which rockets should you build? Should you aim for the Moon first or head straight to the Red Planet?

That's the premise of *Mars Horizon*, a new strategy game from the UK company Auroch Digital, created with help from ESA, and designed to show the gaming community all the aspects behind the development of those technologies necessary for human exploration of Mars.

In *Mars Horizon*, players manage scientific focus, public support and, of course, funds, as they endeavour to complete missions and send their astronauts into space. Agency directors also contend with other major space agencies with the same goals, choosing to work together or venture out on their own. There is a lot of attention to detail—you can't just bolt together a tube, load it up, and fire it off.

Figure 2 – A screen capture from Mars Horizon.

During missions, players face tense turn-based gameplay that determines their success or failure. Every single decision is critical, will you spend time fixing a malfunctioning antenna or conserve power in case of a fuel leak? Perhaps risking an extra three months in mission planning could prevent disaster?

Mars Horizon was developed with the cooperation of ESA, where staff, including team members from the *ExoMars* mission, were consulted on the actual process of planning and executing a mission to Mars. Together with the UK Space Agency, ESA provided technical assistance, gameplay advice, and testing.

ESA also hosted the development team at the ESOC and ESTEC facilities in Germany and the Netherlands for firsthand experience of how space programs are managed. ESA's ongoing and global contribution in advancing the exploration of space, for all humankind, is reflected in the passion, excitement, and attention to detail of the game.

Mars Horizon was launched worldwide in November, available for PC, Xbox One, PlayStation4 and Nintendo Switch, and is accompanied by a physical card game of the same name. The company aims to provide educational versions to schools in order to demonstrate the cooperative strategy needed to put large complex projects together.

You will find the game at https://theirregularcorporation.com. The price is $22.79.

Earth hits the accelerator

Earth just got 7 km/s faster and about 2000 light-years closer to the supermassive black hole in the centre of the Milky Way Galaxy. This doesn't mean that our planet is plunging towards the black hole. Instead, the changes are results of a better model of the Milky Way Galaxy based on new observation data, including a catalogue of objects observed over the course of more than 15 years by the Japanese radio astronomy project VERA.

VERA (VLBI Exploration of Radio Astrometry, where "VLBI" stands for Very Long Baseline Interferometry) started in 2000 to map three-dimensional velocity and spatial structures in the Milky Way. VERA uses a technique known as interferometry to combine data from four 20-m radio telescopes scattered across the Japanese archipelago in order to achieve the same resolution as a 2,300-km-diameter telescope would have. Measurement accuracy achieved with this resolution, 10 micro-arcseconds, is sharp enough in theory to resolve a United States penny placed on the surface of the Moon.

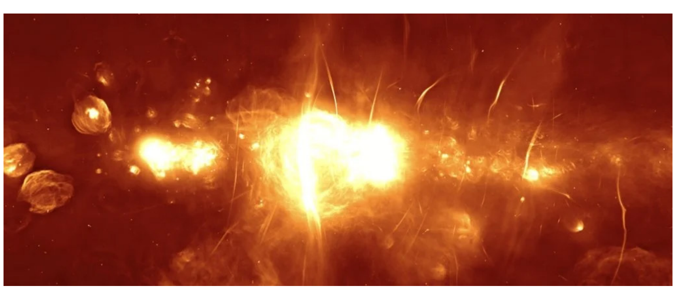


Figure 3 – The galactic centre in radio wavelengths. Source: South African Radio Astronomy Observatory (MeerKAT))

VERA telescopes use a dual beam, with one beam observing a target and the other an extra-galactic reference object, allowing a very precise determination of the target's location. The telescopes are sensitive enough to measure the location and motion of masers all across the galaxy, an important advantage as astrometry is a vital tool to understand the overall structure of the galaxy and our place in it. For this study, the VERA radio telescopes observed 99 maser sources, 21 of which were new, to calculate an average orbital solution for motion around the Milky Way centre.

Based on the VERA observations and those by other groups, astronomers constructed a position and velocity map, from which they calculated the distance of the centre of the galaxy, the point around which everything revolves. The map suggests that the centre, and the supermassive four-million-solar-mass black hole that resides there, is located 25,800 light-years from Earth. This is closer than the official value of 27,700 light-years adopted by the International Astronomical Union in 1985. The velocity component of the map indicates that Earth is travelling at 227 km/s as it orbits around the galactic centre, faster than the official value of 220 km/s.

Now VERA hopes to observe more objects, particularly ones close to the central supermassive black hole, to better characterize the structure and motion of the galaxy. As part of these efforts, VERA will participate in EAVN (East Asian VLBI Network) comprised of radio telescopes located in Japan, South Korea, and China. By increasing the number of telescopes and the maximum separation between telescopes, EAVN can achieve even higher accuracy.

Composed in part using material provided by the National Astronomical Observatory of Japan

A marriage made in the stars: the Blue Ring Nebula

In 2004, scientists with NASA's space-based *Galaxy Evolution Explorer* (GALEX) spotted a large, faint blob of gas with a star at its centre. Because GALEX captured the blob in far ultraviolet (UV) light, it appeared blue in the images (Figure 4); subsequent observations also revealed a thick ring structure within it. The team nicknamed it the Blue Ring Nebula and over the next 16 years, studied it with multiple Earth- and space-based telescopes, including the W.M. Keck Observatory on Maunakea in Hawaii. The more they learned, the more mysterious it seemed.

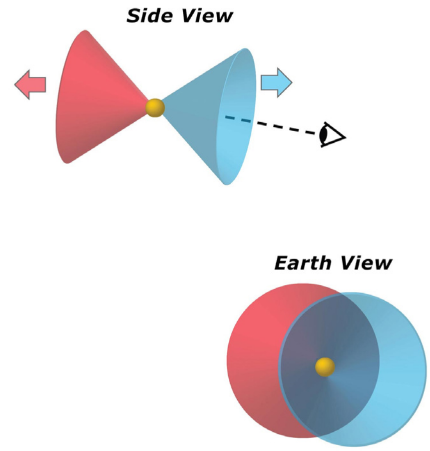


Figure 4 – the Blue Ring Nebula consists of two expanding cones of gas ejected into space by a stellar merger. As the gas cools, it forms hydrogen molecules that are excited by collisions with particles in space, causing it to radiate in far UV light.

Figure 5 – The Blue Ring Nebula consists of two hollow, cone-shaped clouds of debris moving in opposite directions away from the central star. The base of one cone is travelling almost directly toward Earth. As a result, astronomers looking at the nebula see two circles that partially overlap. Image: Mark Seibert

A new study may have cracked the case. By applying cutting-edge theoretical models to the slew of data that has been collected on this object, the authors posit the nebula is likely composed of debris from two stars that collided and merged into a single star.

While merged star systems are thought to be fairly common, they are nearly impossible to study immediately after they form because they're obscured by debris kicked up by the collision. Once the debris has cleared—at least hundreds of thousands of years later—they're challenging to identify because they resemble non-merged stars. The Blue Ring Nebula appears to be the missing link: astronomers are seeing the star system only a few thousand years after the merger, when evidence of the union is still plentiful.

The object's size was similar to that of a supernova remnant, which forms when a massive star runs out of fuel and explodes, or a planetary nebula, the puffed-up remains of a star the size of our Sun. But the Blue Ring Nebula has a living star at its centre. Furthermore, supernova remnants and planetary nebulae radiate in multiple light wavelengths outside the UV range, whereas the Blue Ring Nebula did not.

In 2006, using the 5.1-metre Hale telescope at the Palomar Observatory and then the 10-metre Keck Observatory telescopes in Hawaii, they found evidence of a shockwave in the nebula, suggesting the gas composing the Blue Ring Nebula had indeed been expelled by some kind of violent event around the central star.

"Keck's LRIS spectra of the shock front was invaluable for nailing down how the Blue Ring Nebula came to be," said Keri Hoadley, an astrophysicist at Caltech and lead author of the study." Its velocity was moving too fast for a typical planetary nebula yet too slow to be a supernova. This unusual, in-between speed gave us a strong clue that something else must have happened to create the nebula."

Data from Keck Observatory's HIRES spectrometer also suggested the central star was pulling a large amount of material onto its surface. But where was the material coming from?

To gather more data, in 2012, the GALEX team used NASA's *Wide-field Infrared Survey Explorer* (WISE), a space telescope that studied the sky in infrared light, and identified a disk of dust orbiting closely around the star. Archival data from three other infrared observatories also spotted the disk. The finding didn't rule out the possibility that a planet was also orbiting the star, but eventually the team was able to show that the disk and the material expelled into space came from something larger than even a giant planet. In 2017, the Hobby-Eberly Telescope in Texas confirmed there was no compact object orbiting the star.

More than a decade after discovering the Blue Ring Nebula, the team had gathered data on the system from four space telescopes, four ground-based telescopes, historical observations of the star going back to 1895 (in order to look for changes in its brightness over time), and the help of citizen scientists through the American Association of Variable Star Observers (AAVSO). But an explanation for what had created the nebula still eluded them.

Hoadley was fascinated by the thus-far unexplainable object and its bizarre features, so she accepted the challenge of trying to solve the mystery. It seemed likely that the solution would not come from more observations of the system, but from cutting-edge theories that could make sense of the existing data. So Chris Martin, principal investigator for GALEX at Caltech, reached out to Brian Metzger of Columbia University for help.

As a theoretical astrophysicist, Metzger specializes in cosmic mergers—collisions between a variety of objects, whether they be planets and stars or two black holes.

The team concluded the nebula was the product of a relatively fresh stellar merger that likely occurred between a star similar to our Sun and another only about one tenth that size, about 100 times the mass of Jupiter. Nearing the end of its life, the Sun-like star began to swell, creeping closer to its companion. Eventually, the smaller star fell into a downward spiral toward its larger companion. Along the way, the larger star tore the smaller star apart, wrapping itself in a ring of debris before swallowing the smaller star entirely.

The merger launched a cloud of hot debris into space that was sliced in two by the debris ring. This created two cone-shaped clouds, their bases moving away from the star in opposite directions and getting wider as they travel outward. The base of one cone is coming almost directly toward Earth and the other almost directly away (Figure 5). They are too faint to see alone, but the area where the cones overlap (as seen from Earth) forms the central blue ring GALEX observed.

Millennia passed, and the expanding debris cloud cooled and formed molecules and dust, including hydrogen molecules that collided with the interstellar medium, the sparse collection of atoms and energetic particles that fill the space between stars. The collisions excited the hydrogen molecules, causing them to radiate in a specific wavelength of far-UV light. Over time, the glow became just bright enough for GALEX to see.

Editorial

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

Fellow RASC Members, please join me, your Board of Directors, and the entire Society, in congratulating two of our Members for receiving one of Canada's highest civilian honours.

Dr. P.J.E. "Jim" Peebles and Dr. Sara Seager were appointed to the Order of Canada on November 27. Note that the Order of Canada has three categories, Companion, Officer, and Member.

Dr. Peebles, an Honorary Member of the RASC, was appointed as a Companion of the Order of Canada, for his pioneering discoveries regarding the evolution of the cosmos. I'm particularly fond of his perseverance in the face of pursuing what was considered to be a scientific dead-end in the 1960s. His 2004 Shaw Prize in Astronomy citation states "He laid the foundations for almost all modern investigations in cosmology, both theoretical and observational, transforming a highly speculative field into a precision science." His more than 50 years of contributions to our understanding of the Universe were recognized with his receipt of the 2019 Nobel Prize in Physics "for contributions to our understanding of the evolution of the universe and Earth's place in the cosmos." It's notable that even Canadian elementary students know about the Big Bang and have some perception about our Universe and Dr. Peebles's work, which underlies much of that understanding, and touches all of us in some way.

Dr. Sara Seager, both an Honorary Member and an active Member of the Toronto Centre (thank you, Charles), was appointed as an Officer of the Order of Canada, for her multidisciplinary research that has contributed to transforming the study of extrasolar planets into a full-fledged planetary science. Dr. Seager caught the bug as a child at an RASC star party with her father, then joined the Society as a teenager. I first met Dr. Seager at the Thunder Bay General Assembly, where she was the Keynote Speaker and where she officially became an Honorary Member. Something of greater significance occurred at that GA and I'll point you to the Guest Editorial of your 2015 *Observers Handbook* for her personal account of that and her relationship with the RASC. Dr. Seager received her B.Sc. from the University of Toronto and her Ph.D. from Harvard University. In addition to numerous Academic Awards and Distinctions, the media too has recognized her four times, popularizing astronomy and physics in a unique manner. *Popular Science* named her 5th in their annual Brilliant 10 (2006), *Discover Magazine* placed her with the Best 20 under 40 (2008), *Nature* placed her in the Top Ten (2011), and *Time Magazine* considered her as one of the 25 Most Influential in Space (2012). Perseverance played a role in Dr. Seager's path, too. While many scientists were skeptical of the newly discovered exoplanets and some even thought that claims made in her thesis would never be substantiated, exoplanets kept turning up and her early work was eventually validated. With a focus on theoretical models of atmospheres and interiors of all kinds of exoplanets and introducing new ideas to the field of exoplanet classification, her work has led to the first detection of an exoplanet atmosphere. Currently a Professor at MIT, she was awarded a MacArthur Fellowship in 2013 (AKA the Genius Grant) and she was elected to the National Academy of Sciences in 2015, a significant honour for scholars based on "distinguished and continuing achievements in original research" throughout their careers.

It is encouraging to see our country recognize the hard work and the journey into uncharted territory that Dr. Peebles and Dr. Seager undertook to the benefit of us all. ✷

Feature Articles / Articles de fond

The Biological Basis for the Canadian Guideline for Outdoor Lighting 4—Impact of the Spectrum of Lighting

by Robert Dick, M.Eng., P.Eng., FRASC, Ottawa Centre
(rdick@robertdick.ca)

Abstract

We refer to light by its colour, but colour is a construct created in our brain. Biology is sensitive to the spectrum of the light–the energy it carries, which is a function of its wavelength. So the impact of light is best studied with its spectrum. The first paper of this series on scotobiology (Dick 2020a) introduced the importance of spectrum on the way we interpret the world. The diurnal change in the incident light spectrum complicates our assessment of the impact of artificial light. This paper presents how some wildlife react to the spectra of light, and the spectral characteristics of artificial light that undermine the ecological balance, and human vision.

Introduction

Our current knowledge of the environmental sensitivity to the colour of artificial light at night (ALAN) is at best spotty. Too few animals have been studied to clearly understand all its consequences. However, by assuming the environment is in an initial state of balance, then any change to specific animals in the environment will change that balance. Therefore, we need not wait for a complete data set before we can assess, at least in general terms, the sensitivity of the environment to ALAN. Light thresholds may have to be revised if we find more sensitive animals, but over the past 12 years of study this general approach has not required our lighting limits to change.

There are three ways that light "colours" the landscape. First, there is the colour of the incident light. Second, there is the inherent colour of the surface—or its spectral reflectivity. And third, the spectral sensitivity of our biology and our vision. The combination of these affects how we see the landscape, and its effect on our biology.

Photographers are well aware of how the hue of ambient light changes from dawn to dusk —affected by the clarity of the air, its moisture content, and the elevation of the Sun in the sky. In the morning, the Sun's direct illumination looks "yellow." This is neutralized to "white" around midday (Mie scattering when suspended particles are larger than the wavelength of light and results in forward scattering of light). Later in the afternoon, with increasing humidity, sunlight becomes more "orange" as smaller particles scatter the shorter wavelength blue light over the sky (Rayleigh scattering when particles are smaller than the wavelength of light and is omni-directional), giving it a more saturated shade of blue (Mainster and Turner 2014). At sunset, without the Sun's yellow disk, the dominant colours are red from the lingering glow on the horizon and the blue of the sky. The red illumination dims as the sunset continues to fade, leaving the landscape bathed in blue light, which over time appears to de-saturate as our photopic colour vision grows blind and our more blue sensitive scotopic vision takes over (Raymond 2011).

The evolving hues of the ambient light are not just aesthetically interesting; they provide a survival advantage for some animals. These changes are most evident during the fading twilight. This is the time when the diurnal animals give way to the nocturnal wildlife—changing the competitive players and the ecological balance.

Surfaces change their spectral reflectivity in response to exposure, weathering, or aging. Small fish can change from transparent to opaque as they mature. Most studies have been on relatively small aquatic life forms, but other animals change colour with maturity or for camouflage in response to stress

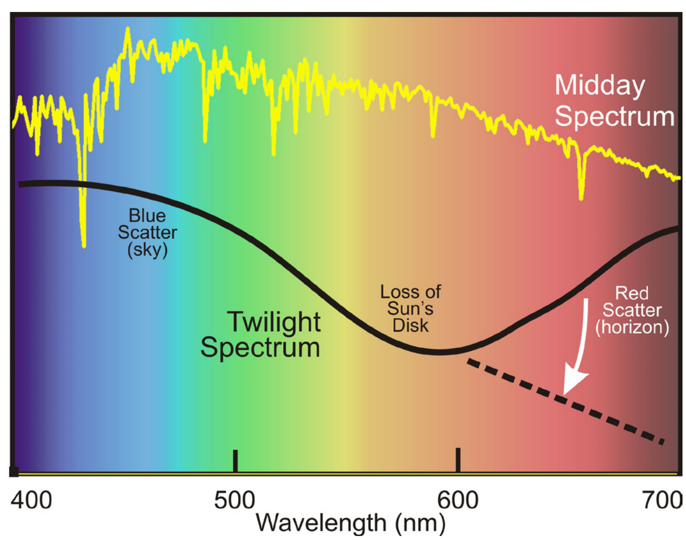


Figure 1 — Evolving spectrum of the day and twilight sky. On clear days, the ambient colour changes from morning to night. This provides visual cues to wildlife as to the period of the day and the approach of night.

Our brain continually "white balances" our vision so this change is not evident to most people. However, when taking pictures, photographers must compensate for this change with coloured filters, image settings in digital cameras, or image processing programs. (Ref: Solar Spectrum – ASTM G173-03, Twilight Spectrum Lee, 2011)

(Duarte 2017). Our skin darkens over a few days in sunlight to protect us from excessive Sun exposure and for most of us, our hair grows grey with age.

Plants

Plants get their energy from the Sun, in particular from the blue and red light. The threshold for photosynthesis for most plants is only about 1000 lux. Some indoor plants die in draped rooms but receive sufficient light in offices. This illumination level is far greater than typical outdoor ALAN, so it may not contribute to energy harvesting, but it is detected nevertheless and affects plant development during the night.

At night, plants concentrate on development that complements that during the day. ALAN, with the characteristic daylight spectrum, provides a cue to daytime development processes at the expense of the nocturnal growth patterns. Though not detrimental to all plants, ALAN will provide undue advantage to some species, unbalancing the natural ecology and possibly encouraging invasive species at the cost of indigenous varieties.

Experiments dating back to the 1920s have shown that the growth pattern of some plants changes from a lengthening of the stock during the day (vegetative growth) to producing leaves at night (flowering) (Tincker 1924, Withrow and Benedict 1936). In the paper by Tincker, a clover plant grew short and bushy with more typical dark periods (night) but grew tall and spindly when exposed to artificially long periods of light (extended day).

The reason, in part, is the spectrum of the light. Plants chemically record the passage of time after the fading of twilight with the decay in darkness of light-transformed molecules. In the longer term, the length of time these molecules decay signals the plant to respond to the changing length of night that occurs with the seasons. This primarily occurs in the temperate latitudes where there are significant differences in the length of night in spring/autumn to that in summer.

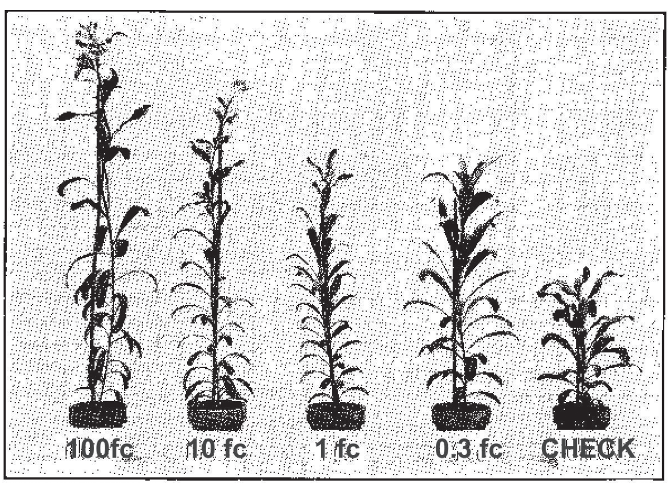


Figure 2 — The perceived length of night changes the growth pattern of some plants. Some plants may benefit from extended daylight. However, the growth of "Short Day Plants" may stimulate vegetative growth instead of flowering, leading to tall spindly stocks. (Withrow and Benedict 1936).

A shortening night indicates spring, and a lengthening night occurs in summer and autumn. Detecting this difference, allows plants to flower at the appropriate time—synchronized with pollinating insects, and birds that will pick and carry off the fruit and seeds. Plants later prepare for winter by withdrawing the nutrients from leaves, which results in the autumn colours and dropping of leaves.

More specifically, this growth cycle is caused by the accumulation and atrophy of red- and far-red absorbing chemicals (phytochrome-R and phytochrome-FR) (Smith 1978). The P_R (phytochrome-R) has an action spectrum between 650–670 nm, and that for P_{FR} (phytochrome-FR) is somewhat longer (705–740 nm) (Bennie 2016). P_R transforms to P_{FR} in sunlight, which is rich in red light. The P_{FR} reverts back to P_R during the night. This reversion of the P_{FR} enables different types of growth. The critical characteristic is not the length of day, but the length of night (Hillman 1973). Indeed, exposure after dark of only a few minutes of light can convert the P_R back into P_{FR}, causing the plant to interpret the light-break as two short nights (spring or summer instead of autumn) and will alter the plant's growth and subsequent survival.

The chlorophyll molecules that help harvest solar energy are sensitive to both blue and red light (Larkum and Kuhl 2005). In addition to these, there is another set of blue sensitive molecules (cryptochromes) that are responsible for

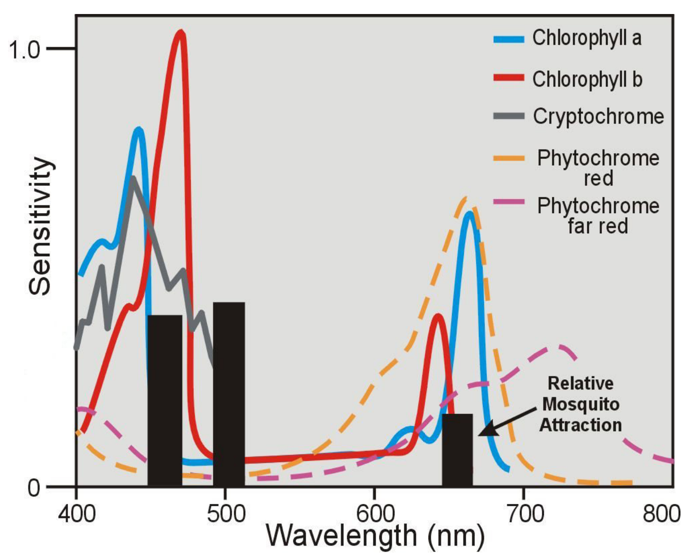


Figure 3 — Action spectra for plants and insects. These plots show the relative sensitivity of plants to the blue and red/IR spectrum for three general types of molecules. Since many plants have less use for green light, it is reflected from the surface giving plants their green colour.

Mosquitoes are also sensitive primarily to blue spectra. The amber colour of commercial bug lights falls between their peak sensitivities.

stem elongation. As twilight fades, the blue light of the day and twilight sky falls below their threshold—it pauses the nocturnal growth of the plant's stock and allows the stored energy to be used for the development of leaves.

The cyclic balance between the phytochrome-R and phytochrome-FR, and cryptochrome raises concern over the impact of the evolving colour characteristics of ALAN. Recent changes from amber high-pressure sodium to white LED lamps alter the phytochrome balance, and the bright emission of blue light bathes the plants in perpetual twilight. The blue light components enable the stock to grow through the night—leading to tall but spindly plants. Taken to the extreme, this would prevent the survival of short-day plants in urban areas, and the birds and insects that depend on them.

Aquatic Life

Light in the water column was discussed in the second paper in this series (Dick 2020b) but there is a spectral component as well. Water transparency studies use a Secchi disk (Wikipedia), a disk with white and black sectors that is viewed at increasing depths to determine the water's transparency. However, it does not provide spectral data.

Figure 4 — Enhanced Plant Growth under White Shoreline Lighting. The consequences of white ALAN tends to be overlooked until it leads to disruption of the water quality and vitality of aquatic life. Excessive plant growth is followed by plant death and decay, which releases toxins into the water. These affect the water quality and produce a rotting smell that affects the enjoyment of waterfront property and recreational fishing.

Increasing the amount of light at night, above natural levels, alters the brightness and spectrum of light deeper in the water column. Whether this is desirable or not depends on the context. Fishing lights increase the harvest of fish, but it stresses the habitat.

As the light penetrates the water column, longer wavelengths are absorbed by suspended particles more than the blue light components. This effect is subtle for inland waterways and can be overwhelmed by the opacity of turbid water but becomes more important in clearer lakes and coastal waters, which are favoured for vacation homes.

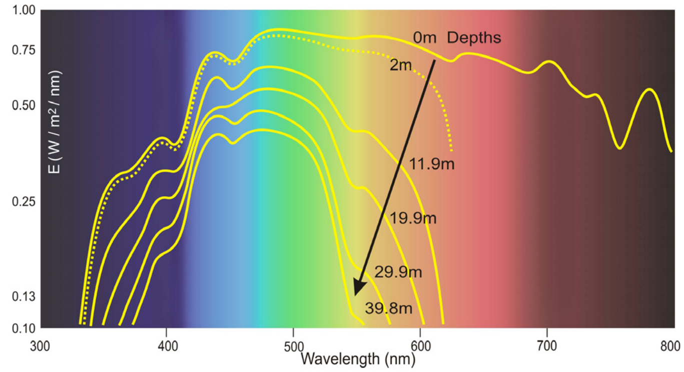


Figure 5 — Marine water transparency as a function of wavelength and depth. Clean water becomes progressively opaque at longer wavelengths. Blue light penetrates deeper. Therefore, longer wavelengths >500 nm will have less of an impact at depth (from Morel 2007).

The natural attenuation of long-wavelength illumination with water depth narrows the spectral range of illumination toward the blue. The wavelength of peak rod sensitivity for fish (roughly 520 nm) lengthens with natural turbidity and shortens with habitat depth (Schweikert 2018). Thus, rods cells of deeper fish can take advantage of the shorter-wavelength blue light that can penetrate to those depths.

Short-wavelength ALAN has three affects. It will increase the visibility of small fish—increasing the predatory success for larger fish. The semi-transparent zooplankton are made more visible to predators by the light they scatter. And it can extend the visible range to enable fish to forage or hunt for food at greater depths. This will affect the ecological balance in the deeper and cooler waters, which are more sensitive to over-grazing.

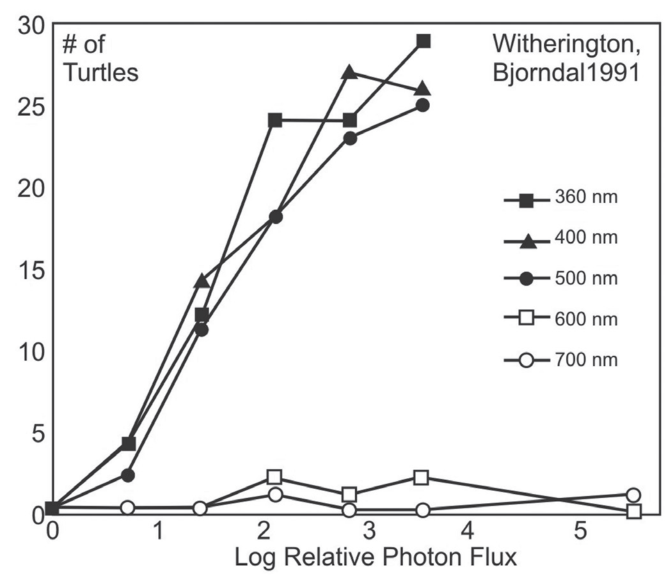


Figure 6 — Attraction of loggerhead turtle hatchlings as a function of wavelength. There was an approximately linear decrease in attraction from 500 nm to 600 nm for a constant brightness. (Witherington and Bjorndal 1991). Note, the "Log Relative Flux" of 2.78 is about 2.5 lux, and 3.5 is approximately 13 lux.

Amphibious creatures also suffer from unshielded fixtures and light with blue-spectral content. A popular example is turtle hatchlings. After breaking free from their shells and surfacing through the sand, they head to the light, which is usually the blue fluorescence of the sea's breaking surf. Landward light, with blue light components, can overwhelm this innate behaviour and attract the hatchlings away from the water, and safety. Studies show that light ≤550 nm is particularly dangerous.

Insects

ALAN distracts insects from more important duties, such as feeding, mating, and migrating, and has additional more-homocentric impacts.

The light spectrum is important in the navigation and survival of insects. Some flying insects avoid predation from birds during the day by foraging during twilight (crepuscular activity). Flying insects are attracted to the light of the blue sky (positive phototaxis). As a result, they have greater sensitivity to blue and ultraviolet light. Thus, blue light attracts insects, whereas longer wavelength light is less attractive.

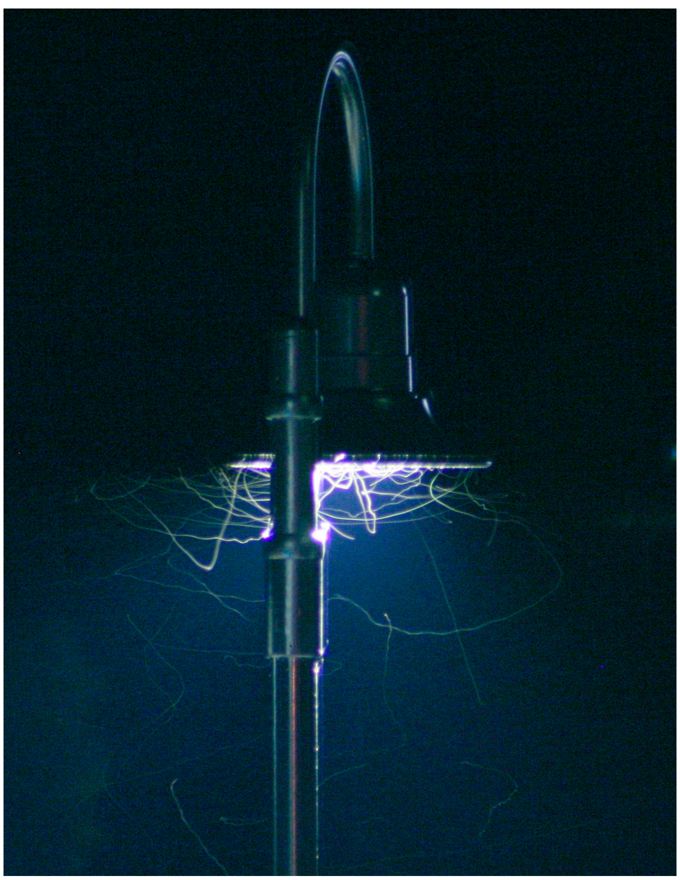


Figure 7 — Positive phototaxis of flying insects, as they are attracted to white light. Insects are attracted by both brightness and the colour of light. Their propensity to short wavelength light draws them to the luminance of the lamp. Their sensitivity to blue light makes a white light appear brighter than humans perceive. The light distracts the insects from their normal behaviour of feeding, mating, and migrating. Since light is usually installed where humans congregate, it increases the nuisance of the swarm.

The main insects amateur astronomers are concerned about are mosquitoes. Some people will recall grandfatherly advice about using amber "bug lights" to reduce the number of mosquitoes on patios and around building entranceways. Using "white light" at night, with its blue-light spectral components, goes against this "common sense." White light attracts insects from afar and increases the "insect density" of an area, which in turn enhances the success of their feeding, and also predation from other insects and animals. Use of white lights also increases the risk of communicable diseases that are borne by flying insects (Barghini and Medeiros 2010).

These are good reasons to not emit blue light and to limit the catchment area of insects by ensuring light fixtures are shielded (2020c).

Birds

Birds "inhabit the skies," so it is to be expected that their cone cells are more attuned to bluer wavelengths. They have four sets of cone cells (tetrachromatic vision) with the blue and UV receptors being more plentiful and sensitive than the green-yellow and orange-red sensitive cells (Hart 2001), and human cone cells, which are somewhat insensitive to blue light. The bright blue spectral components of ALAN from "white" urban lighting are more of a distraction for birds than longer wavelength light. Once distracted they become "lost" in the multiple reflections on glass and steel of buildings and unshielded flood lighting.

Birds are also distracted by aircraft navigation beacons on towers and wind farms where red and white beacons are in common use. Although studies suggest white strobes attract birds less than red lights (Gehring 2009), there are several other characteristics that confuse these findings. There are four specifications that concern the impact of a beacon on the ecology: the colour and brightness, dispersion angle, and the flash duration.

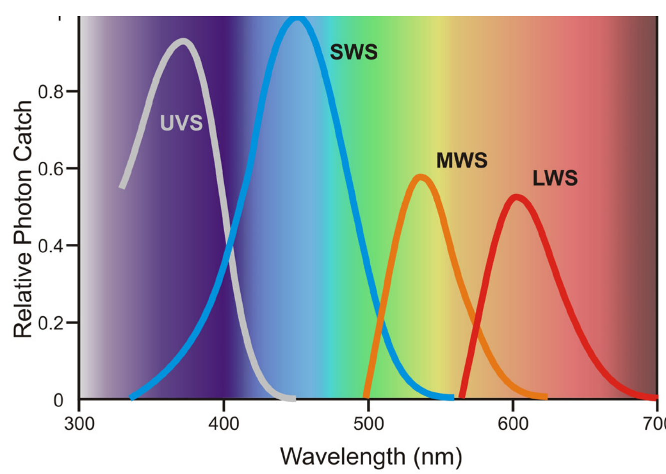


Figure 8 — Relative sensitivity of bird vision cells. In contrast to humans, birds have two sensitive receptor types for short wavelength vision (Ref. Hart 2001). Although human rod cells are sensitive to blue, at these high luminances, the rod cell pigments are bleached.

1) The FAA specifies medium intensity red flashing lights at night (L-864[1]) or white flashing lights (L-865)—both emit 2000 candela. Humans have relatively few blue-sensitive cone cells (Calkins 2001) so the white light will appear much brighter to birds than to humans. The bright white light distracts and attracts the birds toward the light and away from their migration route, sometimes resulting in collisions with buildings and tower guy wires, and more generally wastes time and energy.

2) Older incandescent lamps in red flashing beacons have flash durations of about 1/2–2/3 the flash period, which makes it easier to get a bearing on the location. In the case of 40 flashes per minute (L-857 - white), the bright phase is only 100–250 msec and appears like a "strobe." The frequency and duration of the more modern strobe lights vary depending on the beacon requirement and lamp type (FAA 2016, FAA 2019).

   Their short duration gives little time to orient on the direction of the light. Motorists and pilots will see the flash but may not be able to determine its precise direction either. Therefore, an emission with a longer pulse is more easily identified. Modern white strobes with a very short duration (low lamp duty cycle) may be all that reduces their attraction to birds. Therefore, in earlier studies, it may not be the colour, but the duration that was attracting birds. A red light "slow strobe" may be best for getting a bearing on towers (bad for birds but good for pilots), but the red light is less attractive to birds (good for birds).

3) The electrical power for these beacons can be reduced by collimating the emitted light into narrow cones (20 degrees horizontally and 3 degrees vertically). This reduces their apparent brightness when viewed from the ground and makes them more energy efficient, while retaining high visibility to pilots and birds.

Mammals and Humans

We share our eye structure, visual chemistry, and circadian rhythms with other species, so we should expect that what applies to one species may apply to others—until research determines otherwise.

ALAN affects all life but it may have greater health impact on humans than other animals. Humans consciously illuminate themselves, whereas animals attempt to avoid the light, and our longevity allows the adverse effects to accumulate for a longer period of time.

The circadian rhythm schedules our biochemistry over a 24-hour period (Kothari and Sothern 2006). These rhythms are synchronized to our diurnal cycle of activity by the detection of the end-of-day by non-visual blue-sensitive intrinsically photosensitive Retinal Ganglion Cells in our retina (ipRGCs).

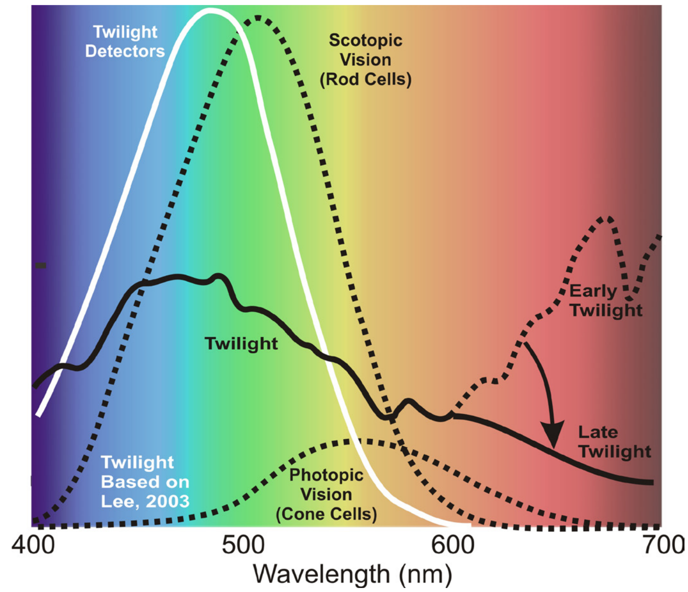


Figure 9 — Comparison between "twilight detector" cells and the rod and cone cells. The action spectrum of the twilight detectors (ipRGCs) peaks about 480 nm in the blue part of the spectrum corresponding to the clear twilight sky. ALAN that is used specifically for scotopic vision will inadvertently affect these cells and alter the circadian rhythm and the subject's chronobiology.

The ipRGCs have an action spectrum that peaks at about 480 nm with a slow decline into the red (Lee 2003). This corresponds to the spectrum of the twilight sky, so they can also be considered "twilight detectors." The fading of blue light at night is an important zeitgeber for the circadian rhythm—though it is also augmented by ambient temperature and the available food supply. Without the contrast between day and night, the phase of this rhythm falls out of step with the animal's activity and environment. So, both the brightness and spectrum of the late-evening light are important for the health and vitality of many species.

The hormone melatonin is accumulated during the day in the pineal gland and is released into our blood when night is detected by the ipRGCs. It prepares our bodies for sleep and also enables the release of other hormones that rejuvenate our bodies as we sleep—in preparation for the next challenging day. Our circadian rhythm prepares this suite of hormones that keep us healthy, but they have a "shelf life," and begin to decay after a few hours, so a delay in their release will reduce their efficacy and the benefit of sleep.

ALAN that is above the ipRGC threshold may delay or abort the release of these hormones. This will undermine subsequent biological activity that should occur at specific times of the night—affecting both our physical and mental health (Bunning 1979, Brainard 1988, Cajochen 2006).

In European experiments, elderly patients have been exposed to bright light during the morning, which prevents the "leakage" of melatonin throughout the day. Darkened bedrooms at night then encourage its release. This has been reported to have significantly reduced the symptoms of dementia in institutionalized patients (Lieshout-van Dal 2019).

As people age, the peak diurnal concentration of melatonin in the blood gets progressively lower, so for senior citizens there is less melatonin for our bodies to use than that in younger people (Reiter 1995). The amount of melatonin can become too low to enable these restorative processes, exacerbating illness and dementia with age (vanHoof 2008, Karasek 2004).

Nocturnal light is problematic when brighter than the threshold limit for the ipRGCs. Determining a precise detection "threshold" has not been possible because of a continuum of effects including the light integration characteristics of these cells (Do 2009). However, the threshold limit seems to be a few times the illumination of the full Moon (Dick 2020), which is needed to enable the release of the hormone melatonin into the blood, though dimmer light over longer time periods might affect other biological processes.

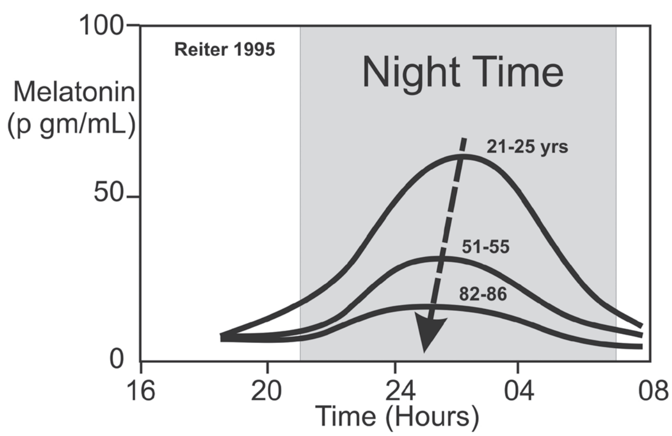


Figure 10 —Variation of melatonin over 24-hours and over a lifetime. The "contrast" between the concentration of melatonin in the day and night steadily declines with age.

Recent studies that combine clinical and geographical data show a direct correlation between ALAN and some diseases attributed to aging: dementia, diabetes (Onaolapo, Onaolapo 2018), obesity (McFadden 2014) and hormonal cancers (Stevens 2013). Figure 10 with data from the Centre for Disease Control (diabetes and obesity) (Willis 2010, Nguyen 2012) and comparing these to the light pollution map of 2012 (www.lightpollutionmap.info). These provide strong arguments against the excessive use of ALAN with blue-spectral components (Bedrosian 2013, Romeo 2012).

This clinical data does not provide the mechanisms for these impacts, but it is a warning, and should not be ignored while waiting for future research to prove these assertions.

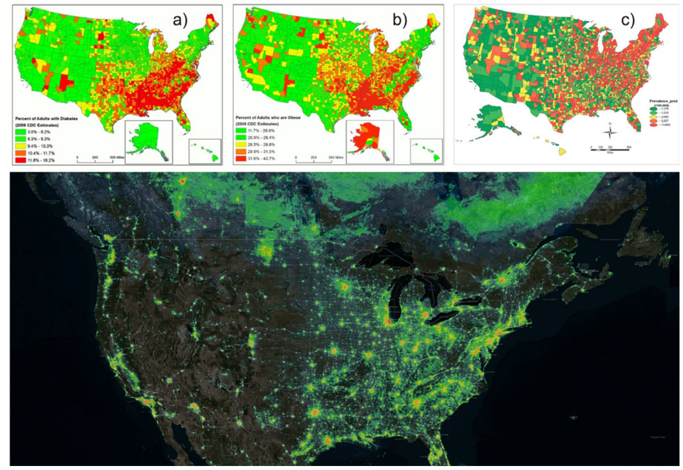


Figure 11 - Correlation between a) Diabetes, b) obesity, and c) Parkinson's disease is normalized and compared to the distribution of urban light pollution. The studies show these diseases primarily affect urban populations. On their own, this suggests a link to light pollution, but other factors may contribute to this trend. For example, light pollution does not correlate equally or consistently with all these ailments. The diffuse (green) skyglow over Canada is due to atmospheric effects. (From CDC 2020, b) Nyguyen 2012, c) Willis, et.al. 2010, and lightpollutionmap.info 2012)

Mesopic Vision and the Sp Ratio

The ratio of the spectral sensitivity of our night (scotopic) vision and our day (photopic) vision (SP ratio) was developed to compare the visual impact of a lamp assuming our rods and cones are working together to form a single image. "*S*" is the normalized scotopic spectrum (maximum sensitivity = 1) convolved with the spectrum of the light source, and similarly "*P*" is the normalized photopic spectrum convolved with the lamp spectrum (Miller 2019).

However, typical urban lighting situations in our photopic range (>5 lux), exceed the bleaching threshold of our scotopic vision. Therefore, in most practical applications, only one of either the rods or the cones is functional, and consideration of the combined scotopic and photopic vision (mesopic vision) is therefore "academic."

Regardless, the SP Ratio is used in the literature and posted on luminaire information sheets. A blue-white coloured lamp will have a *S/P >2*. In contrast, lamps that emit amber light have a very low SP ratio (*S/P* <0.1 for amber LEDs and ~0.2 for HPS lamps).

The SP ratios for several light sources are listed in Table 1 (from LIA 2013). In principle, for a high SP ratio, a designer could use less light for the same visibility, because of the higher sensitivity of our scotopic vision. However, industry lighting guidelines are based on our less-sensitive photopic vision, which underrates the blue light content—leading to brighter lighting.

There are anecdotal comments that low (amber) S/P is 8"promote" the use of white light. So, when engineering the

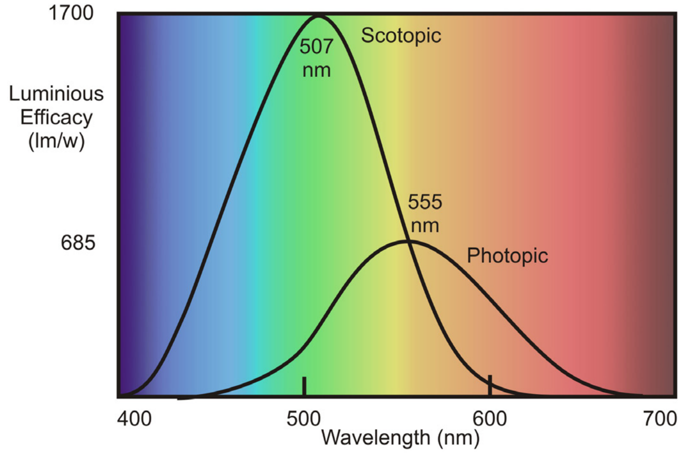


Figure 12 - Luminous efficacy for scotopic and photopic vision. Light with a spectrum of our photopic vision should be 40% of the brightness of light for our scotopic vision if it is to "appear" the same brightness. (Ref. Yao 2018)

lighting system, the illuminance metric, which is based on our photopic vision, is not reduced to reflect our scotopic vision.

The ratio between the peak spectral sensitivity of our scotopic and photopic vision is 1700 lm/w / 685 lm/, or 2.5. Therefore, as a first approximation, the illuminance of white photopic light should be reduced to 40% if it is to appear at approximately the same brightness for our scotopic vision. Based on the de Boer Scale for Glare (Bullough 2009, De Boer 1967), this reduces the perception of glare from "just permissible" to "satisfactory."

Melatonin Suppression Index

In a similar fashion to the SP ratio, a biological sensitivity parameter has been developed called the Melatonin Suppression Index or MSI (Aubé 2013). This is a biological metric whereas the SP Ratio is a vision metric. Lower values of MSI have a lower impact on the natural melatonin levels. Table 1 lists the MSI for a number of light sources with their Colour Rendering Index (CRI - ability to reveal true colours). The CIE D65 is the standard for "daylight." Lamps that emit minimal blue light (<500 nm), such as amber LEDs, have very little impact on the concentration of melatonin in our blood, whereas lamps with higher correlated colour temperatures have a greater effect.

Summary

The colour of ALAN is more than aesthetically pleasing. It changes the natural environment that would normally "inform" our biology. It also changes the natural colour of the landscape, which distracts and confuses the behaviour of animals that do not understand its artificial nature.

Our colour perception adapts to changes with the illumination level—our brain automatically "white balances" the scene. However, our spectral sensitivity to ALAN does not adapt. It extends our biological perception of daylight and delays critical processes that occur as we sleep. This affects human physical and mental health and also that of other animals.

Lamp	CRI**	S/P**	MSI**
Low-Pressure Sodium	-47	0.25	0.017
Amber LEDs*	47	0.07	0.043
High-Pressure Sodium (70W)	19	0.21	0.118
Incandescent	93	1.36	0.255
4000K LED	90	1.6	0.452
Metal Halide	48	2.4	0.624
CIE D65 Spectrum	100	~2.18	1.000

** Nichia Corporation   ** all values are sensitive to specific lamp spectrum*

Table 1 — Comparison of Melatonin Index of Different Light Sources.

Our understanding of how the spectrum of ALAN affects biology and behaviour provides us with a fourth "tool" we can use to reduce its impact. The next paper will discuss the scheduling of the light and how it affects the behaviour of wildlife. ✷

Endnotes

1 L-XXX is the FAA designation and the CL-XXX is the Transport Canada Designation, CAR 2019

References

Apogee Instruments, www.apogeeinstruments.com/conversion-ppfd-to-foot-candles, Accessed 2020 May 29
Aubé, M., Roby, J., Kocifaj, M., (2013) Evaluating Potential Spectral Impacts of Various Artificial Lights on Melatonin Suppression, Photosynthesis, and Star Visibility, *PLoS ONE 8*(7): e67798. doi:10.1371/journal.pone.0067798, Accessed 2020 June 24
Barghini, A., and Bruno A. S. de Medeiros, B.A.S.,(2010) Artificial Lighting as a Vector Attractant and Cause of Disease Diffusion, Environmental Health Perspectives, *National Institute of Health*, doi: 10.1289/ehp.1002115 (available at http://dx.doi.org/) Accessed 2020 June 24
Bedrosian, T. and Nelson, R., (2013) Influence of the Modern Light Environment on Mood, *Molecular Psychiatry (2013) 18*, 751–757
Bennie, J., et.al, (2016) Ecological Effects of ALAN on Wild Plants, *Journal of Ecology, Vol. 104*, pp 611–620, 2016
Bullough, J.D., (2009) Spectral Sensitivity for Extrafoveal Discomfort Glare, *Journal of Modern Optics, Vol. 56, No. 13*, 1518–1522 Accessed 2009 July 20
Brainard, G., et.al., (1988) Dose-Response Relationship between Light Irradiance and the Suppression of Plasma Melatonin in Human Volunteers, *Brain Research, 454* (1988) pp. 212–218
Bunning, E., (1979) Circadian Rhythms, Light, and Photoperiodism: A Re-Evaluation, *Botany Magazine, No. 92*, pp. 89–103
Cajochen, C., et.al., 2006, High Sensitivity of Human Melatonin, Alertness, Thermoregulation, and Heart Rate to Short Wavelength Light, *Journal of Clinical Endocrinology & Metabolism 90 (3)*, pp. 1311–1316
Calkins, D. (2001) Seeing with S Cones, *Progress in Retinal and Eye Research, Vol.20, No. 3*, pp. 255–287, 2001
CAR (2019), CAR Standard 621, www.tc.gc.ca/en/transport-canada/corporate/acts-regulations/regulations/sor-96-433/standard-621.html, Accessed 2020 May 12

CDC (2020) Centre for Disease Control, National Diabetes Statistics Report 2020, www.cdc.gov/diabetes/pdfs/data/statistics/national-diabetes-statistics-report.pdf, Figure 3. Accessed 2020 March 30

De Boer, J.B. (1967) *Public Lighting*; Philips Technical Library: Eindhoven, 1967

Dick, R., (2020a) The Biological Basis for the Canadian Guideline for Outdoor Lighting 1—General Scotobiology, *JRASC*, June 2020

Dick, R., (2020b) The Biological Basis for the Canadian Guideline for Outdoor Lighting 2—Impact of the Brightness of Light, *JRASC*, October 2020

Dick, R. (2020c) The Biological Basis for the Canadian Guideline for Outdoor Lighting 3—Impact of the Extent of Lighting, *JRASC*, December 2020

Do, M., et.al. (2009) Photon Capture and Signalling by Melanopsin Retinal Ganglion Cells, *Nature, Vol. 457*, 2009 January 15, doi:10.1038/nature07682

Duarte, R., Flores, A., Stevens, M., (2017) Camouflage through colour change: mechanisms, adaptive value and ecological significance, *Philosophical Transactions, Royal Society B, Biological Sciences, 372(1724)*: 2017 July 5; 20160342, Available at: www.ncbi.nlm.nih.gov/pmc/articles/PMC5444063, Accessed 2020 May 24

FAA (2016) AC 70 7460-1L – Obstruction Marking and Lighting – Change 2, www.faa.gov/documentLibrary/media/Advisory_Circular/AC_70_7460-1L_-_Obstuction_Marking_and_Lighting_-_Change_2.pdf, Accessed 2020 May 12

FAA (2019) AC 150/5345-43H, Specification for Obstruction Lighting Equipment, Table 3-4, Accessed 2020 May 24

Gehring, J., Kerlinger, P., and Manville, A., (2009) Communication Towers, Lights, and Birds: Successful Methods of Reducing the Frequency of Avian Collisions, *Ecological Applications, 19(2)*, 2009, pp. 505–514

Hart, N., (2001) The Visual Ecology of Avian Photoreceptors, *Progress in Retinal and Eye Research Vol. 20, No. 5*, pp. 675–703, 2001

Hillman, W., (1973) Light, Time, and the Signals of the Year, *BioScience 1973, Vol. 23 No. 2*, pp. 81–86

Koukkari, W. and Sothern, R., (2006) *Introducing Biological Rhythms*, Springer Science, 2006

Miller, N., (2019) M/P ratios – Can we agree on how to calculate them?, IES, Nov. 2019, www.ies.org/fires/m-p-ratios-can-we-agree-on-how-to-calculate-them/, Accessed, 2020 April 17

Karasek, M., (2004) Melatonin, Human Aging, and Age-Related Diseases, *Experimental Gerontology 39*, 1723–1729 (2004)

Larkum, A. and Kuhl. M., (2005), Chlorophylld: The Puzzle Resolved *Trends in Plant Science, Vol. 10, No. 8*, August 2005

Lee Jr., R. and Hernandez-Andres, J., (2003) Measuring and Modeling Twilight's Purple Light, *Applied Optics, Vol. 42, No. 3*, 2020 January 20

Lee, R. (2011), Atmospheric Ozone and Colors of the Antarctic Twilight Sky, *Applied Optics, Vol. 50, No. 28*, 2011 October 1

LIA (2013), SP Ratios and Mesopic Vision, *Lighting Industry Association* 2013, www.thelia.org, Accessed 2020 April 17

Lieshout-van Dala, E., Snaphaan, L., and Bongers, I., (2019) Biodynamic Lighting Effects on the Sleep Pattern of People with Dementia, *Building and Environment, 150* 245–253 (2019)

Mainster, M. and Turner, P. (2014) Glare's Causes, Consequences, and Clinical Challenges After a Century of Ophthalmic Study, *American Journal of Ophthalmology*, April 2012

McFadden, E., et.al., (2014) The Relationship Between Obesity and Exposure to Light at Night: Cross-Sectional Analyses of Over 100,000 Women in the Breakthrough Generations Study, *American Journal of Epidemiology* 2014 May 29, DOI:10.1093/aje/kwu117

Morel, A., et.al., (2007) Optical Properties of the "Clearest" Natural Waters *Limnology and Oceanography, 52(1)*, 217–229, (2007)

Nguyen, T. (2012) Does driving make you fat? From www.zdnet.com/article/does-driving-make-you-fat-infographic/ Accessed 2020 February 10

Onaolapo, A. and Onaolapo, O., (2018) Circadian Dysrhythmia-linked Diabetes Mellitus: Examining Melatonin's Roles in Prophylaxis and Management, *World Journal of Diabetes, Vol. 9 (7)*; 2018 Jul 15, PMC6068738

Reiter, R., (1995) The Pineal Gland and Melatonin in Relation to Aging, *Experimental Gerontology, Vol. 30, Nos. 3/4*, pp. 199–212, 1995

Romeo, S., et.al, (2012) Bright Light Exposure Reduces TH-Positive Dopamine Neurons: Implications of Light Pollution in Parkinson's Disease Epidemiology, *Scientific Reports, 2012, 3*:1395, DOI:10.1038/srep01395

Schweikert, L., et.al. (2018), Variation in rod spectral sensitivity of fishes, *Journal of Experimental Biology, 95*:179–185, 2019

Smith, H., ed. (1978) *The Molecular Biology of Plant Cells, Chapter 14—Phytochrome Action*, University of California Press 1978

Stevens, R., et.al., (2013) Adverse Health Effects of Nighttime Lighting: Comments on American Medical Association Policy Statement, *American Journal of Preventative Medicine, 45 (3)*: pp. 343–346, 2013

Thomas, B. and Vince-Prue, D., (1997) *Photoperiodism in Plants*, Ed.2, Academic Press, 1997

Tincker, M.A.H. (1924), Effect of Length of Day on Flowering and Growth, *Nature,* 1924 September 6, pp. 350–351

vanHoof, J., et.al., (2008) Ambient Bright Light in Dementia: Effects on Behaviour and Circadian Rhythmicity, *Building and Environment* (2008), doi:10.1016/j.buildenv.2008.02.005

Walton, J., Weil, Z., and Nelson, R., (2010) Influence of Photo Period on Hormones, Behavior, and Immune Function, *Frontiers in Neuroendocrinology*, (2010), doi:10.1016/j.yfrne.2010.12.003

Wikipedea, https://en.wikipedia.org/wiki/Secchi_disk, Accessed 2020 May 12

Willis, A., et.al., (2010) Geographic and Ethnic Variation in Parkinson Disease: A Population-Based Study of US Medicare Beneficiaries, *Neuroepidemiology 2010; 34*:143–151, DOI: 10.1159/000275491

Witherington, B. and Bjorndal, K., (1991) Influences of Wavelength and Intensity on Hatchling Sea Turtle Phototaxis: Implications for Sea-Finding Behavior, *Copeia, 1991,(4)*, pp. 1060–1069

Withrow, R. and Benedict, H., (1936) Photoperiodic Responses of Certain Greenhouse Annuals as Influenced by Intensity and Wavelength of Artificial Light used to lengthen the Daylight Period, *Plant Physiology, 11(2)*, pp. 225–249, April 1936

www.lightpollutionmap.info

The Montréal Centre of the RASC 1958 – 1965: A Retrospective

By Klaus Brasch

"The history of astronomy is a history of receding horizons."

– Edwin P. Hubble, *Realm of the Nebulae*, 1936

Abstract

The Montréal Centre was one of the most active amateur astronomy organizations in North America during the 1950s and 60s, thanks to a core of dedicated and enthusiastic lovers of the hobby. I was fortunate to join them in my teens, after the launch of *Sputnik 1* in 1957 at the very onset of the Space Age. The ensuing years were truly a golden era of amateur astronomy. They were also formative years in my life and that of many of my contemporaries and led directly to my becoming a professional scientist and an avid amateur astronomer to this day.

Figure 1, 1a — (top) My father, Heinz Brasch, and Louis Duchow with my 3-inch refractor at the 1963 total solar eclipse in Plessisville, Québec, and (bottom) the Montréal Centre Observatory (RASC archives).

I joined the RASC in Toronto as soon as I was old enough in 1957. These were truly exciting times, with the launch of *Sputnik 1*, the world's first artificial satellite, and the International Geophysical Year. These preludes to the Space Age were also a golden age for amateur astronomy, which grew in popularity, especially among young people who longed to be part of the great adventure to come. That feeling was accentuated in 1961 by President Kennedy's call for human exploration of the Moon.

In 1958, my father's company transferred us to Montréal because they needed an electrical engineer there who spoke French. Although I was sad to leave my friends behind and attend a new high school, that was soon mollified by the welcoming reception I got upon joining the Montréal Centre. It began with a phone call from one Geoffrey Gaherty Jr. who wanted to recruit me for an exciting new program called the Lunar Meteor Search. Although I had no clue what that was really about, Geoff soon persuaded me that this was an actual research program for amateurs with telescopes. I immediately accepted, as I was now proud owner of a brand new 3-inch refractor my dad and I had fashioned from war surplus optics and spare parts from his company. That Saturday I eagerly attended the Centre's weekly (yes, weekly!) meeting at its observatory on the McGill University campus.

As I hesitantly knocked on the door, I was met by a tall, blond, bespeckled young man with hand extended asking "Are you Klaus Brasch?" Geoff Gaherty not only warmly welcomed me, he introduced me to others and then chewed my ears off about this new A.L.P.O. (Association of Lunar and Planetary Observers) program to monitor the crescent new and old Moon telescopically, looking for potential meteor flashes on the unlit portions of our satellite. That sounded most intriguing and soon Geoff and I began a friendship that lasted until his untimely death in 2016.

The Lunar Meteor Search program was the brainchild of A.L.P.O. founder Walter Haas, who was interested in detecting possible transient phenomena on the Moon at a time when that was deemed highly unlikely. He proposed all this in a seminal paper (Haas, 1942) which drew both scorn and praise. Ironically, although no confirmed lunar meteor event was ever observed visually at the time, reports of flashes and other lunar transient phenomena continue to this day.

I quickly discovered that the Montréal Centre was one of the most active amateur groups in North America. In large measure, that was due to two things. First, there was the Centre's small but well-equipped observatory, complete with a dome housing a fine 6-inch refractor, a well-stocked library, lecture room, and telescope-making workshop. This was quite unusual in those days and provided a comfortable hideaway from the noise and bright lights of the city.

Second, any newbie was quickly taken under the wing of a veteran and encouraged to get involved in one of the many observing programs offered: Messier club, observing the Moon and planets, nova searches, lunar occultations, sunspot monitoring, to name but a few. Most intimidating to novices, but also most exciting, was being asked to give a presentation on any subject of astronomical interest during a Saturday meeting. That really helped shy teens like me to gain confidence in public speaking to a friendly audience and also to learn something new each time. For a complete history of those heady days, see *Fifty Times Around the Sun: A History of the Montréal Centre of the RASC 1918–1968*, edited by Isabel K. Williamson (Williamson 1968).

The observatory building, used by McGill University during World War II for classified radar research, was leased to the Montréal Centre for a token fee on multi-year terms, and fully repurposed and equipped for astronomy by its members. In 1964 the Centre was incorporated under a Provincial Charter.

Miss Williamson and Charles Good soon became my most influential mentors. Though ordinary businesspeople with day jobs (she worked for an insurance company and he for the provincial electric company), they were fountains of knowledge, experience, and wisdom, as well as patient and kind teachers. I also soon met and befriended other younger members, including George Wedge, Constantine Papacosmas, Jim Low, Bryan Rawlings, and Kenneth Chalk. Much later, David Zackon, David Levy, and Howard Simkover also joined. Sadly, many of them are gone now, though I am still in sporadic touch with both David Levy and Howard Simkover. In fact, Howard and I reconnected again in Flagstaff in 2014.

Geoffrey, George, Kenneth, and I eventually formed the core of regular lunar and planetary observers and made steady contributions to *Skyward*, the Centre's monthly newsletter, meticulously edited and published by Isabel and Charles. George started the lunar height measurement program, whereby members made visual estimates of the length of shadows cast by crater rims or mountains like Pico. Geoffrey, very admirably, used Montréal Centre observations made during the 1960–61 opposition of Mars to construct a map of its albedo features as a term project in a geography course.

Our intrepid group of planetary watchers soon learned that the best way to ensure our observations and sketches were as reliable and accurate as possible, was to coordinate our observing sessions and compare results afterwards. That was especially important when looking for the ever-elusive cloud

Figure 2, 2a — RASC archival photos from mid-1950s, (top) showing the newly installed 6-inch refractor. Miss Williamson is in the foreground at left and standing in the back are Frank DeKinder and George Wedge at right. (bottom) The view of the main floor meeting room and library.

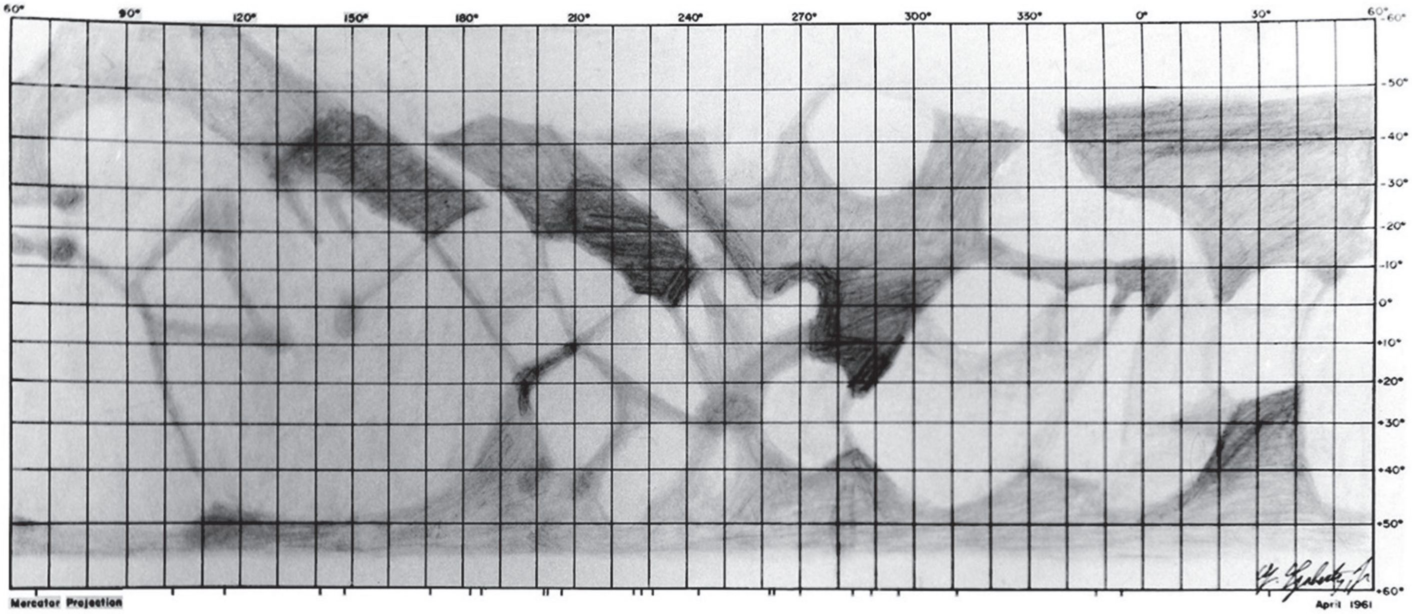


Figure 3 — Geoff Gaherty's Mars map.

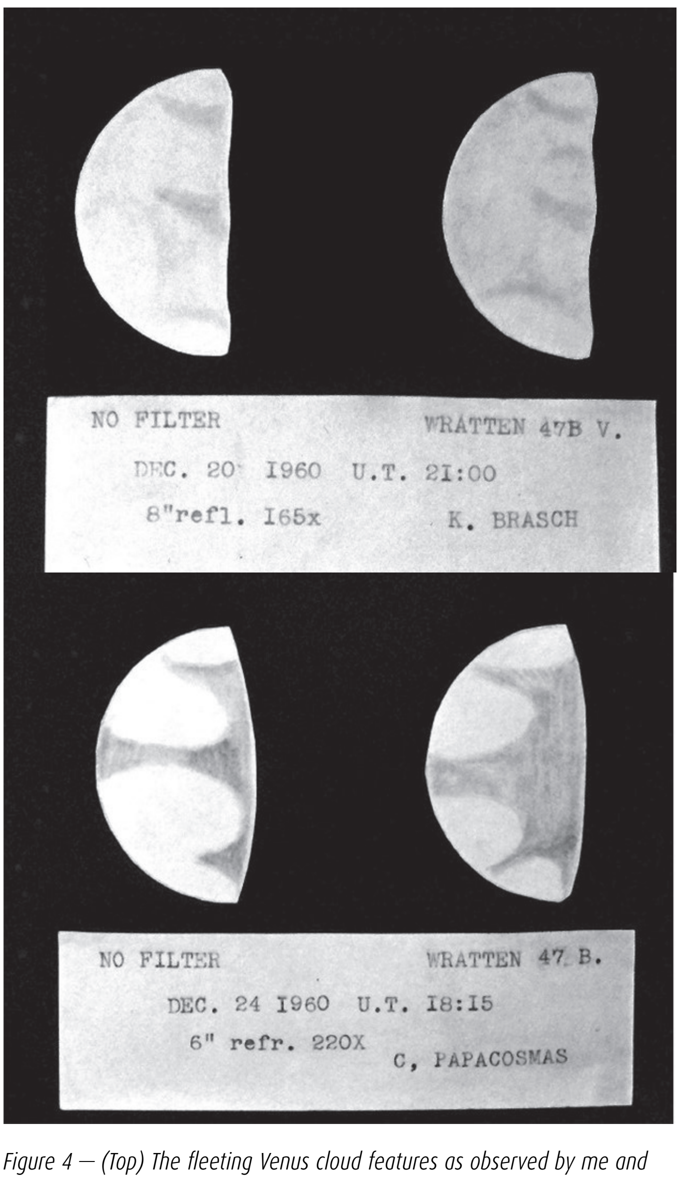


Figure 4 — (Top) The fleeting Venus cloud features as observed by me and Constantine Papacosmas (Bottom) with deep-violet filters and different telescopes four days apart in December 1960.

markings on Venus or doing transit timings of Jupiter's more prominent atmospheric features and moons.

It's worth noting that in the early 1960s many basics about the Moon and planets were far from established, including the rotation periods of Mercury and Venus, the nature and origin of lunar craters, and the atmospheric dynamics of Jupiter and Saturn's atmospheres. It was also unclear if the Moon was still geologically active and whether cratering was mainly due to volcanism or impact events. Regarding Venus, there were major uncertainties about its surface conditions; was it a steaming jungle, covered with water or an arid desert? Mars, of course, was the most tantalizing planet. While the canals theory had been largely abandoned, it still seemed plausible that the secular trends shown by many of the planet's albedo features might be evidence of seasonal changes in lichen-like vegetation. For a fuller sense of our state of knowledge at the time, see Chapter 7 of the beautifully illustrated *Larousse Encyclopedia of Astronomy* (Rudaux and De Vaucouleurs, 1959). All of that changed of course, just a few years later, with the *Mariner 2* and *4* flybys of Venus and Mars, respectively, and the Ranger lunar impactors.

We also joined A.L.P.O., made contributions to its publication, *The Strolling Astronomer* (Brasch, 1969), and presented papers at annual conventions of the RASC (Brasch, 1961, 1963; Gaherty, 1961). In 1962, the Montréal Centre hosted the 10th annual convention of A.L.P.O., its first outside the United States. Shortly after, Walter Haas asked me to serve as the organization's Mars Recorder, a position I held till 1965 when I left for graduate studies at Carleton University in Ottawa.

Figure 5 — (top) ALPO 1961 convention in Detroit, MI, showing from left, Walter Haas, Klaus Brasch, Geoff Gaherty and Clark Chapman; (Right) a sketch of Jupiter made on 1961 September 2, under exceptionally good seeing with my 8-inch reflector with Cave Astrola optics. Chapman subsequently became a leading expert on asteroids and comets.

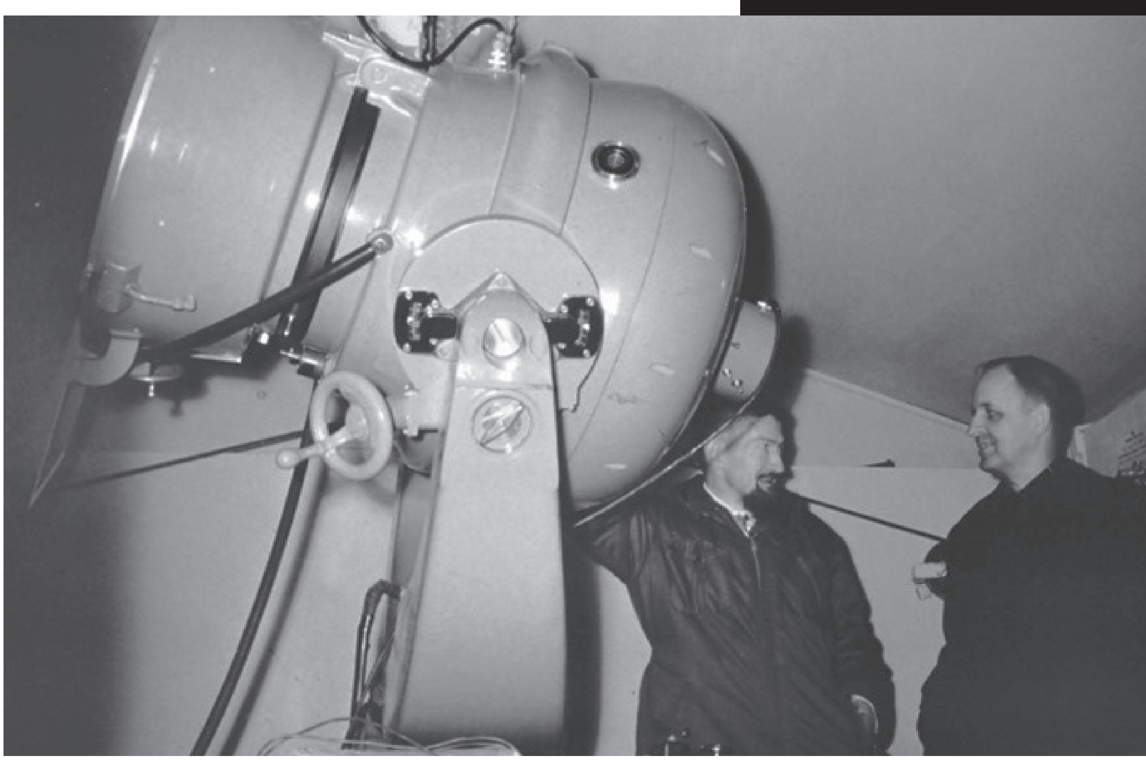
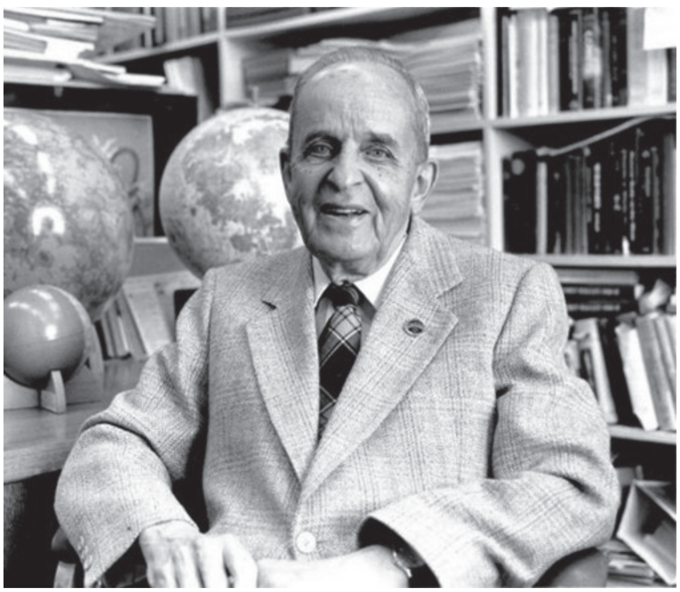


Figure 6 — Jack Grant and Peter Millman with the Super-Schmidt Meteor camera at Newbrook Observatory in Alberta (RASC archives).

Systematic observations of meteor showers are among my most enjoyable recollections of activities undertaken jointly by Montréal Centre members. Under the guidance of renowned Canadian astronomer, Peter Millman, we regularly participated in this important scientific program. Dr. Millman was interested in the chemical composition, frequency, direction, magnitude, and colour of meteors, crucial information at the time in preparation for human spaceflight (Millman, 1963). He enlisted several astronomy groups around the country to systematically monitor meteor showers and then forward the data to the National Research Council of Canada in Ottawa for analysis. Dr. Millman also directed an ambitious program to photograph meteors using specially constructed Super-Schmidt Meteor cameras at Meanook and Newbrook observatories in Alberta. This was part of a joint US–Canada program for large-scale meteor monitoring from 1952–57 (ARHP, 2020; Jarrell, 2009).



On several meteor-observing occasions, members would assemble at my parents' home in Rosemère, Québec, then still a nice rural suburb north of the city and with very dark skies. Armed with outdoor recliners, blankets, red lights, a shortwave radio, and special NRC star charts, we formed a circle with a recorder at centre, and shouted "Time!" when a meteor was spotted, its magnitude called, and path plotted. Depending on the season, horrid-smelling bug repellant, or hot chocolate and cookies prepared by my mother, would smooth the way. Afterwards, we would repair to the house for refreshments and socializing. Good memories for sure.

Another highpoint of my time in Montréal was when nearly all Centre members and their families ventured to three locations in eastern Québec on 1963 July 20 for a total eclipse of the Sun. Charles Good arranged for us with Hydro Québec, to assemble at one of their fenced-off areas in Plessisville and set up telescopes. Although passing clouds posed a threat, the much-too-brief (1 min 40 sec) totality was glorious. Another memory never to be forgotten.

By 1965, when I left Montréal, many of our core observers had or were about to move on. Geoff Gaherty pursued graduate work in anthropology at U. C. Santa Barbara, George Wedge tragically died in a plane crash while honeymooning in Spain, and Kenneth Chalk started working at the Dow Planetarium. Subsequently many other younger members of the Centre also worked at the planetarium. Constantine Papacosmas, and young bloods like Leo Nikkinen, Si Brown, David Levy and Howard Simkover carried the torch, along with Isabel Williamson, Frank DeKinder, and many others. In some ways, though, this marked the end of a remarkably active era of the Montréal Centre's rich history.

Speaking for myself, but probably also for many of my RASC contemporaries at the time, astronomy was not just an engaging hobby, but also a life-long intellectual engagement. Not only is it the oldest of sciences but also the most overarching, with impact on the arts, philosophy, and even our future. Although we did not dream of it then, we now live at a time where such

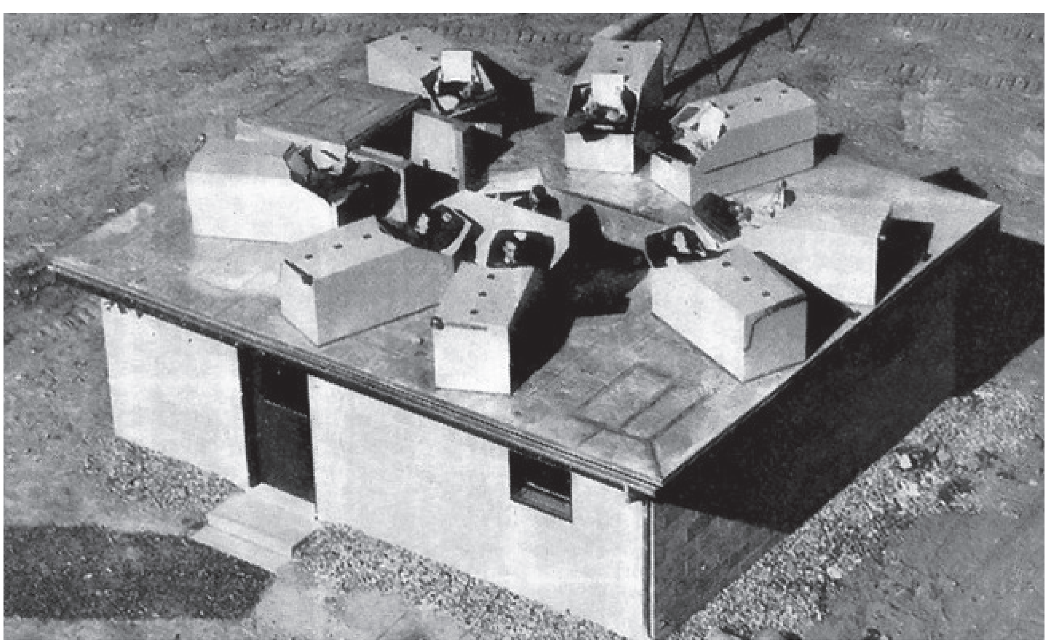


Figure 7, 7a — (Top) Dr. Peter Millman in retirement (RASC archives) (Left) The NRC Springhill Meteor Observatory, with observers in "coffins" to shield against the elements; our Montréal set ups were far less luxurious with simple lawn chairs and blankets.

profound questions as the origin of the Universe, is there life on other planets and are we alone in the cosmos, may finally be answered. ✶

Acknowledgements

The author is indebted to RASC Archivist Randall Rosenfeld and Montréal Centre alum Howard Simkover for support and assistance with this retrospective.

Klaus Brasch is professor emeritus of biology from California State University, San Bernardino, a longtime member of the RASC, and volunteer at Lowell Observatory in Flagstaff, Arizona, which recently named Asteroid 25226-Brasch for his many years of service.

References

AHRP (2020) https://hermis.alberta.ca/ARHP/Details.aspx?DeptID=1&ObjectID=4665-0529

Brasch, K.R. (1961) Observations of Venus, *JRASC 55, 6*, 254–255.

Brasch, K.R. (1963) A study of the phase of Venus, *JRASC 57, 6*, 264–265.

Brasch, K.R. (1969) Report on the 1964–65 Apparition of Mars, Pat II, *Strol. Astron. 21*, 7–8, 125–131.

Gaherty, Jr. G. (1961) Jupiter in 1961, *JRASC 57*, 5, 114–115.

Haas, W. (1942) Does anything ever happen on the Moon? *JRASC 36*, 237–272.

Jarrell, R.A. (2009) Canadian Meteor Science: The first phase 1933-1990, *J. Astro. Hist. and Herit. 12*, 224–234.

Millman, P.H., 1963 Meteor counting, *JRASC 57, 6*, 266–267.

Rudaux, L. and De Vaucouleurs, G. (1959) *Larousse Encyclopedia of Astronomy*, Batchworth Press Ltd., London

Williamson, I. (1968) www.rasc.ca/sites/default/files/ardocuments/FiftyTimesAroundTheSun.pdf

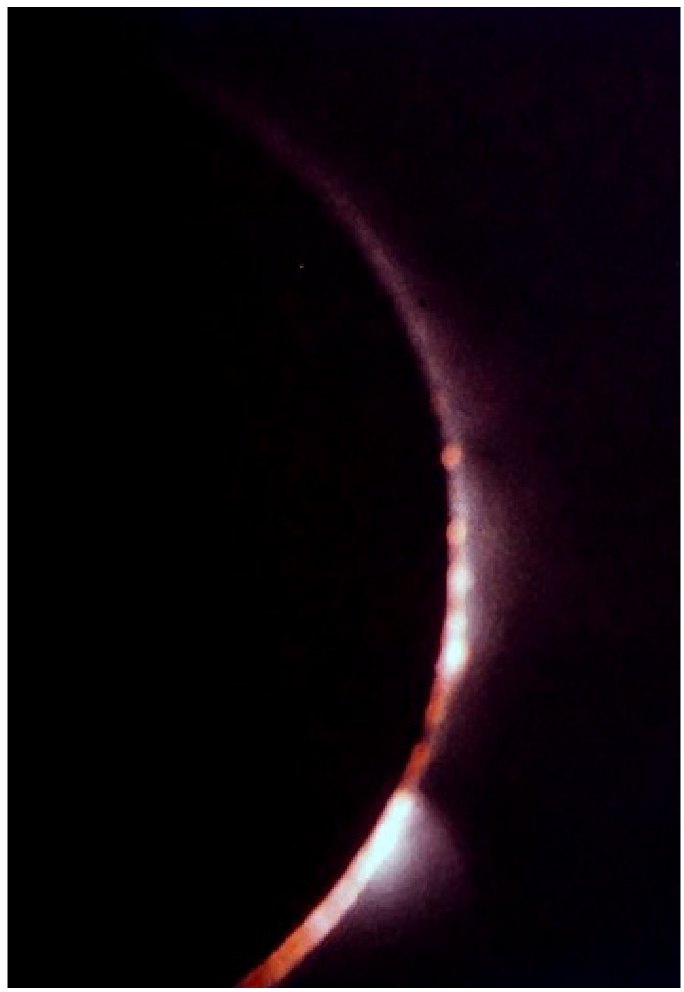


Figure 8, 8a — (Top) After a most eventful day, some tired but happy eclipse chasers gather for a group photo, left to right: Geoff Gaherty and George Wedge letting loose, my mother, future wife, Margaret Schoening, with my sister Pat, and my father not anxious to drive us back home. (Above) although mediocre by modern standards, I was thrilled with my fuzzy photo of Baily's Beads.

Skyward

Hello, Bennu, and Remembering a Very Special Date

by David Levy, Kingston & Montréal Centres

Not long ago, OSIRIS-REx, a spacecraft sponsored by the University of Arizona and a NASA mission, gently touched the surface of asteroid No. 101955—named Bennu—grabbed some material, then quickly took off again. It was the first try, but it was a huge success! The craft gathered more than twice what was expected—so much that some small pieces of material started to leak out.

Of course, if all the sample leaked out, then there was no sample. But that didn't happen. NASA transferred the material to a safe storage container earlier than expected, and then the sample will be safe.

The mission cost the U.S. taxpayers about $800 million, plus about $185 million for the launch aboard an Atlas V rocket. OSIRIS-REx is an acronym for Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer. Asteroid Bennu is an interesting choice. Bennu was the name for an Egyptian mythological bird associated with creation, the Sun, and rebirth. But much as the name might inspire us to look back at the early days of our Solar System (which it does), that's not the real reason this particular asteroid was chosen. Bennu is a C-type asteroid. It is also a sort of time capsule dating back to the birth and early evolution of the Solar System. C is for carbonaceous asteroid, but it is a B sub-type because it is primitive. The reason for this is that it had undergone almost no geological change since it formed.

If you pay taxes in the United States, you may wonder why more than $800 million was sent to this distant spot of light in the sky. I could begin to answer this by saying that Bennu's sample will teach us about what the Solar System was made of at its formation. From that, Bennu could give us a healthy idea about what the Earth itself was like at its birth. Sometime after it was formed, its orbit changed so that now, every few dozen years it gets pretty close to Earth. There is a very small chance that it might hit Earth in the distant future. Dolores Hill, a long-time member of the OSIRIS-REx team adds: "NASA sent this mission to Bennu, a primitive body, to return a pristine, protected sample so we could better understand the beginning and history of the Solar System, formation of organic compounds important to life, and understand how main-belt asteroids migrate to the inner Solar System to become near-Earth asteroids."

Figure 1 — This photograph of asteroid Bennu It is a composite of images taken from the OSIRIS-REx spacecraft on 2018 December 2.

All this is fine, but couldn't that money be better spent on Earth, to feed the starving, cure those afflicted with coronavirus, house the homeless, and do all the

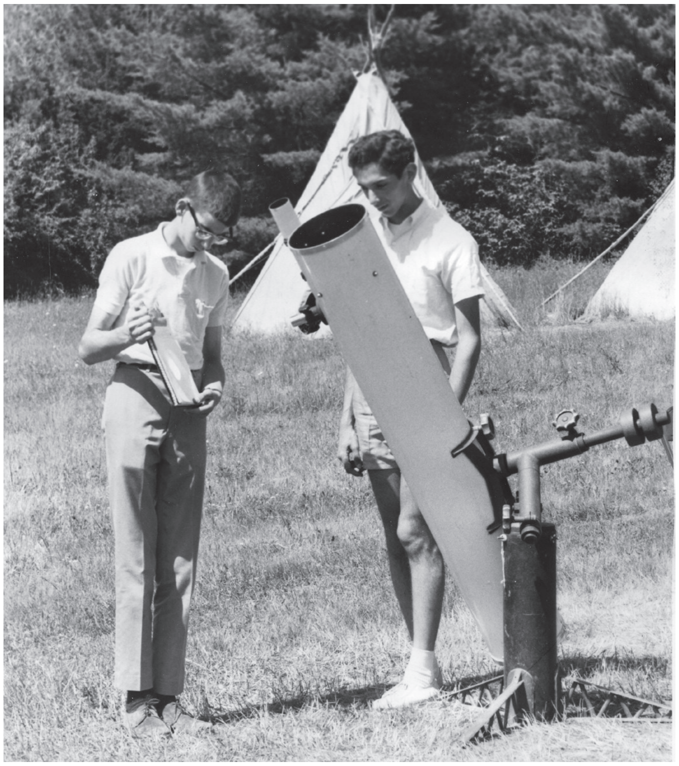


Figure 2 — I have owned and used Pegasus, an 8-inch diameter Cave reflector, for more than half a century. In this picture, camper Andy Bauman and I are pointing Pegasus to project the Sun, at the Adirondack Science Camp, in 1966. I used this telescope on my first night of comet-hunting in 1965. Credit: Joe Howard.

other things we thought we could do when we decided to go to the Moon in the 1960s?

Yes, it could. Except for one thing. Going to the Moon seemed pointless until we all were glued to our televisions, watching breathlessly as one human stepped onto the surface of another world. Dear readers, we are explorers. It is in our blood, our DNA, in our hopes and dreams. And in the midst of this horrible pandemic, a small piece of human-built machinery tapped the surface of a distant world and grabbed a sample. Indeed, space journeys like this one help make life worth living. We live here. This is our neighbourhood. We reach for the stars.

Remembering December 17

The night of 1965 December 17 changed my life. That was the night I began a search for comets that goes on to this day. It represents the second most important decision I have ever made: To begin a visual search for comets and exploding stars that are called novae. The first most important decision, of course, was to marry Wendee. Both decisions made my life what it is today.

November, December, and April are the typically the cloudiest months in Montréal. Therefore, I wasn't counting on a clear sky that evening. After a Friday evening dinner with my family, I walked over to my friend Tom Meyer's home, and we visited for a while. Afterwards, around 11 p.m., I took Clipper, our little beagle, for a walk toward the summit of the hill on which we lived.

It was during this little stroll with Clipper that things began to change. Toward the west, there appeared to be some lightening of cloud cover, and soon after, a clearing. Within about 15 minutes, large swaths of sky were showing some stars. I couldn't believe it. I turned toward home, and for a few seconds Clipper and I enjoyed a tug-of-war until he gave up and walked back home with me. Just before midnight, on the 17th, I began my first comet-hunt, and I scanned the sky between Pollux and Castor, in the constellation of Gemini. The clouds returned after that.

As the famous ABC news reporter Jules Bergman said on the launch of *Telstar,* the world's first active telecommunications satellite in 1962: "And it all began today." For me, it surely did. In December 2020, 55 years will have passed, and I still am searching almost every clear night. There are 22 comets roaming about the Solar System with the Levy name on them, plus one named Jarnac. Jarnac Observatory is the name of our observing site here in Vail, Arizona, and is named in turn after my grandfather's cottage, Jarnac, near Ripon, Québec. An object was found and automatically reported by Tom Glinos, well-known in the RASC, who once had an automated telescope here. Because he incorrectly identified the object as an asteroid, when it turned out that it sported a tail and was reclassified as a comet, it was named—following the rules—for the observatory, not for the discoverer. Thus, my total is now 23 comets. If my grandfather knew that his beloved cottage (and later observatory) now had a comet with its name on it, he would be dancing all over heaven. It is a happy story that still goes on today. ✶

David H. Levy is arguably one of the most enthusiastic and famous amateur astronomers of our time. Although he has never taken a class in astronomy, he has written more than three dozen books, has written for three astronomy magazines, and has appeared on television programs featured on the Discovery and the Science channels. Among David's accomplishments are 23 comet discoveries, the most famous being Shoemaker-Levy 9 that collided with Jupiter in 1994, a few hundred shared asteroid discoveries, an Emmy for the documentary Three Minutes to Impact, *five honorary doctorates in science, and a Ph.D. that combines astronomy and English Literature.*

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

Observing

Peering at Mars

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

My first telescope arrived amidst two exciting events, the March 1997 Mars Opposition and Comet Hale Bopp. Mars became the first object I observed through a telescope of my own as I chased sucker holes in a broken cloudy sky. I would get one fleeting glimpse before the next cloud obscured the view, but I was able to observe the polar caps, Syrtis Major (I mistakenly thought this was the Mariner Valley) and some of the deserts. The thrill of seeing Martian polar caps for the first time is indescribable, and so reminiscent of our view of Earth one can't help but imagine more similarities than differences between our worlds. But what are we looking at exactly when we see something on the *surface* of Mars? With Mars having reached opposition on 2020 October 13, and likely the best view from Canada until 2035, I thought now might be a good time to dig a little deeper.

The Two Faces of Mars: Surface vs. Albedo Features

Syrtis Major was first sketched by Huygens in 1659 and appears as the most distinct dark patch. Originally believed to be a plain, thanks to *Mars Global Surveyor* we now know Syrtis Major is a low-relief shield volcano with basaltic rock and relatively low levels of dust in the area causing the region to appear dark. The difference between what is seen at the eyepiece and the actual surface is a battle between human perception, Earth's atmosphere, and a planet more than 54 million kilometres away at its closest point.

The naked-eye view of our Moon displays soft, rounded forms of bright highlands and impact regions with dark lava plains. At the threshold of vision, you may be able to glimpse a few craters, but a view through any instrument reveals a synthesis of features were actually observed. These naked-eye observations demonstrate albedo features, when the surface of a Solar System body is seen as the contrast between brighter and darker areas, which may only be hinting at the surface detail.

Peering at Mars through a telescope, we view the planet much as that unaided eye view of the Moon and observing those albedo features. In 1840, when the first Martian albedo map was drawn by Johann Mädler and Wilhelm Beer using a 95-mm telescope, the albedo features on Mars were given uninspired letter designations, a, b, c, d, etc. Richard Proctor was more creative with his features, paying respect to the contributions of past astronomers, including Dawes, whose observations were used as a base for the map. We find continents named after Herschel and Fontana not to mention the optimistically titled Beer Sea. Nathaniel Green's 1877 map uses Proctor's labels and demonstrates the beauty of Mars seen through small instruments. However, that same year Giovanni Schiaparelli published his own nomenclature, which drew heavily on his belief that many albedo features were seas, lakes, and swamps and named them accordingly. Such imagery must have been strong and when E.M. Antoniadi took over as the lead Mars observer, and one of the last great observers of the Red Planet before the space age, he used Schiaparelli's names, which now form the basis for the nomenclature officially adopted by the IAU in 1958 under the guidance of Audouin Dollfus. Space-probe flybys of the 1970s dashed all hopes of a Beer Sea and revealed surface details necessitating a closer alignment between albedo and actual surface.

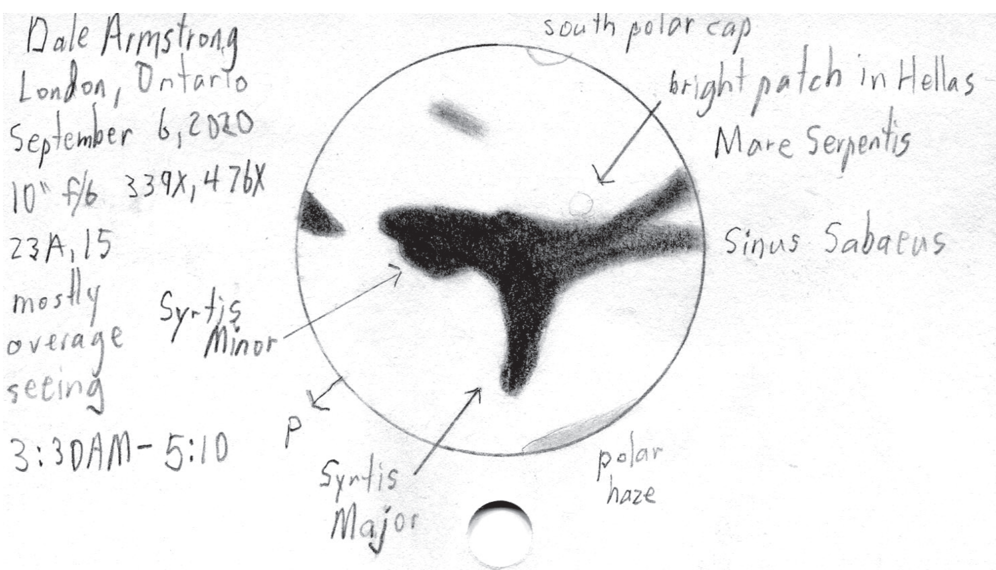


Figure 1 — Dale Armstrong, September 6, 3:30 a.m. to 5 a.m. EDT using a 250 mm Newtonian with 23a and #15 filters and 339× and 476×. Mars near opposition.

Some 2020 Pre-Opposition Observations

Dale Armstrongs excellent field sketch, see Figure 1 at left, gives an accurate representation of the Syrtis Major and polar cap features for those who remain snug in bed at 4 a.m. Below, Gerry Smerchanski's colour portrait provides an accurate Martian "red" and north polar shroud he describes as follows:

> After a few attempts of observing Mars I finally got a morning of good seeing that

Figure 2 — Gerry Smerchanski's sketch from August 29, 5 to 6 a.m. CDT using a 150-mm Mak-Newt with binoviewers above 250×.

> allowed a high-magnification view. The colour of this photo is not quite what I sketched, but close enough. The colour on that shroud over the north pole was supposed to be more bluish than green. There definitely was a hint of blue to that shroud over the polar region (opposite the bright southern polar cap). The Southern Polar Cap is the most delineated feature out there. Even in poor seeing it stands out. I worry that its brightness makes me want to make it larger than it really is. The seeing was very good. A hint of that is the use of 250x to view the planet. I also made sure that it wasn't a case of atmospheric prismatic distortion as Mars was quite high (just past the meridian) at that point and there was no hint of the corresponding red on the opposite limb. I also saw similar bluish colouration back in 2005 when I last saw Mars this good.

I found Gerry's observation interesting and had recently observed the blue zone, with a bit of white on top. I thought the blue was the little bit of chromatic aberration left in my 60-mm refractor but decreasing the power and using a lower-element eyepiece only made the effect stronger. Gerry reminded me that Earth's atmosphere can impart secondary colour, but Mars was likely too high in my sky at this time to cause it.

In Sketch 3, Dave Chapman demonstrates what a light bucket and a couple pint glasses of Tele Vue glass can do. "The big Dob collects too much light! I had to use at least a Moon filter to cut the glare. Even then, I noticed considerable diffraction from the secondary vanes, so I tried an aperture stop that gives

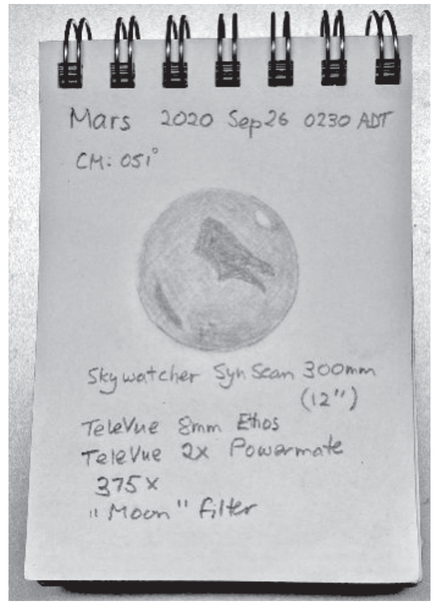


Figure 3 — Dave Chapman's sketch from September 26, 2:30 a.m. ADT. Mars CM:51° using a 300-mm Newtonian with a "Moon" filter and an 8-mm Tele Vue Ethos eyepiece plus a 2× Powermate for 375×.

a 130-mm off-centre opening. This reduced the glare and diffraction, and I did not really need the filters."

Since my early days, I learned that to observe Mars, it's all about pre-opposition preparedness. Get out more than a month before opposition night and invest lots of early morning starts to begin teasing out subtle details on the tiny disk of Mars when it is high in the stable pre-dawn sky. You may begin to feel like some sort of nocturnal creature of the night, but the practice will train your eye to see more by the time Mars is at its best. ✶

Acknowledgments

Thanks to Dale Armstrong, Gerry Smerchanski, and Dave Chapman for kindly allowing their sketches and observations to illustrate this article.

References

De Callatay, Vincent, Dollfus, Audouin. (1967). *Atlas of the Planets*. Portsmouth. NH: Heinemann Educational Books.

Grego, Peter. (2012). *Mars and How to Observe It.* New York. NY: Springer.

Moore, Patrick. (1998). *Patrick Moore on Mars.* New York. NY: Sterling.

Sheehan, William. (1996). *The Planet Mars.* Tucson. AZ: University of Arizona Press.

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

Pen & Pixel

Figure 1 — The December 21 conjunction between Jupiter and Saturn was a sight to be seen. Gary Stone imaged our Solar System's giants two days before the pair were the closest. He shot this from the Gardiner Dam, Saskatchewan, using a 50-mm ƒ/1 lens for 2.5 seconds with a Canon Rebel SX.

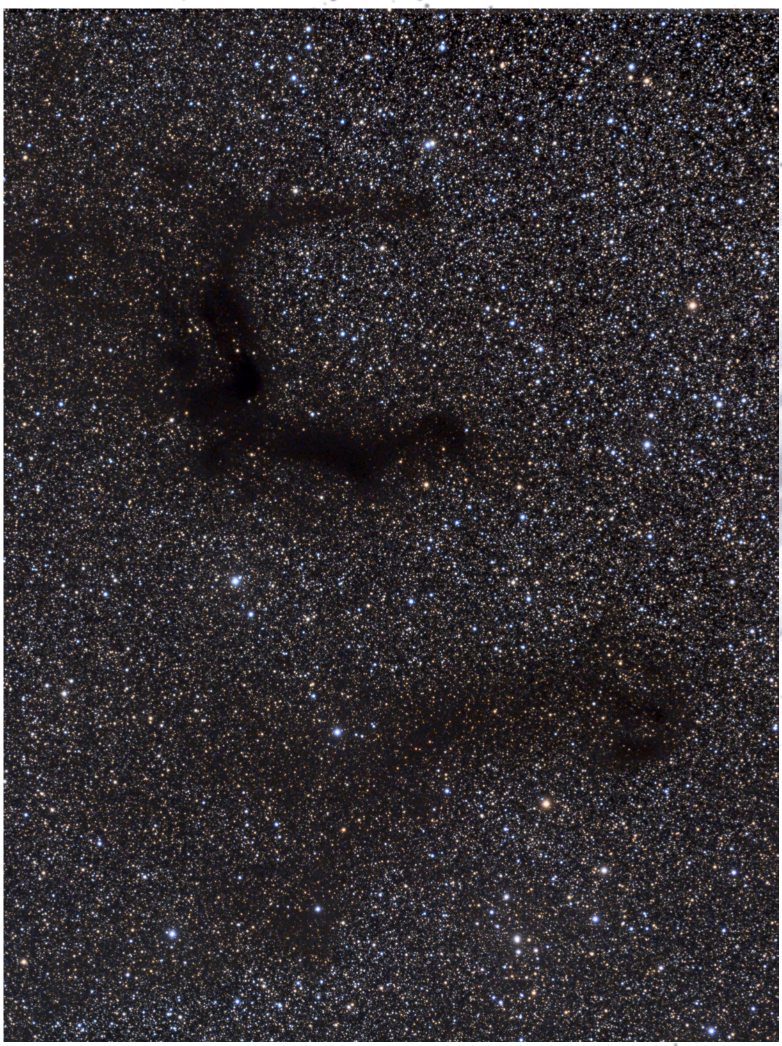


Figure 2 — Dark nebulae—thick dust that obscures any stars behind them—are some of the most amazing photographic sights in the night sky. Ron Brecher captured a pair: Barnard 142 (top) and 143, together known as Barnard's E from his SkyShed in Guelph, Ontario. Acquisition, focusing, and control of Paramount MX mount (unguided) was done with TheSkyX. All pre-processing and processing were done in PixInsight. Luminance: Sky-Watcher Esprit 150 ƒ/7 refractor and QHY 16200-A camera with Optolong UV/IR filter Chrominance: Takahashi FSQ-106 ED IV @ ƒ/3.6 and QHY367C one-shot colour camera with Optolong UV/IR filter. Luminance: 36 × 5m = 3hr00m, Chrominance: 20 × 3m = 1hr00m Total: 4 hours.

Figure 3 — Dave Dev imaged the VDB 141 (Ghost Nebula) region from Mount Forest, Ontario, in September 2020. He used an Esprit 120-mm refractor with an ASI 2600 colour camera on an EQ6 mount. He took 4-minute exposures for a total of 8 hours. The final image was processed with PixInsight.

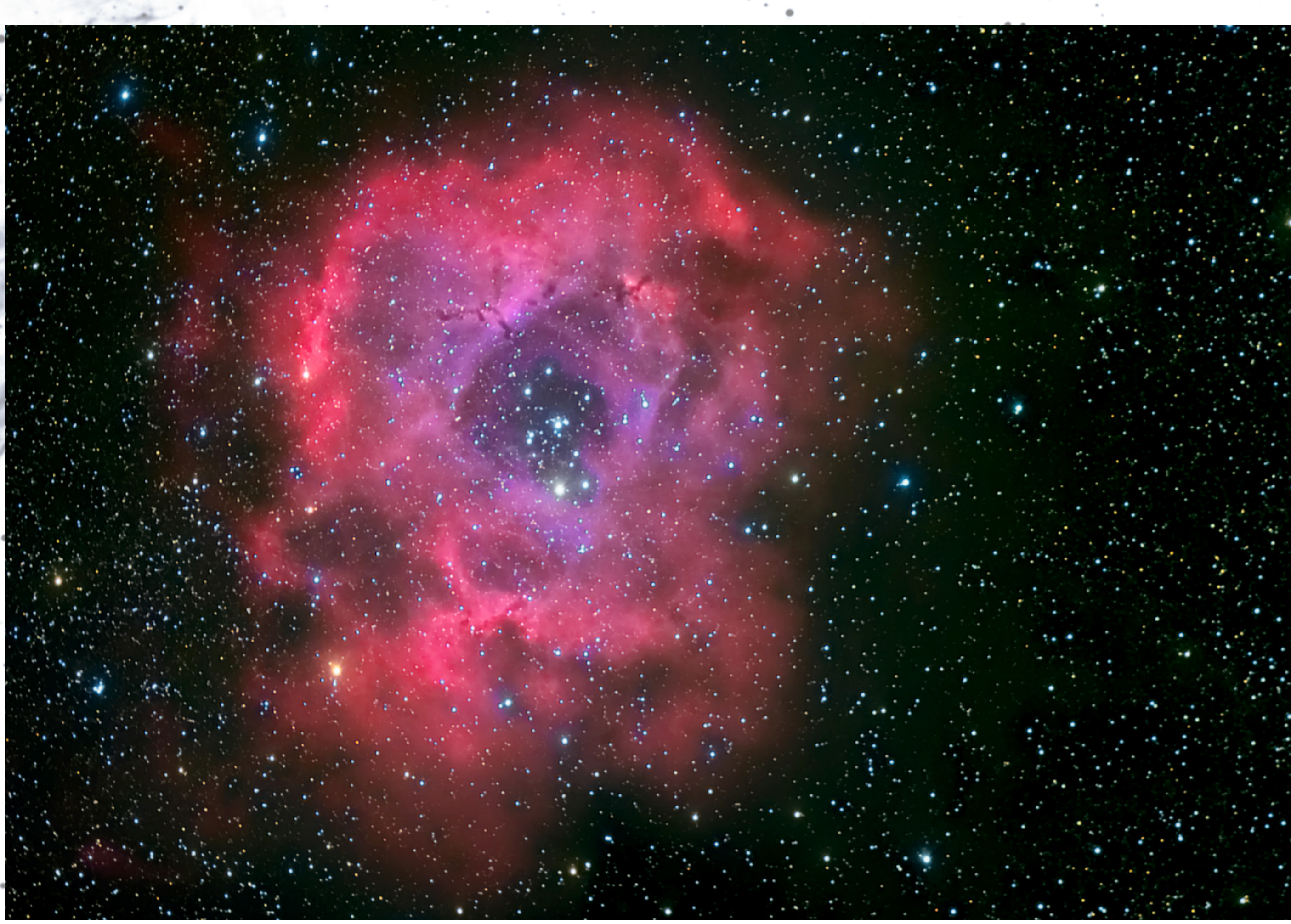


Figure 4 — Sheila Wiwchar says the Rosette Nebula is one of her favourite winter targets and she took this amazing photo of it from Kaleida, Manitoba. She used a Canon 60Da at ISO 6400 with a William Optics Star 71 on an HEQ5 mount. The final image was obtained using 100 × 3-minute subs and no flats, darks, or autoguiding.

Astronomical Art & Artifact

Charles Messier and the RASC: When Did Society Members Turn to Observing Deep-Sky Objects?

by R.A. Rosenfeld, FRASC
(r.rosenfeld@rasc.ca)

Abstract

Deep-sky observing and imaging are integral parts of modern amateur astronomy. This is often seen as a major difference between the culture of modern amateurs, and their Victorian predecessors. How accurate is this view? When did RASC members turn to the deep sky? What resources were available to them as guides? How easy was it to find Messier's list, and when did it start to be recommended as a gateway to the observation of deep-sky objects (DSOs)?

First Steps Beyond the Solar System

Charles Messier (1730–1817), "Astronomer of the French Navy" and renowned discoverer of comets, is a veritable tutelary deity for visual observers today.[1] Messier's "Catalogue of Star Clusters and Nebulae" (1774, 1780, & 1781), originally conceived as a tool for the comet hunter, has become a gateway to the deep sky. This can be seen in the place the Messier Catalogue occupies in the RASC's informal sequence of systematic observing programs, and its placement among the deep-sky lists in the *Observer's Handbook*.[2] It enjoys a primacy of foundation (1981) within the Society's present national observing programs. The role and rank of the Messier list within observing programs is not peculiar to the RASC, but is widespread among amateur groups, as epitomized in the programs of the Astronomical League.[3]

On the eve of the space age, Owen Gingerich, who played a considerable role in giving currency to the Messier list as a modern observing tool, noted that:

> "The observing repertoire of a great many amateurs is, unfortunately, limited to the moon, planets, Orion nebula, Andromeda galaxy, Hercules cluster, and a few other choice favorites….Many other worthwhile celestial objects, however, can be seen with a telescope of 6- or 8-inch aperture. The brightest of these may be found in the Messier catalogue…." (Gingerich 1954, 157).

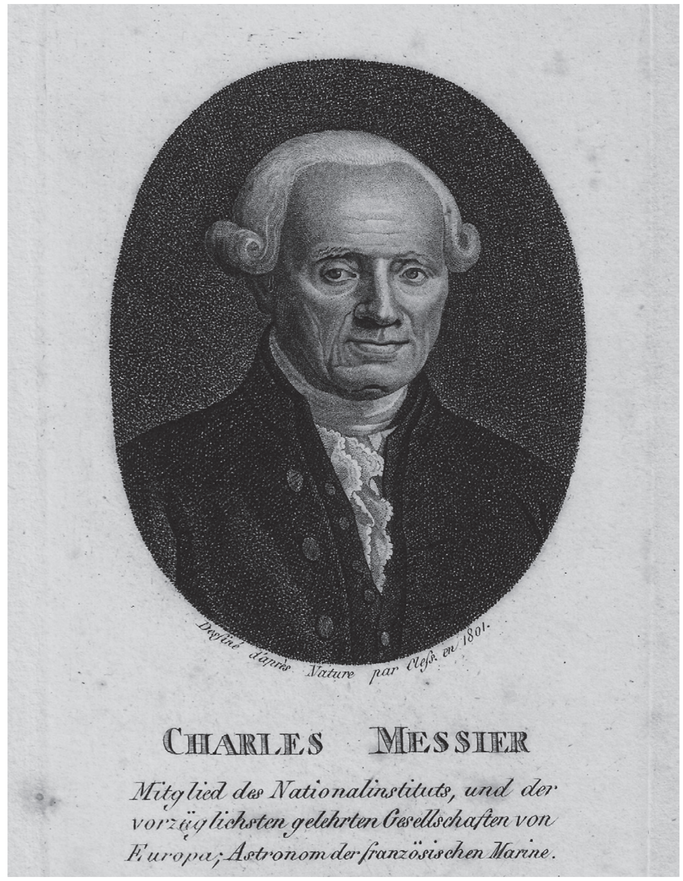


Figure 1 — Portrait "drawn from life" of Charles Messier at 71 years of age, by Jean-Henri Cless (1774–1812), stipple engraving, 1801. Reproduced courtesy of the Specula astronomica minima.

To many of us casually recalling the shaping of the modern era of amateur astronomy, the advent of the modern Messier list seems located in the mid-20th century, initiating the opening of the deep sky to ever more challenging visual and imaging goals. As amateurs' ambitions for aperture grew, so did the craving to capture ever fainter, and more-obscure objects. This changed the cultural sphere of the amateur as a whole, and not just the rarified portion inhabited by elite visual observers and imagers. It brought about more aperture for less cost, first among amateur telescope makers, then in the commercial sector catering to amateurs. In the later 1970s, Robert Burnham explained the nature of his *Celestial Handbook* as shaped by a welcomed increase in larger aperture instruments available to amateurs:

> "…earlier observing guides were written for the possessor of the standard telescope of about 1900, the classic 3″ refractor. Today's average amateur telescope is a 6″ to 12″ instrument, and the increasing availability of good quality large reflectors has opened up a vast new world of deep sky objects for the modern observer;" Burnham 1978, 7.

The relationship between increasing and more affordable aperture, and more-challenging observing lists was doubtless symbiotic. The conviction that the modern Messier list played an instrumental role in laying the groundwork for these changes almost seems self-evident. And the first modern Messier handbook, John Mallas, Evered Kreimer, and Owen Gingerich's *The Messier Album*, appeared at the same time (1978) as the first volume of Burnham's more advanced work, and eventually spawned a host of successor Messier albums and handbooks in various languages.[4]

If we conjure the amateurs' world prior to the space age, we see in our mind's eye instruments of long focal length (*f*/8 to *f*/20), with apertures in the range of 3 to 8 inches, used preponderantly on Solar System objects and phenomena, and double- and variable-star observations (definitely in second place).

How accurate is this view? More locally, when did RASC members turn to the deep sky? What resources were available to them as guides? How easy was it to find Messier's list, and when did it start to be recommended as an entry to the observation of deep-sky objects (DSOs)?

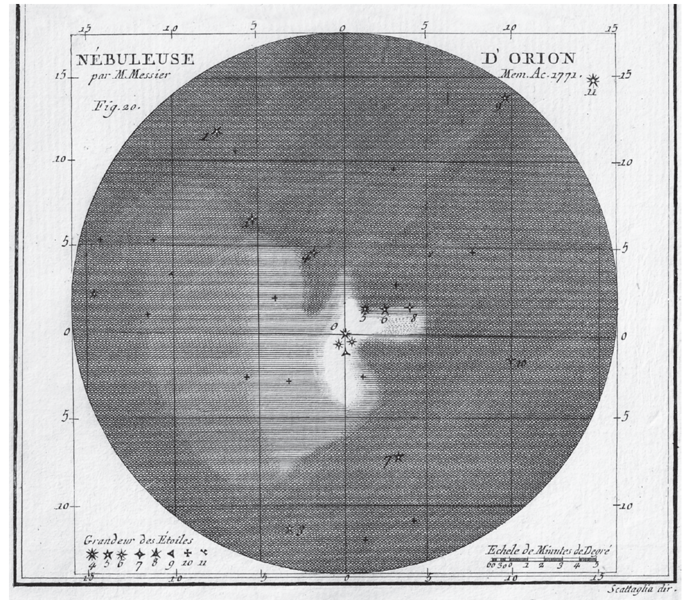


Figure 2 — Messier's drawing of the Great Nebula in Orion, M42, copper-plate engraving by Pietro Scattaglia (ca. 1739–ca. 1810), 1771. Reproduced courtesy of the Specula astronomica minima.

The early RASC and DSOs

Chris Beckett (2019) has recently written about the development of DSO lists in the *Observer's Handbook*. This study is a supplement to his results, and will bring other, and earlier types of evidence to bear on the questions posed above.

The Society's first foundation was late in 1868, and its second foundation (or reestablishment) was in 1890. The characterization of Victorian amateur observing tastes briefly sketched above does have some evidential support. There is absolutely no evidence in documents surviving from the activity of the Society in its first period of existence (1868 December 1 to 1869 December 7) that any DSOs were actively observed. Only one nebula is mentioned as a subject of discussion at the monthly meetings, the "Eta Argus Nebula" (a now archaic designation for the Eta Carinae Nebula), and the larger structure of which it is part, the Great Carina Nebula (NGC 3372). The talk was about the nature of the phenomenon based on others' observations, for the constellation could not be viewed from Toronto (Clare 1868–1869, 9, 17–19, meetings of 1869 February 2 and April 6).

The Society in its revived guise (1890–) had high hopes of establishing sections, much as the British Astronomical Association did at the time. Most of the TAS (Toronto Astronomical Society, as the RASC then was) and BAA sections were devoted to objects of the Solar System, with a few others taken up with stellar work (BAA), instrumentation (BAA), and computation (BAA) (Broughton 1994, 139, 159; Kelly *et al.* 2011, 65–128). The single exception in the Canadian organization was the Opera Glass Section (see below), which did consciously intend to include DSO observation in its program. The BAA Sections, more diverse than the RASC ones, have proved to be more long-lasting, and vastly more productive than their Canadian counterparts. Why this is so remains to be explored.

In 1897, the Society's Corresponding Secretary, George Lumsden FRAS, during the 11th meeting of the Society on June 8, left us a direct statement of the hierarchy of fields of observation for the amateur, in answer to the question "what is the best method of making the work of the Society valuable" (Lumsden 1898, 31):

> "What we had best do, therefore, is to select some one of the branches. There is, in the order in which I would place them, first, the Moon ; second, the Sun ; third, the planets; fourth, the stars of the naked eye magnitudes; fifth, telescopic objects such as the other stars and the nebulae, and sixth, comets" (35).

DSOs are nearly at the bottom of the list. It is surprising that comets are noted even lower down.

The impression of the primacy of Solar System observation among amateurs is supported by at least one advanced observing guide intended to provide instruction to those wishing to embark on meaningful observing programs gathering useful scientific data (Oliver 1888). Its editor writes: "The scope of the volume, it need hardly be remarked, has been limited to astronomical work (as distinguished from desultory star-gazing for recreation or amusement) suitable to the capacity of amateurs…" (5). The projects have mostly to do with the Solar System, and a few are stellar. The single exception, and it is an intriguing one, is investigating through observation the contours of the Milky Way (here termed "stellar distribution," 282–289).

While there is truth to the sense that Victorian amateur astronomy was Solar System dominated, the reality of the matter is rather more complicated, and more interesting. From the second foundation of the Society in 1890, DSOs were on the active observing horizon of members.

At the eighth meeting of 1891 June 16:

> "Mr. D. J. Howell, seconded by Mr. A. F. Miller, gave notice of a motion having for its object the formation of an Opera-Glass Section for the benefit of those members and others who had not taken up a regular course of observing, and also for the study of the constellations and certain of their features, including coloured, variable, and easy double-stars, *stellar-clusters, nebula etc*…instruments to be field and opera-glasses and portable telescopes" (emphasis mine; Anon. 1892, 21).

Unfortunately, I have thus far been unable to find further details revealing the specific objects observed, and of the nature of the observations.

That same year, at the 22nd meeting of the Society 1891 December 29, a paper "New Nebulae" by the notable expert on meteor showers, W.F. Denning, was presented, in which he described his discovery of two fairly bright hitherto unrecorded nebulae, and he invited Society members to engage in similar work (Denning 1892, 69–71).

On 1895 January 22, at the first meeting of the year, Annie G. Savigny: "read some notes on the telescopic study of the nebulæ, and the pleasure to be derived from it. Many of the objects within the power of a small instrument were described…" (Savigny 1896, 2).

At the fourth meeting, on March 5, A.F. Miller spoke on "The Spectra of the Nebulae," one passage of which offers a description so compelling it's as if we're beside him at the spectroscope:

> "And now you may not unnaturally ask me what is the portion of the humble amateur telescopist in investigations and researches of so difficult a character that they tax to the uttermost the skill and patience of the ablest trained observers of Europe and the United States, though armed with the most powerful and perfect instruments the world has yet seen….I answer that if he cannot repeat the observations….But to fully appreciate that of which he hears or reads, he should behold for himself some of these wonders; for despite much that may be urged to the contrary, seeing and believing will always be closely associated in the human mind. Having then adapted a simple spectrum ocular to his telescope, he readily notes the nebular line in such a familiar object as the Ring-nebula in Lyra, or another of the same class. But for larger nebulæ a slit-spectroscope becomes necessary, together with a certain degree of skill in its use. Follow me then in fancy for a few moments while, as an amateur, I show you by description, a few of the wonders an amateur's small instruments are capable of revealing. Suppose you stand beside me in my small observatory on a clear cold winter's night, such as best suits for viewing the Orion nebula. The observers should be warmly clad, but the hands are uncovered despite the frosty and nipping air, for as a cat with mittens catches no mice, similarly a gloved spectroscopist catches few lines. A small telespectroscope is adjusted to the eye end of the telescope, the slit being carefully set parallel to the diurnal motion, and the focus adjusted for greatest distinctness in the region of the green and blue. The finder serves to bring the object upon the slit, which already has been placed by mechanical adjustment in the principal focus of the objective. Bringing the eye to the ocular, at once three beautiful gaslines shine out…But now what beautiful sparkling rays are these, which, shooting up, cross the gaseous spectrum at right angles? They are the continuous spectra of the trapezium stars….A cylindrical lens over the ocular, though it spreads out the stellar streaks reveals nothing of these delicate rays, which indeed, have only been seen by means of large instruments, or on the photographic plate; and with our modest appliances our expectations must be proportionally moderate. A spectrum ocular would probably show bright lines if such exist in these stars, were it not that the series of nebular images in light of the chief nebular lines overlap and hide every thing else. Withdrawing the cylindrical lens we again see the crossing lines held steady by the driving-clock and the observer's practiced hand" (Miller 1896, 18–19).

Later in the year, at the 20th meeting on October 15:

> "Mr. Lindsay reported some observations made with an eight-inch reflector recently figured and silvered by the Messrs. Collins. The telescope was the property of Mr. E. W. Syer, of Chicago, and was to be mounted at Niagara-on-the-Lake for use during the summer months. The mirror performed exceedingly well on many difficult objects, especially the ring-nebula in Lyra. It was thought to be a matter of congratulation that this instrument was to be brought into active service in Canada" (Sparling 1896).

On 1896 July 21, at the 14th meeting, Arthur Harvey remarked that:

> "On comparing a sketch I made last winter of the great nebula in Orion, a constellation well named the California of the skies, with that given in my edition of Sir John Herschel's astronomy, published in 1842, differences are apparent which I do not like to ascribe to careless drawing…" (Harvey 1897, 48–49).

At the 18th meeting on 1899 September 19:

> "Dr. J. J. Wadsworth, of Simcoe, had forwarded some notes on the interest taken in astronomy in his locality. The

Figure 3 — Messier's observatory at the Hôtel de Cluny, Paris, steel engraving after drawing by Frederick Nash (1782–1856), 1820. Reproduced courtesy of the Specula astronomica minima.

> Doctor wrote :—…Two nights ago I had thirteen visitors, a few being ladies….Then I used the circles and showed nebulae and clusters in Hercules and Sagittarius, and the grandeur of the universe began to dawn on them as it seldom does for most men." (Lindsay 1900, 43).

And finally, in the Annual President's Address summarizing the world of astronomy of 1899, Arthur Harvey FRAS, noted that: "Double stars and nebulae are always with us, I was about to say unchanged, but that is not the case; companion stars circle about each other, while changes in the form and relative brightness of parts of some nebulae are thought to be noticeable also" (Harvey 1900, 90).

Access to DSOs in Observing Guides

Did Society members have relatively easy access to instructions for finding DSOs, before the ready availability of modern Messier lists and guides (*e.g.* Mallas & Kreimer 1967; 1970; 1978)? The most straightforward way to answer that question is to offer a survey of representative guides from the 1860s, when the Society was first founded, to the 1960s, when Mallas & Kreimer started their articles in *Sky & Telescope*.

Data on 20 guides are given below (Table 1), under the categories: i) abbreviated bibliographical citation (keyed to the full bibliography below); ii) representation of the Messier objects; iii) representation of DSOs from other catalogues; iv) clusters; v) nebulae (including planetaries); vi) galaxies; vii) notes.

Most of these guides could have been available to Society members. Foreign language guides 1, 12, & 19 are included here for comparative purposes; 19 would have been better known to French Canadian members.

Table 1

1) i) von Littrow (1866), *Atlas des gestirnen Himmels*; ii) the Messier catalogue as such is absent, but a substantial number of the more prominent objects are present, but for the most part without their M numbers; iii) a considerable number of brighter DSOs are catalogued and discussed, again usually without their standard catalogue numbers; iv) many; v) many; vi) many;

2) i) Proctor (1880; orig. 1873, the preface is dated 1868), *Half-Hours with the Telescope*; ii) the Messier catalogue as such is absent; iii) some from John Herschel's (HII) *General Catalogue*; iv) many; v) a few of the more prominent, such as M1, M31, M42; vi) a few, such as the Virgo Cluster of galaxies; vii) Note: "Orion affords the observer a splendid field of research. It is a constellation rich in double and multiple stars, clusters, and nebulae" (38);

3) i) Proctor (1887), *New Star Atlas*; ii) the catalogue as such is absent, but many, and possibly all M objects are present; they are not always given their M numbers; iii) many of the brighter objects present from HII's *General Catalogue* (GC); iv) many; v) many; vi) many; vii) Note: "With a very few exceptions, all the objects mentioned in that work [Webb *Celestial Objects for Common Telescopes*] are shown in this Atlas…all the objects in Admiral Smyth's 'Celestial Cycle,'…all the nebulæ down to the order marked 'very bright' in Sir John Herschel's great catalogue, are introduced here…" ; the *Atlas* is intended as a companion to the author's *Half-Hours with the Telescope* (see entry 2 above);

4) i) Noble (1887) *Hours with a Three-Inch Telescope*; ii) the catalogue as such is absent, but many M objects are presented in their contexts with M numbers; iii) absent; iv) many; v) many; vi) many;

5) i) Oliver (1888), *Astronomy for Amateurs*; ii) the catalogue is never mentioned, and only a handful of M objects are referred to in passing, as M31 in connection to a "variable star," M13 and M42 are cited in a quote by Sir Robert Ball concerning two of the three most interesting celestial objects to observe in the N. Hemisphere, and M57 and

M97 are mentioned in connection to comet hunting; iii) three nebular objects are cited from HII's GC in connection with comet hunting, and the nebula around Eta Carinae (η-Argus) is mentioned in a discussion centred around that star, but without its GC number; iv) few; v) few; vi) few; vii) Note: "The scope of the volume, it need hardly be remarked, has been limited to astronomical work (as distinguished from desultory star-gazing for recreation or amusement) suitable to the capacity of amateurs…" (5), work which either is almost entirely directed to objects in the Solar System, stellar astronomy, or the aurora. The single exception, and it is an interesting one, is investigating through observation the contours of the Milky Way (here termed "stellar distribution," 282–289);

6) i) Young (1889/1897), *Uranography*; ii) the list is mentioned by name, though not reproduced. Over 30% of the M objects are present, and designated by their M numbers; iii) a few of the brighter objects from "Herschel's catalogue" are listed by their number; iv) some; v) some; vi) some;

7) i) Peck (1891), *Popular Handbook and Atlas of Astronomy*; ii) the catalogue as such is absent, and not mentioned, but approximately half of the objects are present, with M numbers; iii) many of the brighter objects from HII's *General Catalogue* (1864), although the catalogue is not mentioned; iv) many; v) many; vi) many;

8) i) Ball (1892), *Atlas of Astronomy*; ii) the catalogue as such is absent, and not mentioned, but some of the objects are present; iii) HII's GC is not mentioned, but some of the brighter objects from it are by their GC number; iv) a small selection of brighter examples; v) a small selection of brighter examples; vi) a small selection of brighter examples;

9) i) Webb-Espin (1893-1894) *Celestial Objects for Common Telescopes* 5th ed.; ii) one of the latter editions of M's catalogue is mentioned, which although it is not reproduced as a continuous catalogue, the bulk of its objects are distributed throughout the text; iii) HII's *General Catalogue* is mentioned, and many objects occur in the text; iv) many; v) many; vi) many;

10) i) Gibson (1894), *Amateur Telescopist's Handbook*; ii) the catalogue is mentioned, although it is not reproduced as a continuous catalogue, but the bulk of its objects are distributed throughout the text; iii) various of HI's catalogues (likely those of 1786, 1789, 1802), Dunlop's Catalogue (1828), HII's *Observations of Nebulae and Clusters of Stars* (1833), HII's GC (1864); iii) many; iv) many; v) many;

11) i) Klein (1901), *Star Atlas*; ii) the catalogue as such is absent, and not mentioned, but some of the M objects are present, but never with M numbers; iii) HII's GC is the main source for brighter DSOs, but numbers from Dreyer's NGC are provided as well (the implication is that the NGC is subordinate to the GC!); iv) many; v) many; vi) many; vii) Note: The text is striking compared to its predecessors above—the length and style of object descriptions are much closer to those found in "modern" observing guides;

12) i) Messer (1902), *Stern-Atlas für Himmelsbeobachtungen*; ii) list of DSOs includes nearly all the M objects, identified by M number, and the catalogues are mentioned; iii) NGC is the main source for the brighter DSOs; iv) many; v) many; vi) many;

13) i) Olcott (1909), *In Starland with a Three-Inch Telescope*; ii) while absent from the index(!), "M" is one of the catalogue abbreviations employed; a little under *ca*. 25% of the M objects are present, but nearly 40% of those are not identified with their M numbers; iii) HII's GC is the source of other DSOs (it is often accorded familiar precedent over the M numbering); iv) many; v) many; vi) many; vii) Note: In Virgo "Many nebulae are to be seen in the bowl-shaped region formed by the stars (β), (η), (γ), (δ), (ε), which is called "The Field of the Nebulae" (17);

14) i) Norton (1910), *Star Atlas and Telescopic Handbook*; ii) "M" is employed as a catalogue abbreviation denoting "Messier's nebulae number"; *ca*. 20% of the M objects are described, only one of which is not identified by its M number; iii) "H" indicates an object with "Sir W. Herschel's number", and "h" an object with "Sir J. Herschel's number"—in neither case are the specific catalogues identified; iv) some; v) some; vi) some;

15) i) Riegler (1910), *The Amateur Astronomer*; ii) neither Messier nor his list are specifically mentioned; over ca. 25% of the M objects are described, but the M numbers are never given; iii) objects discovered by Herschel I & II are described and attributed, but their catalogue numbers are not given(!); iv) some; v) some; vi) some;

16) i) Olcott & Putnam (1937), *Field Book of the Skies*; ii) while absent from the index(!), "M" is one of the catalogue abbreviations employed; *ca*. 33% of the M objects are present, although 20% of those are not identified with their M numbers; iii) the "Herschel" catalogue, presumably the GC, is the source of other DSOs (it is often accorded familiar precedent over the M numbering)—one would have thought that by this date the NGC would be cited instead; iv) many; v) many; vi) many;

17) i) McKready (=Murphy) (1937), *A Beginner's Star-Book*; ii) Messier's catalogue is mentioned, though not reproduced in its entirety; *ca*. 30% of the M objects are described, and the M number takes precedent over H II's GC and Dreyer's NGC numbers; a little over 9% of the M objects

are not identified by number—these are the largest, brightest, and best known; iii) some objects are identified by either or both their H II GC and NGC numbers; iv) many; v) many; vi) many; vii) Note: The identification of DSOs in his "A Brief Observer's Catalogue of Telescopic Objects" (pp. 116-136) is noticeably inconsistent; sometimes M, GC, and NGC numbers are all given, sometimes only M numbers, and sometimes no catalogue numbers. The usage appears wholly arbitrary;

18) i) Zim, Baker, & Irving (1956), *Stars*; ii) catalogue is mentioned, but not reproduced. *Ca*. 9% of the M objects are mentioned, but only a little over half of those are identified by their M numbers; iii) a few brighter NGC objects are mentioned, but almost none by their NGC numbers; iv) some; v) some; vi) some; vii) Note: this is the simplest, most basic of the observing guides surveyed here—it displays much inconsistency in referring to DSOs;

19) i) Sagot & Texereau (1963), *Revue des constellations*; ii) the successive Messier catalogues are mentioned, the entire catalogue is given in tabular form (20), and every M object is described in considerable detail, and plotted on the charts; iii) many objects from the NGC and IC, and clusters from Melotte's and Shapley's Harvard catalogues are listed; the modern catalogue numbers have precedence over the M numbers; iv) many; v) many; vi) many; vii) Note: this is a very sophisticated observing handbook, and far and away the most advanced of all those listed here;

20) i) Howard (1967), *Telescope Handbook and Star Atlas*; ii) the Messier catalogue is mentioned—and interestingly enough it's often referred to as a list (*e.g.* 45), and the entire catalogue arranged by seasonal visibility (hence some objects appear twice) is presented before the appendices (190-202); all are described, and plotted on the charts; iii) The NGC and IC are mentioned, and their numbers have precedence over the M numbers; ; iv) many; v) many; vi) many.

Reference to Table 1 amply shows that the contents of most of the observing guides catering to amateur astronomers did provide access to and guidance for observing DSOs, from the period of the RASC's original founding to the publication of an extended series on the Messier objects in *Sky and Telescope*.

What of access to the Messier list in its entirety? It's incomplete in most of the observing guides surveyed in Table 1. Was Gingerich's publication of the list in *Sky & Telescope* (1954) the first that made it generally available to amateurs in North America? Were Mallas's & Kreimer's articles the first modern Messier guide? Or were RASC members privileged by being ahead of the game through Jack Heard's inclusion of the Messier list in *Observer's Handbooks* from 1937-1942, and the work of the Montréal Centre's Messier Club starting in the early 1940s (Williamson 1968)? The claims for that club to be the first in North America may be one RASC legend that is largely true. [5] And C.A. Chant and Jack Heard deserve credit for deciding to include the Messier list in the *Observer's Handbook* in the late 1930s.

In fact, the Messier list was available to amateurs much earlier still, and in prominent publications. None other than Harlow Shapley, with Helen Davis, published the list in useable form in 1917 in the *Publications of the Astronomical Society of the Pacific* (Shapley & Davis 1917). And in the same year appeared the first of a series of eighteen articles in *L'astronomie* by Camille Flammarion, constituting the first modern Messier guide (1917 December to 1919 April). It's surprising that it was never translated into English, but in its original language would have served the needs of French speaking RASC members very well.

Some answers…

It is clear from the material presented here that it would be inaccurate to state that Victorian amateurs wholly ignored the deep sky. There is no surviving evidence that Society members in 1868-1869 veered from a steady diet of Solar System observations, but by the 1890s, that was certainly not the case. And one of the earliest papers on the rewards and challenges of observing DSOs with small instruments was the work of a female observer (Savigny 1896). Denning even introduced the possibility of conducting original nebular research with modest instruments, demonstrating that there were still undiscovered nebulae within the reach of dedicated amateurs (Denning 1892).

Denning's example doesn't seem to have taken—here, or in Great Britain. What is undeniable, however, is that throughout the period covered here, serious work by "advanced amateurs" was not seen as lying in the deep sky. Amateurs doing real science were amateurs observing Solar-System phenomena, or double or variable stars with a program. What is odd about this is that professional nebular work in the earlier part of the period examined here was concerned with the question whether nebulae changed in appearance over relatively brief periods of centuries, decades, years, or even months, or days. And that is work amateurs could have contributed to with modest instruments (Harvey 1897; Harvey 1900). Why didn't they?

When did RASC members turn to the deep-sky? By at least the early 1890s; but most of that observing seems to have been recreational.

The April 2021 *Journal* deadline for submissions is 2020 February 1.

See the published schedule at

rasc.ca/sites/default/files/jrascschedule2021.pdf

As to the availability of resources for finding and observing DSOs, they were in major guidebooks to varying degrees throughout the life of the Society. What's interesting is that the coverage of DSOs in German guidebooks seems to have been more thorough than in English ones, perhaps revealing a difference in "national" cultures of observing—yet some of those books were translated into English (*e,g.* Klein 1901).

How easy was it to find Messier's list in print? Reasonably easy, it would seem, at least from 1917 (Shapley & Davis; Flammarion). And when did Messier's list start to be recommended as an entry to the observation of DSOs? Certainly by 1917 in French (Flammarion). What of the English-speaking world? Shapley & Davis (1917) can be interpreted as obliquely implying that use, thought it takes considerable reading between terse lines, but it's likely an idea that had to be introduced more than once before it began to gain wider currency. That instrumental use may very well have been a main motivation for the creation and continuance of the Montréal Centre's Messier Club in the 1940s—but it doesn't appear strongly stated in the surviving documents unearthed this far. It seems to be hinted at by Watson when he published the list in *Popular Astronomy* in 1949 (Watson 1949, 14), as it is by Gingerich in 1954 (Gingerich 1954, 154). But not even Mallas and Kreimer in their epochal Messier guide present the list as a steppingstone to the NGC, and beyond. It may have been Burnham who did so, by incorporating the Messier objects in a vastly larger complex of DSO choices, in which they were surrounded in print by much more challenging objects. ✶

Acknowledgements

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

References

Manuscripts, Books, and Articles

Anon. (1892). Eighth Meeting. *Transactions of the Astronomical and Physical Society of Toronto, for the Year 1891*, 21–22
Anon. (1948). Amateur Astronomers. *Sky and Telescope 8, 1* (November), 17
Ball, R.S. (1892). *An Atlas of Astronomy…* London–Liverpool: George Philip & Son
Beckett, C. (2019). The Classic RASC Observing List, The Observer's Handbooks 1943–1980: A Foundation for Deep-sky Observing in Canada. *JRASC 113, 5* (October), 204–205
Broughton, R. Peter (1994). *Looking Up: a History of the Royal Astronomical Society of Canada*. Toronto–Oxford: Dundurn Press
Burnham, R. (1978). *Burnham's Celestial Handbook: An Observer's Guide to the Universe Beyond the Solar System*, I. New York: Dover Publications, Inc.
Clare, S. (1868–1869). Minutes of the Meetings of the Society
Denning, W.F. (1892). New Nebulae. *Transactions of the Astronomical and Physical Society of Toronto for the Year 1891*, 69–71
Dyer, A. (2019). The Messier Catalogue. In (Ed.) J.S. Edgar, *Observer's Handbook 2020* (pp. 314–317). Toronto: Royal Astronomical Society of Canada
Flammarion, C. (1917). Nébuleuses et amas d'étoiles de Messier. *L'astronomie 31*, 449–453
Flammarion, C. (1919). Nébuleuses et amas d'étoiles de Messier. *L'astronomie 33*, 206–209
Gibson, F.M. (1894). *The Amateur Telescopist's Handbook*. New York: Longman, Green, and Co.
Gingerich, O. (1954). Observing the Messier Catalogue. *Sky and Telescope 13, 5* (March), 154–159
Harvey, A. (1897). Falling Stars and Meteorites. *Transactions of the Astronomical and Physical Society of Toronto for the Year 1896*, 42–49
Harvey, A. (1900). Astronomy, in Infancy, Youth and Maturity. *Transactions of the Astronomical and Physical Society of Toronto for the Year 1899*, 67–95
Howard, N.E. (1967). *The Telescope Handbook and Star Atlas*, 1st ed. New York: Thomas Y. Crowell Company
Kelly, H.L. (Ed.), McKim, R., & Williams, S. (2011). *The History of the British Astronomical Association: the First Fifty Years*, 3rd ed., B.A.A. Memoirs, 42, 1. London: British Astronomical Association
Klein, H.J. (1901). (Tr.) E. McClure, *Star Atlas…*, 3rd ed. London–New York: Society for the promotion of Christian Knowledge, E. & J.B. Young & Co.
Levy, D.H. (2019). Observing Comets. In (Ed.) J.M. Edgar, *Observer's Handbook 2020* (pp. 265–267). Toronto: Royal Astronomical Society of Canada
LeRoy, C.H. (1949). Observers Club in Pittsburgh. *Sky and Telescope 8, 6* (April), 146
Lindsay, T. (1900). Eighteenth Meeting. *Transactions of the Astronomical and Physical Society of Toronto for the Year 1899*, 42–43
Lumsden, G.E. (1898). The Necessity for Individual Effort. *Transactions of the Astronomical and Physical Society of Toronto for the Year 1897*, 30–36
Mallas, J.H., & Kreimer, E. (1967). A Messier Album–1. *Sky and Telescope 33, 5* (May), 285–287
Mallas, J.H., & Kreimer, E. (1970). A Messier Album–41. *Sky and Telescope 40, 3* (September), 152–153
Mallas, J.H., & Kreimer, E. [& Gingerich, O.] (1978). *The Messier Album: an Observer's Handbook*. Cambridge–London–New York–Melbourne: Cambridge University Press & Sky Publishing Corporation
McKready, K. (=Murphy, E.G.) (1937). (Rev.) M.K. Murphy, *A Beginner's Star-Book: An Easy Guide to the Stars and to the Astronomical Uses of the Opera-Glass, the Field-Glass and the Telescope*, 4th ed. New York–London: G.P. Putnam's Sons
Messer, J. (1902). *Stern-Atlas für Himmelsbeobachtungen…*, 2nd ed. St. Petersburg–Leipzig: Verlag von K.L. Ricker
Miller, A.F. (1896). The Spectra of the Nebulae. *Transactions of the Astronomical and Physical Society of Toronto for the Year 1895*, 9–19
Noble, W. (1887). *Hours with a Three-Inch Telescope*. London: Longmans, Green , and Co.
Norton, A.P. (1910). *A Star Atlas and Telescopic Handbook (epoch 1920) for Students and Amateurs*, 1st ed. London–Edinburgh: Gall and Inglis
Olcott, W.T. (1909). *In Starland with a Three-Inch Telescope: A Conveniently Arranged Guide for the Use of the Amateur Astronomer…* New York–London: G.P. Putnam's Sons
Olcott, W.T., & Putnam, E.W. (1937). *Field Book of the Skies: a Presentation of the Main Facts of Modern Astronomy and a Practical Field Book for the Observer*, 3rd ed. rev. New York–London: G.P. Putnam's Sons
(Ed.) Oliver, John A. Westwood (1888). *Astronomy for Amateurs, a Practical Manual of Telescopic Research in All Latitudes Adapted to the Power of Moderate Instruments*. London–New York: Longmans, Green, and Co.
Peck, W. (1891). *A Popular Handbook and Atlas of Astronomy…* London–New York: Gall and Inglis, G.P. Putnam's Sons
Proctor, R.A. (1880). *Half-Hours with the Telescope; A Popular Guide to the Use of the Telescope as a Means of Amusement and Instruction*, 7th ed. London: David Bogue

Proctor, R.A. (1887). *A New Star Atlas for the Library, the School, and the Observatory, in Twelve Circular Maps…Intended as a Companion to 'Webb's Celestial Objects for Common Telescopes'…*, 12th ed. London: Longmans, Green, and Co.

Riegler, G. (1910). (Tr.) G.A. Clarke, *The Amateur Astronomer*. London–Leipzig: T. Fisher Unwin

Sagot, R., & Texereau, J., *et al.*, (1963). *Revue des constellations*, 1str ed. Paris: Société astronomique de France

Savigny, A.G. (1896). Star Clusters and Nebulæ. *Transactions of the Astronomical and Physical Society of Toronto for the Year 1895*, 2–3

Shapley, H., & Davis, H. (1917). Messier's Catalog of Nebulae and Clusters. *Publications of the Astronomical Society of the Pacific, 29, 170* (August), 177–179

Sparling, C.P. (1896). Twentieth Meeting. *Transactions of the Astronomical and Physical Society of Toronto for the Year 1895*, 103–104

von Littrow, J.J. (1866). *Atlas des gestirnen Himmels für Freunde der Astronomie…* Stuttgart: Verlag von Gustav Weise

Watson, Paul S. (1949). Messier's Catalogue. *Popular Astronomy 57, 1* (January), 14–17

Webb, T.W. (1893–1894). (Ed.) T.E. Espin, *Celestial Objects for Common* Telescopes, 5th ed., 2 vols. London–New York–Bombay–Calcutta

Williams, T.R. (2000). Getting Organized: A History of Amateur Astronomy in the United States, Ph.D. Thesis

Williamson, I.K. (1968). The Messier Club. In (Ed.) I.K. Williamson, *et al.*, *Fifty Times Around the Sun: a History of the Montreal Centre, 1918–1968*. Montréal: Royal Astronomical Society of Canada, Montréal Centre, 35–36

Young, C.A. (1889/1897). *Uranography: a Brief Description of the Constellations…with Star Maps, and Lists of Objects Observable with a Small Telescope*. Boston–New York–Chicago–London: Ginn and Company

Zim, H.S., Baker, R.H., & Irving, J.G. (1956). *Stars: A Guide to the Constellations, Sun, Moon, Planets and Other Features of the Heavens*, A Golden Nature Guide. New York: Golden Nature Press

Endnotes

1 The list could also include Tycho Brahe (1546-1601), Johannes Hevelius(1611-1687), William (1738-1822), Caroline (1750-1848), and John Herschel(1792-1871), S.W. Burnham (1838-1921), E.E. Barnard (1857-1923), E.M. Antoniadi (1870-1944), the Rev'd Robert Evans (1937-)…the truth of the matter is that we all construct our own lists. They may reveal much about our individual views of virtuosity in observing. And the overlaps are doubtless interesting.

2 Dyer 2019 is a most usefully arranged presentation of Messier's list. David Levy has formulated the "gateway" function of the list in the context of training the eye to see both comets, and DSOs: "It is important to know the sky well before beginning a comet search program, but it is more important to know the difference between the fuzzy appearances of comets compared to galaxies, nebulae, and clusters. Observing all the objects in THE MESSIER CATALOGUE provides an excellent education in what these distant objects look like…;" Levy 2019, 266.

3 https://www.astroleague.org/al/obsclubs/messier/mess.html; https://www.astroleague.org/al/obsclubs/binomess/binomess.html. This is well illustrated in the introduction to the Leagues, program one step up from the Messier list: "For many years, Amateur Astronomers have enjoyed the challenge and excitement provided by the Messier Program of deep-sky objects. The 110 or so objects in the Messier Catalog introduced the observer to the importance of careful observing and record keeping. Upon completion of this project, however, the amateur was left somewhat in a void. He or she wanted to further the quest for deep-sky objects, but outside of the vast New General Catalog, there was no organized program that would provide that next vital step upward. With this idea in mind, the formation of the Herschel Observing Program began;" https://www.astroleague.org/al/obsclubs/herschel/hers400.html..

4 The book was based on a series of 41 articles that appeared in *Sky & Telescope* during the late 1960s and beginning of the 1970s (Mallas & Kreimer 1967; Mallas & Kreimer 1970).

5 The evidence is sparse, but it leans in that direction. Anon. 1948 announced the existence of the Montréal's Centre's Messier Club in the Amateur Astronomers column of *Sky & Telescope*, which would have afforded its existence and example wide circulation, and LeRoy 1949 announced the creation of a Messier Club by The Amateur Astronomers Association of Pittsburgh, in a latter issue of the same magazine. LeRoy implies that there were several "Messier clubs" in existence in North America, but only makes definite reference to the Montréal one. Tom Williams gives some credence to the possibility that the Montréal Centre's Messier Club was the first (Williams 2000, 342, note 44).

"He Who Controls the Spice Controls the Universe"

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

This is a review of *Cosmographia*. Chris Laurel created the software as a general interest Solar System simulator, but the Navigation and Ancillary Information Facility (NAIF) at NASA extended the open-source tool to make use of SPICE data that the public may use.

Funny Timing

During the Mars madness activities around the 2020 apparition of the Red Planet, I tried desperately to find a software tool that rendered Mars accurately and with some detail.

Two years ago, I was certain I had used an app or website that showed the planet as a three-dimensional globe with albedo features identified. I also wanted control over the presentation so I could emulate views for any type of telescope. A few weeks after opposition, while reading Unk Rod Mollise's blog, I spotted Adrian Ashford's *Mars Mapper* JavaScript tool.

"Was this what I had been thinking of?" I thought. Sadly, Ade's app does not support simulated eyepiece views.

After trying many products, I remained unsatisfied. And, sadly, I had deleted the good iOS app *Mars Atlas* (reviewed in the June 2018 *Journal*). When I heard of *Cosmographia* I perked up.

www.cosmos.esa.int/web/spice/cosmographia

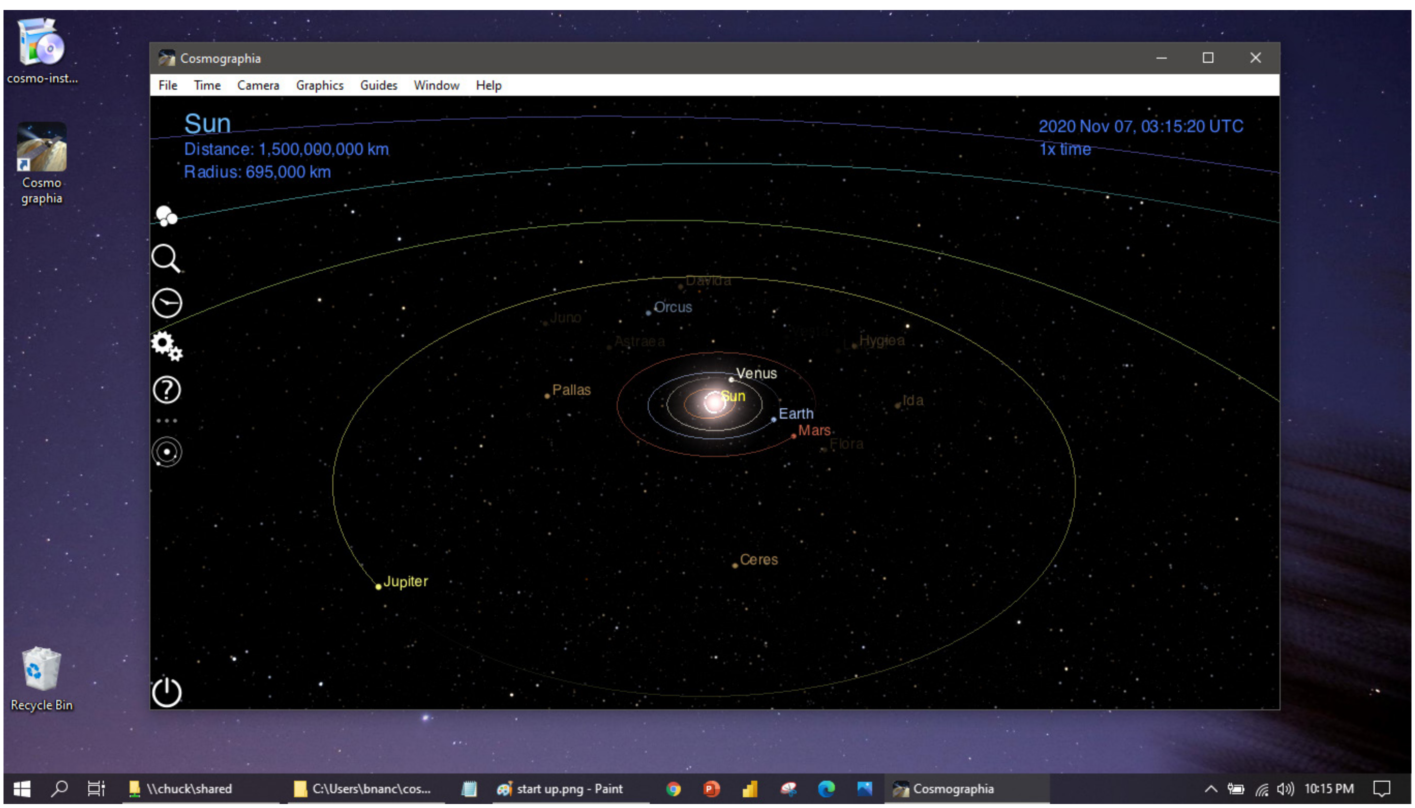
I grabbed *Cosmographia* version 4.0 for Windows. The free SPICE-enabled 64-bit application is also available for Mac OS and Linux.

Getting Going

The downloading and installation of the app was fairly straightforward, although my Chrome browser protested at receiving an EXE and the OS install process triggered an alert. I ran a virus-scan just to be sure. The setup screen was a little peculiar, without any graphics, just black text in a white dialogue but all went well. The installer did not add entries to Windows desktop or Start menu. I was fine with the former, but the latter might be a stumbling block for some users.

Upon starting *Cosmographia*, I was presented with a familiar scene (see Figure 1). In my imaginary spaceship I hovered high above the plane of the Solar System with our glowing white star at the centre. The small information panel at the top left showed I was 1.5 terametres from the Sun. The time matched my computer's clock thus the app was showing Solar System bodies as they were now. I could see the Earth overtaking Mars, Jupiter in the early evening sky, and Venus visible before sunrise. I noted various asteroids and minor planets and distant stars in the background.

Figure 1 — Starting Cosmographia *shows a view of the Solar System.*



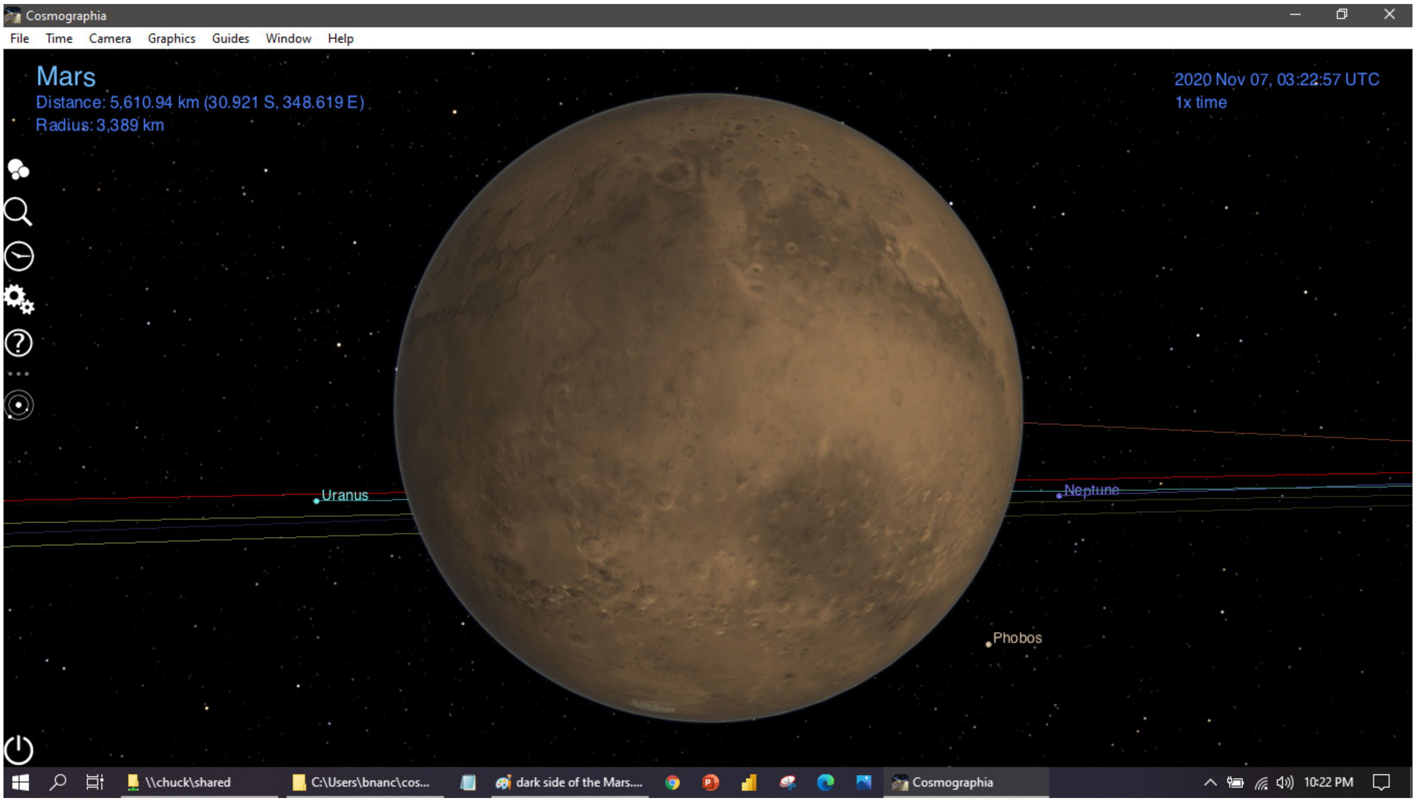


Figure 2 — A simulated view of Mars and its moons.

Discovering the Controls

A pop-up panel welcomed me and encouraged me to read the manual, but I'm a man and I don't need directions.

"Let's try some things," I thought. I clicked and dragged: it worked; I was able to pan the field. I rolled the roller on my mouse: it worked; I zoomed in and out. I always enjoy the immersive experience with these types of apps. In fact, *Cosmographia* reminded me of *Eyes on the Solar System* (reviewed in the February 2017 *Journal*).

Yearning to visit Mars, I double-clicked on the marker that triggered a go-to action and, in short order, my spaceship was in orbit about 6000 km above the oxidized surface (Figure 2).

One can easily search for objects with the magnifying glass toolbar button or browse using the Major Objects button.

I panned around Mars to put the Sun at my back, noting the south polar cap (SPC) and haze in the thin Martian atmosphere. "Hey, there's little Phobos."

In the toolbar at the left edge of the screen, I clicked the clock button. I was not surprised to see a date-time control panel with rate adjustments. For fun, I set Mars spinning rapidly then I quickly reset things with the handy Real Rate and Now buttons. Keyboard controls also permit rapid adjustments to the date.

Actuating the gears toolbar button was rewarding. On the Graphics tab, I turned on the Milky Way display and bumped-up the star brightness. The clouds of Magellan showed up.

"Cool!" I played with the star style trying Diffraction and Points, then returned to Gaussian. The Interface tab let me hide the toolbar and change the measurement units.

"Aha!" The Guides tab was most satisfying. I turned on the surface-feature labels, constellation figures and names, as well as the star names. Now I had albedo and feature nomenclature for Mars. But I thought, "Is that it?" I was looking for still more control.

I was starting to feel discouraged until I learned about right-clicking. This contextual menu revealed commands for showing the planet's direction of travel, arrows pointing to the Sun and Earth, the longitude and latitude grid lines, as well as object properties. This was good stuff although I thought it odd that these commands were not exposed in the Settings menu (Figure 3). It was only then that I noticed the full menu bar at the top of the screen with many keyboard shortcuts listed. "Duh!"

I headed off to Jupiter and was pleased to find a very detailed rendering of the planet (Figure 4) and that the application could simulate moon shadows floating across the cloud tops.

While I could not find telescopic-view controls in the software, I was pleased to add another tool to my kit for examining Mars and its features. The hyper-realistic views of Solar System bodies will be useful in educational scenarios and astronomy presentations. The software product was pretty easy to get up and running and fun to use for its early intended purpose.

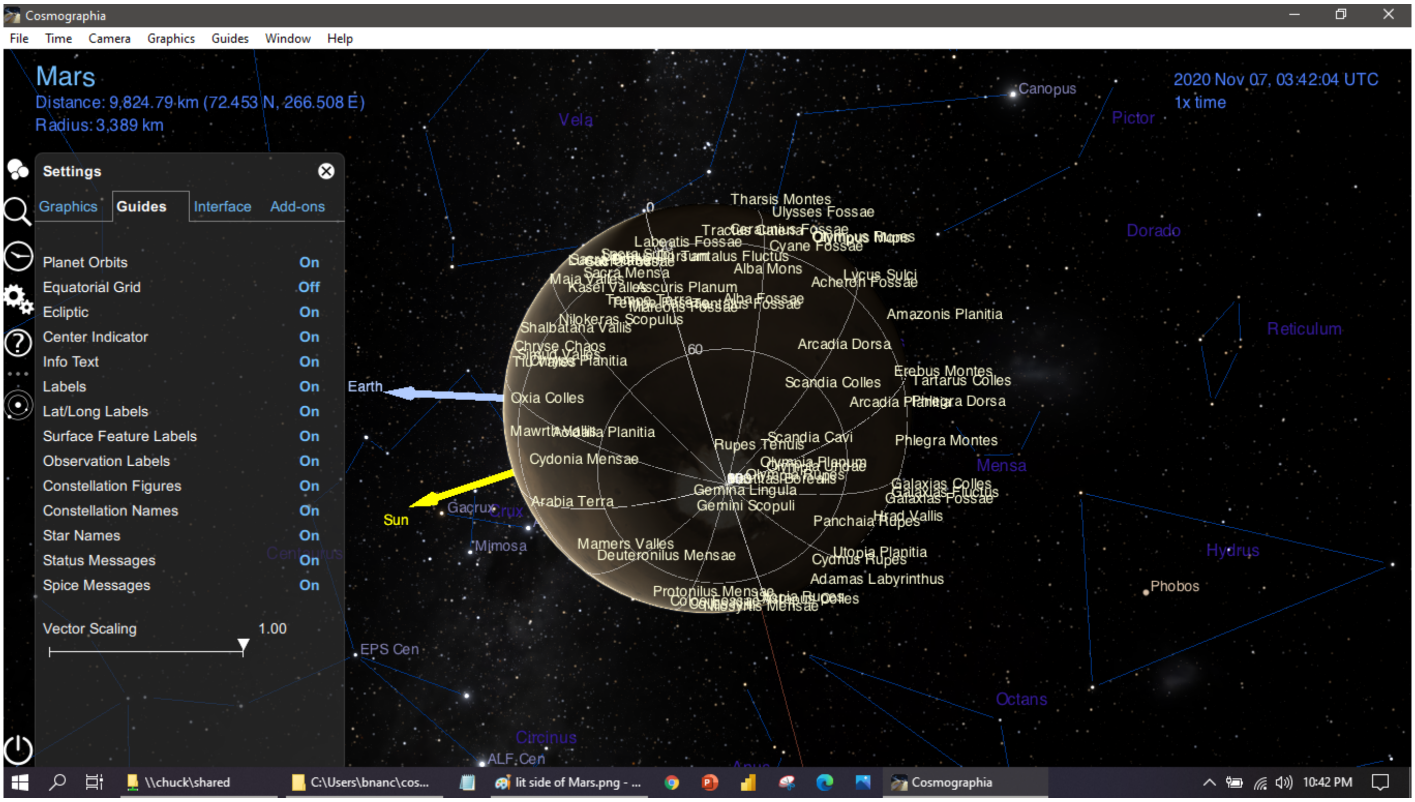


Figure 3 — Mars with surface features labelled, controlled by the gears toolbar button.

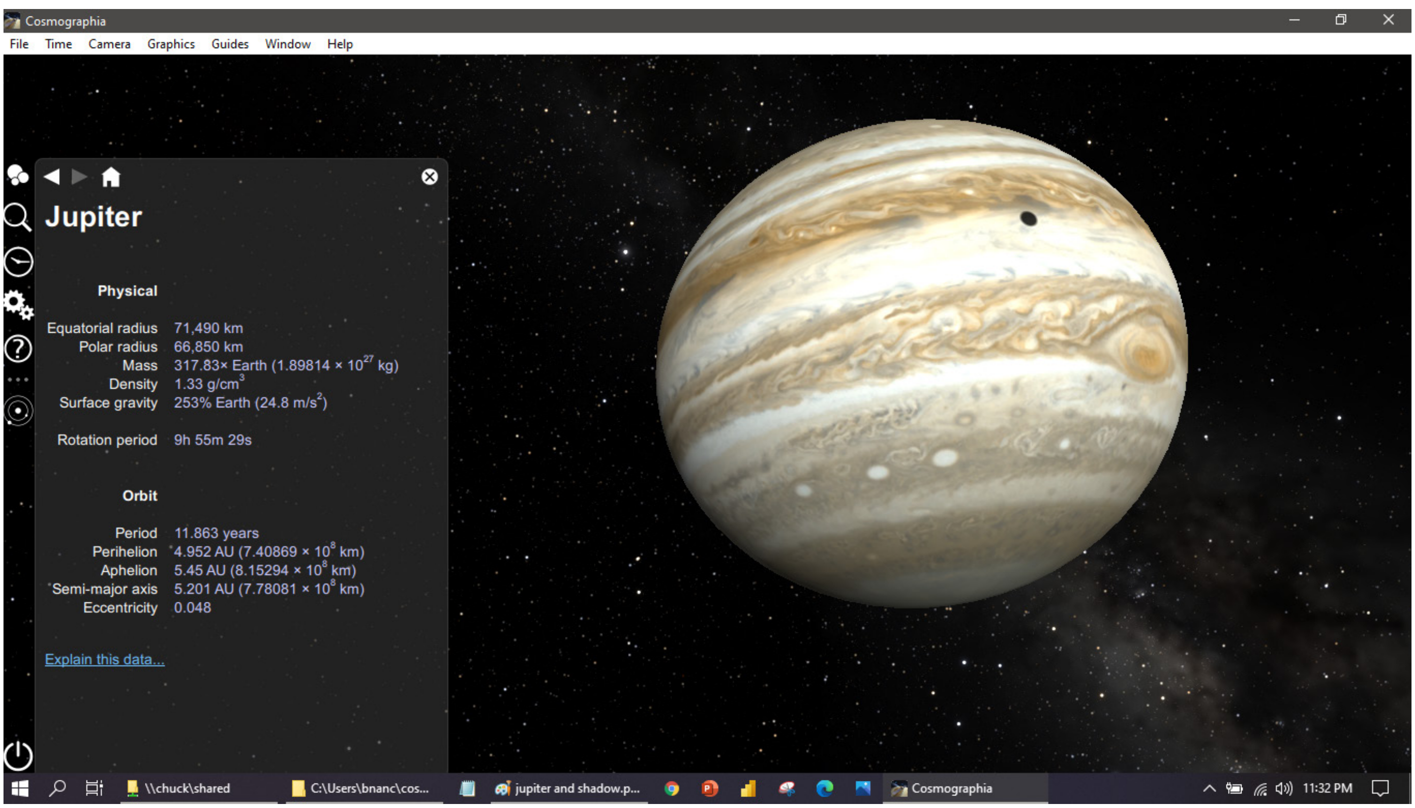


Figure 4 — Realistic view of Jupiter from orbit during a Galilean moon shadow transit.

At last, I had a look at the Add-ons list in the Settings menu. I turned on the ISS and Hubble elements, positioned in low-Earth orbit with the *International Space Station* nearby, and flew around our orbital outpost like an astronaut. Other add-ons show aurora rendered over the Earth's poles and the sunlit geysers on icy Enceladus. These are fun.

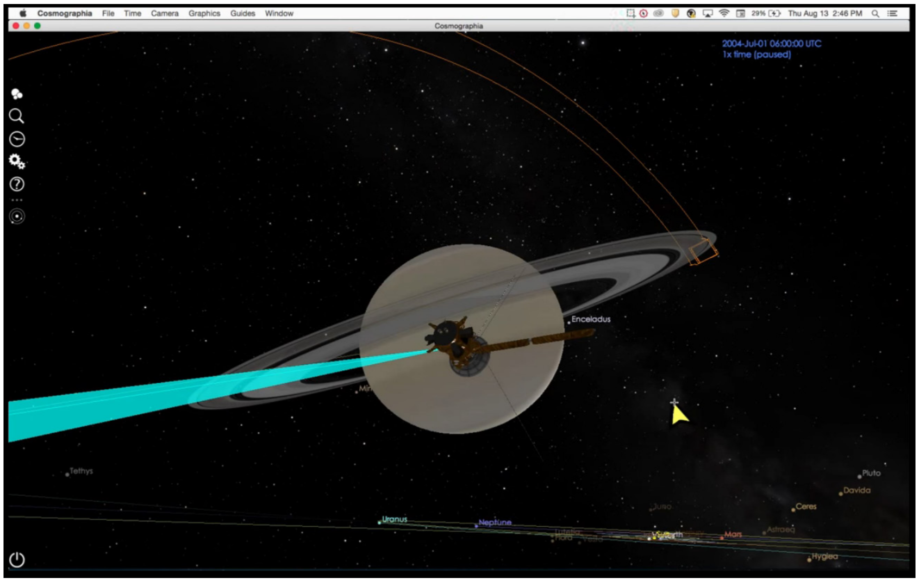


Figure 5 — SPICE data for Cassini *loaded including the spacecraft, a wide-field sensor, and the observation plan. Captured from the* YouTube *tutorial.*

Advanced Use

I was curious about other capabilities of *Cosmographia* and what SPICE meant in particular.

Was it a subtle reference to Frank Herbert's *Dune*? In the fiction novel, spice "melange" from Arrakis is used by Spacing Guild Navigators to see safe paths through spacetime. It took me a while to learn that it was in fact a rich set of logical components and data files including Solar System object and spacecraft ephemerides, instrumentation profiles, orientation information, and timing data. SPICE data or "kernels" for ESA Planetary missions are produced by the ESA SPICE Service. One can learn a great deal at the NAIF page at NASA's website.

https://naif.jpl.nasa.gov/naif/spiceconcept.html

Another NASA webpage makes an intriguing claim. The software can:

> *"…accurately model the observation geometry of planetary missions for which substantial or complete sets of SPICE data are available. With these extensions SPICE-enhanced Cosmographia should be of interest to scientists and engineers."*

I was keen to try these rich datasets to review space missions in great detail, so I watched the online *YouTube* tutorial to review procedures. The thought of creating new missions was intriguing. If I accessed the *Cassini* probe data I could fly around Saturn with a front-row seat and replicate the scientific work conducted there.

I created an FTP network connection in Windows File Explorer and initiated the transfer. "Wait, what?" To get the entire *Cassini* dataset was going to take 23 hours for all 63 gigabytes! I bailed out. "How about the *Mars InSight*," I thought. I started to load the much smaller SPICE dataset into the tool and stumbled…

It seems there is a great deal of configuration and coding work required to properly load catalogue files for craft and instrument data. I know how to program computers but I found the process bewildering and received numerous error messages on every attempt. I simply could not get it working. People smarter than me should have no trouble with this. I will continue exploring the rich and exciting SPICE capability of *Cosmographia*.

Miscellaneous Items

I confess, I did review the online user's guide and found it quite good.

There is no red-light setting, but *Cosmographia* offers stereo viewing modes. Get out the anaglyph glasses!

The tool supports various reference frames. For example, using *body fixed frame* puts the viewer in a geostationary orbit over the selected body.

And from what I can see there's no view flipping. While I cannot replicate a view for my Schmidt-Cassegrain telescope with mirror diagonal (making three reflections), it's easy to spin or rotate, which allows one to mimic the appearance in a Newtonian. I have a feeling if I can master the SPICE instruments controls, I can create a camera view to laterally invert the field.

The tool itself is remarkably small and light weight. It downloaded quickly and ran fast on my basic Windows 10 laptop. That was refreshing.

So, give *Cosmographia* a try and explore the Solar System. I'm anxious to know if someone can figure out SPICE catalogues and will share their findings.

Bits and Bytes

Stellarium 0.20.3 is out and offers many improvements, including ocular mask transparency and search history. ✶

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

Imager's Corner

Looking at Exposure

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

The idea for this issue's column came from a friend who asked about how much exposure is enough. The classic answer is to refer to the signal-to-noise ratio (SNR), wave your magic wand, and proclaim that ten days of exposure seemed to be the best answer. There is absolutely no doubt that longer exposures produce more detailed and *quieter* images, but where is the limit? How much is enough? In this edition of Imager's Corner, we will take a look at this question and see what else could be at play in determining what exposure length is required for a given image. Let's start with a review of the classic SNR approach. The SNR equation that is used to describe the data collected by a CCD camera is:

$$SNR = \sqrt{N}\,\frac{E_{obj}t}{\sqrt{E_{obj}t + E_{sky}t + N_d + R_{on}^2}}$$

Equation 1 — Classic SNR equation.

Where:

- N is the number of sub-exposures combined (assumes averaging)
- E_{obj} is the number of electrons captured per second from the object
- t is the sub-exposure time in seconds
- E_{sky} is the number of electrons captured per second from the sky
- N_d is the dark current in electrons
- R_{on} is the read noise in electrons

The SNR equation can be very enlightening. For instance, in the case where the sky is much brighter than the object (the normal in astrophotography), if we assume that the dark current is very low or properly averaged master dark frames are used in the calibration, then the equation reduces to:

$$SNR = \sqrt{N}\,\frac{E_{obj}t}{\sqrt{E_{sky}t + R_{on}^2}}$$

Equation 2 — Simplified SNR equation.

Now we can see a simple definition for a sky-limited exposure. When the first term in the denominator becomes much larger than the second, the readout noise, we are then sky limited. The only thing left then is to determine how much larger the noise from the sky photons has to be before it swamps out the read noise. There is a simple closed-form solution for this, but it is sometimes easier to see how things work from a more graphical approach. The plot below shows the ratio of the sky photon noise to the total noise as the ratio of sky noise to read noise climbs.

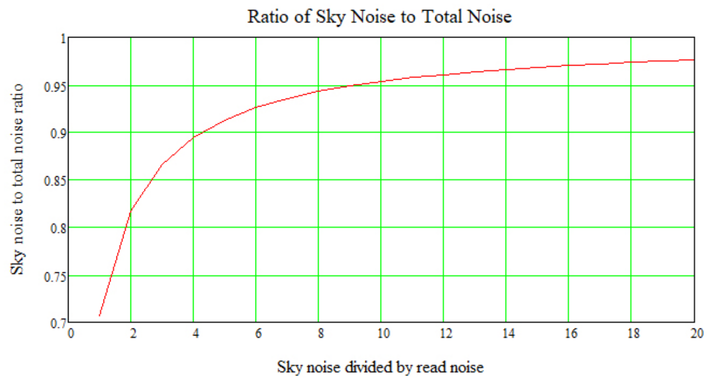


Figure 1 — How total noise changes with sky-to-camera noise ratio.

What you see from the plot is that, as the exposure time in Equation 2 is increased, then the contribution of read noise to the total noise is reduced. If $E_{sky}t$ is two times the square of the read noise, then the sky noise is just over 81.6 percent of the total noise. Looking at the plot, when the sky noise is just over nine times the read noise squared, there is a five percent contribution from the camera read noise. This is the usual definition for a sky-limited sub-exposure; we would like the camera noise to contribute less than five percent to the total noise of the image. Generally, and only because it is easy to remember, I usually aim for having the sky photon noise ten times the camera read noise squared. Now we can easily make a simple expression to take all of this into account.

$$t = \frac{10R_{on}^{2}}{E_{sky}}$$

Equation 3 — Time in seconds for sky limited sub-exposure.

Now R_{on} can be measured or simply read from your camera specification and E_{sky} can be measured from a quick test exposure. Take a five-minute exposure and read the average value of the background and simply divide by the exposure time in seconds to get E_{sky} in ADU and use your camera's gain spec to convert this to electrons per second. Pop this and the read-noise value into Equation 3 and it is a simple matter to calculate the minimum time required for a photon noise or sky-limited exposure.

Since we are talking about the sky background in the image here, then the simplified SNR equation becomes:

$$SNR = \frac{\sqrt{N} \cdot E_{sky} \cdot t}{\sqrt{E_{sky} \cdot t + R_{on}^2}}$$

Equation 4 — Simplified SNR calculation for the sky background.

With $E_{sky}t$ much greater than R_{on}^2 (ten times in fact) we can ignore R_{on} and replace $E_{sky}t$ with $10R_{on}$ so the expression further reduces to:

$$SNR = \sqrt{N \cdot 10} \cdot R_{on}$$

Equation 5 — Sky SNR.

For a single sub N=1, we have:

$$SNR = \sqrt{10} \cdot R_{on}$$

Equation 6 — Final sky SNR equation.

Now that we have the time required for a properly exposed individual sub-frame or sub, the next step is to figure out the total exposure required. If we assume that sky-limited subs allow us to ignore camera-read noise, then each time we double the number of subs we pick up root two or 3 dB in SNR. Increasing the number of subs averaged from one to two or increasing the number from 16 to 32 produces the same 3 dB increase in SNR, so you would think that shooting ever-longer total exposures will produce better data, and indeed it does for scientific purposes. But scientific data is not what we are usually working toward; generally, our goal is a pretty picture and not competition for Hubble. Here we have to look at the human eye-brain combination in order to determine the SNR required for a pleasing image.

In fact, the human eye has a threshold SNR. Above this value we can no longer see much of an improvement as SNR increases. For purposes of writing this column I did a very short, not entirely scientific, study to determine the value of this threshold. That, by the way, is the wordy way of saying that I had forgotten the value and couldn't find my reference. I created an image of a uniform brightness and then added noise to the data to create several additional images of varying SNRs and had six people rank them from the image with the least noise to the noisiest. The SNR of the noisier images varied by 3 dB, but toward the high SNR end of the scale, the images varied by 6 dB as it was impossible to tell the difference when it was only 3 dB. All six said they had no difficulty in ranking the images up to an SNR of about 42 dB. After that the images varied by 6 dB and several people still had difficulty in ranking images above 42 dB.

Figure 2 — Image on the left has an SNR of 27 dB while the image on the right has an SNR of 30 dB.

Figure 3 — Image on the left has an SNR of 42 dB while the image on the right has an SNR of 45 dB.

Because of this human eye threshold, once an image passes about 42 dB SNR, additional subs will not make a substantial visual improvement in our perception of noise. It becomes so difficult to visually see a difference above 45 dB that even a 6-dB difference is virtually unnoticeable.

Figure 4 — The image on the left has an SNR of 45 dB while the image on the right has an SNR of 51 dB.

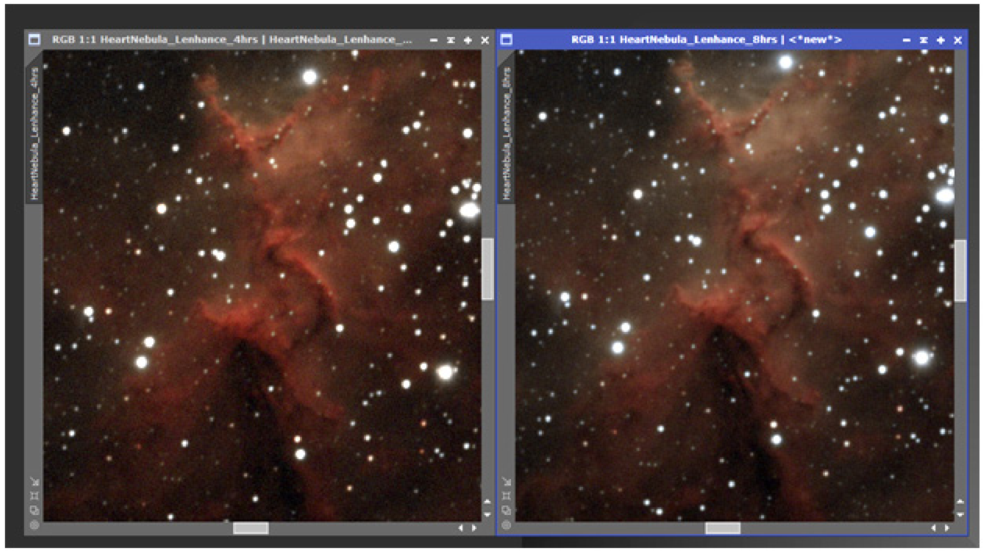


Figure 5 — 100 percent crop of both images. Image on the left is a 4-hour exposure, while the image on the right is an 8-hour exposure.

Now we have all the information we require to calculate the total exposure for the best image we can get with a given camera. Start with Equation 6 and your camera's read noise in order to calculate the SNR of an individual sub-exposure and then use the fact that doubling the number of subs produces a root 2 or 3 dB improvement in SNR to calculate the total number of subs required.

By way of example, let's look at the results for a shiny new ZWO AIS2600MC Pro camera that just arrived at my door. The read noise with a gain of 0.25 electrons per Analogue to Digital Unit (ADU) is 1.45 electrons and a 180-second exposure gives a background calibration of 756 counts after bias calibration (I didn't use darks as the camera has virtually no dark current). Dividing by 180 seconds yields 4.2 ADU per second and applying the gain gives 1.05 electrons per second. Now using Equation 3, we calculate a sky-limited sub-exposure time of about 20 seconds. Any value longer than this will be out of the camera noise and Equation 6 tells us that the single sub will have an SNR of 4.59 or 13.23 dB. Finally, solving Equation 5 for N yields:

$$N = \frac{SNR^2}{10 \cdot R_{on}^2}$$

Equation 7 — Total number of sub-exposures required for 42 dB SNR.

And using the linear value for 42 dB or 125.89 for the SNR gives us the total number of 20-second subs, 753.81. This gives us a total exposure time of just over 4.19 hours. Keep in mind that you do not need to use 20-second exposures. Any value above 20 seconds will produce about the same SNR as long as you capture a total of 4.19 hours of data.

By way of supporting the 42-dB threshold, here is an image taken by Jason Dain. He was working on a very nice image of the core of the Heart Nebula and captured 8 hours of data. He then made two stacks from the data, one with 4 hours of total exposure and one with 8. When stacked, the 4 hours of data produced an image with 42 to 43 dB SNR while the full 8 hours produced an image with 45 dB SNR.

Jason applied the same linear stretch to both images with no noise reduction. As you can see from Figure 5, there is very little visual difference between the two. This is not to say that the 8-hour exposure does not have a better SNR, just that your eye will have difficulty above 42 dB seeing any difference. Remember that the file format and your video card also have an impact on what SNR will be visible. A JPEG file uses 8 bits per colour per pixel to represent the scene. This means that the absolute best SNR supported by the format is 20log(256) or 48.2 dB. At any SNR above, this the noise will have a value less than 1 and cannot be supported by the format. As a result, at SNR's above 48.2 dB a JPEG file will, on average, clip the noise out of existence leaving a noise free image.

Please keep in mind that this technique of calculating the required exposure time is based on the background-sky SNR. It is entirely possible that the object SNR will be lower than the sky as the object surface brightness is often lower than the sky brightness. It is possible to use a similar approach to calculate the object SNR but measuring the surface brightness of the target is difficult at best. Published numbers are an integrated magnitude and do not take change in brightness over the area of the target into account. In a future edition we will take a look at a method that gives a "reasonably good" estimate of target SNR for a given exposure that takes your optical system into account with a simple calibration.

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.

CFHT Chronicles

Looking Back at the Past Decade

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

I was recently asked to compile CFHT's science highlights over the past decade with an emphasis on our Canadian PIs. The task proved challenging; how do I choose? I moved to Hawaii 17 years ago to work at CFHT, having graduated from college a month earlier with my degree in astronomy and astrophysics. I operated MegaCam, then WIRCam and ESPaDOnS for seven and a half years, observing for astronomers across Canada, France, Hawaii, and the world. When I returned in 2014, my job changed. No longer did I observe, but I share the discoveries made using CFHT with the world. I feel a deep sense of obligation; to the PIs, to CFHT, and Maunakea, to tell their stories.

I asked colleagues, our director Doug Simons, and of course our director of science operations, Daniel Devost, for their input. The list was long and varied, but two topics rose to the top: large programs and high-resolution spectroscopy. My final compilation ran 16 pages long with 8,100 words—essentially a year and a half of this column. I promise I will not just keep submitting a decade's worth of science highlights into 2022, but I wanted to take the first column of 2021 to highlight our new instruments, CFHT Legacy Survey, and two science discoveries that occurred prior to the start of this column.

I wish you a happy 2021!

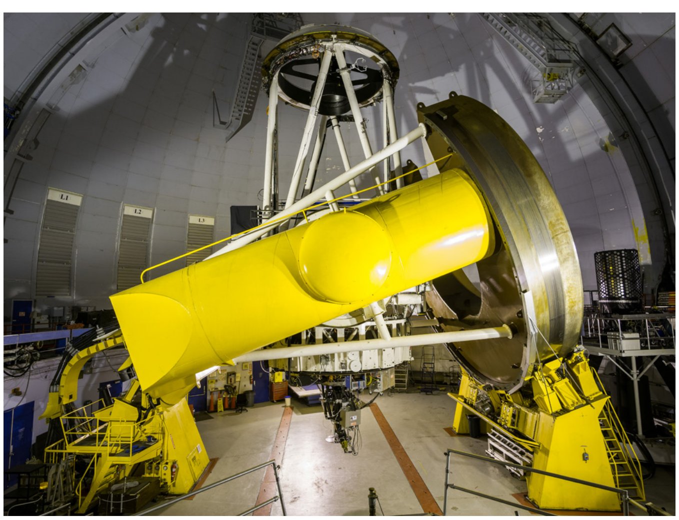


Image 1 — The Canada-France-Hawaii Telescope.

Instrumentation

Over the past decade, CFHT introduced two new instruments—SITELLE in 2015 and SPIRou in 2018. I've written extensively about both instruments in this column, but here is a brief overview of how these instruments, along with ESPaDOnS, contributed to the rise of CFHT as a high-resolution spectroscopic facility since 2010.

SITELLE is an optical-imaging Fourier-transform spectrometer (IFTS) providing integral field unit (IFU) spectroscopic capabilities in the visible (350 to 900 nm) over an 11 x 11-arcminute field of view, with a variable spectral resolution from R=2 to R>104 which allows for low- to high-spectroscopic studies. SITELLE is the direct successor of SpIOMM, a similar instrument attached to the 1.6-m telescope of the Observatoire du Mont-Mégantic in Québec. CFHT's excellent optical seeing of 0.8 arcsec measured in the R band is well sampled by the 0.32 arcsec pixel scale of SITELLE. Mounted at the Cassegrain focus of CFHT, SITELLE is the largest visible IFU at this time. The SITELLE focal plane is made of two 2048 x 2048-pixel, low-noise, e2V CCD231-42 cameras with a 5e readout noise in 1-second read time and 3.5 electrons in 2 seconds.

SPIRou, a near-infrared spectropolarimeter, optimized for high-precision radial-velocity measurements, arrived at CFHT in 2018. It is fibre-fed from the Cassegrain focus of the CFHT and built to obtain very high radial-velocity accuracy, of the order of metres/second over several years. SPIRou is designed as an echelle spectrograph that allows one to observe a reference spectrum simultaneously with the object of interest. The SPIRou Cassegain unit includes a polarimeter to change the polarization of the incident light and derive linear or circular polarization states of the observed target. The SPIRou spectrograph is embedded in a cryogenic vessel cooled down to a temperature of 80 K and stabilized at a precision below 2 mK. The spectrograph provides YJHK spectra from 0.95 to 2.35 microns in a single shot, at a spectral resolution of ~75,000.

Canadian institutions played a critical role in the development of both instruments.

A project that I have written about less in the past few years but is nonetheless critical is Gemini Remote Access to CFHT ESPaDOnS Spectrograph (GRACES). GRACES began in 2015 and is a joint CFHT-Gemini project to connect ESPaDOnS with Gemini. Engineers connected the two facilities with a 304-metre (1000 ft) fibre-optic cable taking the light from Gemini's 8-m mirror and feeding it into ESPaDOnS inside CFHT. Gemini users now have access to the high-resolution spectroscopy features of ESPaDOnS, but not the spectropolarimeter features.

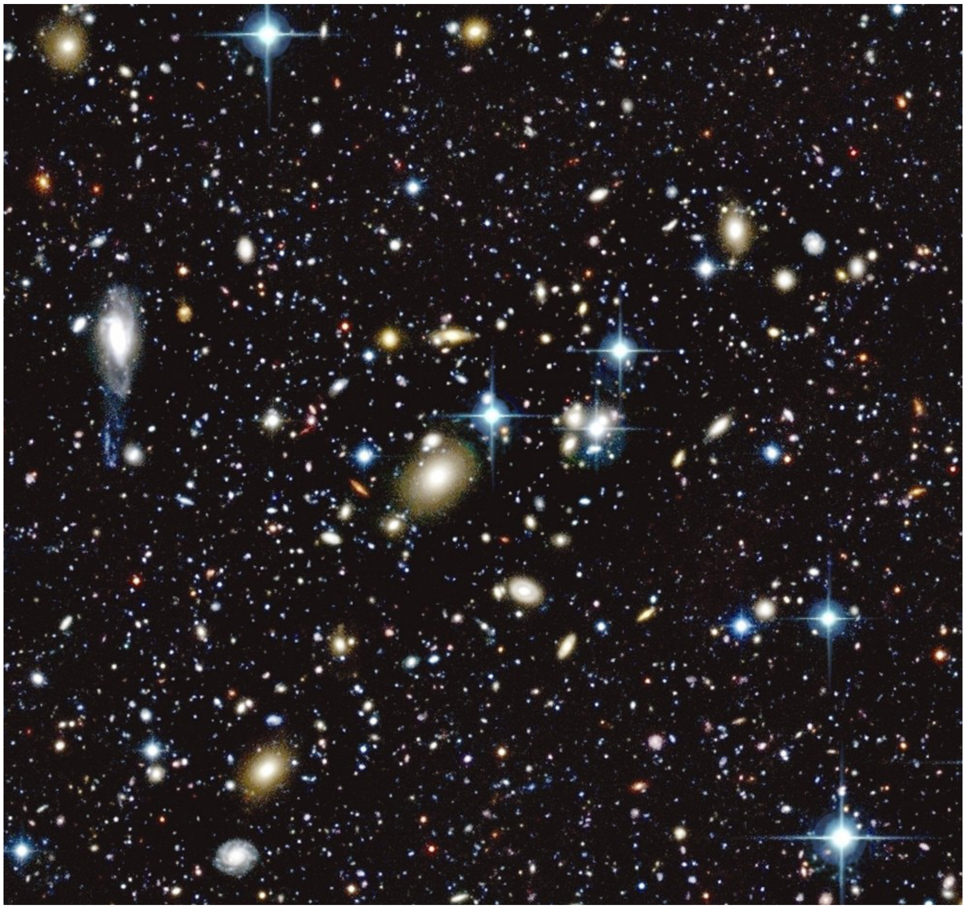


Figure 2 — This tiny fraction of a CFHTLS Deep Field reveals a wallpaper pattern of galaxies. At least a thousand distant galaxies can be identified on this image as little fuzzy dots (the crossed type disks are foreground stars from our own galaxy). The entire CFHTLS revealed tens of millions of galaxies like these. © CFHT/Coelum

The CFHT Legacy Survey

CFHT has hosted large programs at CFHT since 2003. While the first large program, the CFHT Legacy Survey or CFHTLS finished in 2009, the impacts of CFHTLS continue to be felt today, both scientifically and programmatically.

More than 2,300 MegaCam hours (about 450 nights!) over 5 years were devoted to CFHTLS, which had three components: 1) the supernova survey and deep survey, aimed at the detection and monitoring of Type Ia supernovae; 2) the wide synoptic survey, studying the large-scale structures and matter distribution though weak lensing and galaxy distribution and; 3) the very wide survey, covering a fraction of the ecliptic plane for an unprecedented sample of the Solar System population beyond Neptune.

Some significant Legacy Survey research beyond the direct cosmological outcome of the supernovae and lensing surveys is listed below. Please note this list is not exhaustive: hundreds of scientists have worked on the CFHTLS data set and a great variety of results have indeed come out:

- The survey's Deep- and Wide-field imaging revealed 1,200 candidate galaxy clusters with various masses, thus notably increasing the number of known high-redshift cluster candidates, which is an important step toward using cluster counts to measure cosmological parameters.
- The clustering analysis of 3 million galaxies in the Legacy Survey over four independent fields allowed the most accurate measurement of the mass of the dark-matter halos in which galaxies reside. The study revealed a preferred halo mass for star formation to be efficient and that this mass evolves through cosmic time.
- Thanks to the high precision of MegaCam photometry, the Supernova Legacy Survey has now started to perform measurements on the rate of supernovae at different cosmological epochs. This will furnish a measure of the amount of cosmic star formation arising over large volumes of space and encompassing a large number of galaxies.
- CFHT's Strong Lensing Legacy Survey has recently compiled a selection of 127 lens candidates in the 155 square degrees of the CFHTLS Wide survey to study the geometric distortion of gravitational-lensing effects. The results will offer a clue as to how mass, in particular dark matter, is distributed in the halo.
- The excellent image quality of the CFHTLS data allowed researchers to identify major galaxy mergers based on the presence of tidal tails and bridges. A study of some 1,600 merging systems revealed that the visible fraction of merging galaxies evolves over time and also that star formation is triggered at all phases of a merger, with larger enhancements at later stages.

The CFHT Legacy Survey gave more than just data; it provided a legacy of large programs that, along with the rise of high-resolution spectroscopy, defined CFHT over the past decade. The programs range from our Solar System to z-7 quasars, from exoplanets to Andromeda, single stars to superclusters. The scientific merit of these programs is also enormous, playing a large role in CFHT's consistent high rankings in scientific productivity worldwide.

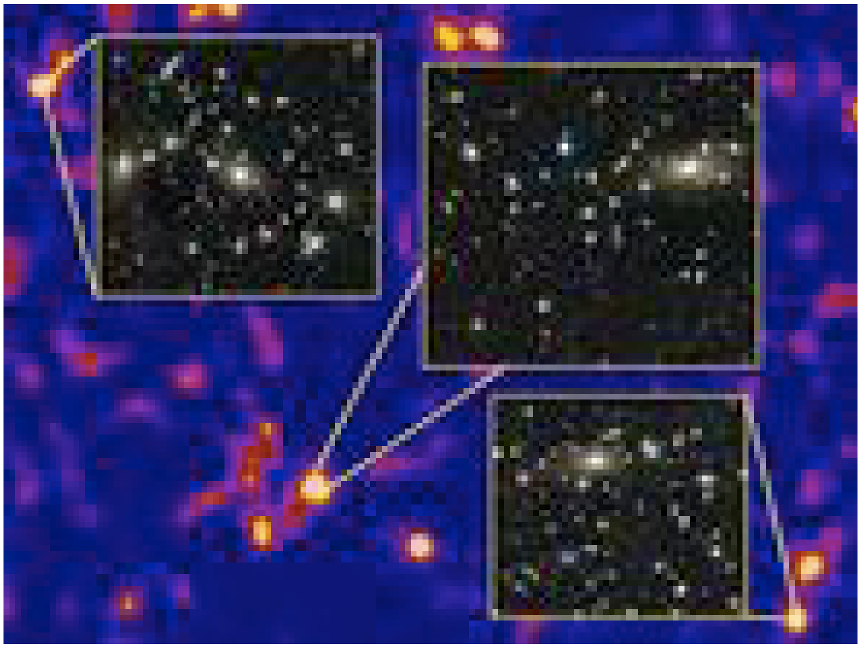


Figure 3 — The densest regions of the dark-matter cosmic web host massive clusters of galaxies. Credit: Van Waerbeke, Heymans, and CFHTLens collaboration.

2012 Astronomers Reach New Frontiers of Dark Matter (MegaCam)

For the first time, astronomers have mapped dark matter on the largest scale ever observed. The results, presented by Dr. Catherine Heymans of the University of Edinburgh, Scotland, and Associate Professor Ludovic Van Waerbeke of the University of British Columbia, Vancouver, Canada, were presented to the American Astronomical Society meeting in Austin, Texas. Their findings reveal a Universe comprised of an intricate cosmic web of dark matter and galaxies that spans more than one billion light years.

An international team of researchers led by Van Waerbeke and Heymans achieved their results by analyzing images of about 10 million galaxies in four different regions of the sky. They studied the distortion of the light emitted from these galaxies, which is bent as it passes massive clumps of dark matter during its journey to Earth.

Their project, known as the Canada-France-Hawaii Telescope Lensing Survey (CFHTLenS), uses data from the Canada-France-Hawaii Telescope Legacy Survey. This accumulated images over five years using the wide-field imaging camera, MegaCam, a one-degree by one-degree field-of-view optical imager.

Galaxies included in the survey are typically six billion light-years away. The light captured by the telescope images used in the study was emitted when the Universe was six billion years old—approximately half the age it is today.

The team's result has been suspected for a long time from studies based on computer simulations but was difficult to verify owing to the invisible nature of dark matter. This is the first direct glimpse at dark matter on large scales showing the cosmic web in all directions.

"It is fascinating to be able to 'see' the dark matter using space-time distortion," Professor Van Waerbeke said. "It gives us privileged access to this mysterious mass in the Universe which cannot be observed otherwise. Knowing how dark matter is distributed is the very first step toward understanding its nature and how it fits within our current knowledge of physics."

Dr. Heymans, a lecturer in the University of Edinburgh's School of Physics and Astronomy, said: "By analyzing light from the distant Universe, we can learn about what it has travelled through on its journey to reach us. We hope that by mapping more dark matter than has been studied before, we are a step closer to understanding this material and its relationship with the galaxies in our Universe."

For CFHT, 2012 and now, these results illustrate the strong legacy value of the CFTHLS. To this day, it enables exciting results obtained by teams from around the globe that use the CFHTLS images. Anyone (readers included) can download the data from the Canadian Astronomy Data Centre.

2014 A Very Lonely Planet (WirCam)

A gas giant has been added to the short list of exoplanets discovered through direct imaging. It is located around GU Psc, a star three-times less massive than the Sun and located in the constellation Pisces. The international research team, led by Marie-Ève Naud, a Ph.D. student in the Department of Physics at the Université de Montréal, was able to find this planet by combining observations from the Observatoire Mont-Mégantic (OMM), the Canada-France-Hawaii Telescope (CFHT), the W.M. Keck Observatory, and the Gemini North and South Observatories.

GU Psc b is around 2,000 times the Earth-Sun distance from its star, a record among exoplanets. Given this distance, it takes approximately 80,000 Earth years for GU Psc b to make a complete orbit around its star! The researchers also took advantage of the large distance between the planet and its star to obtain images. By comparing images obtained in different wavelengths (colours) from the OMM and CFHT, they were able to correctly detect the planet.

Observing a planet does not directly allow determining its mass. Instead, researchers use theoretical models of planetary

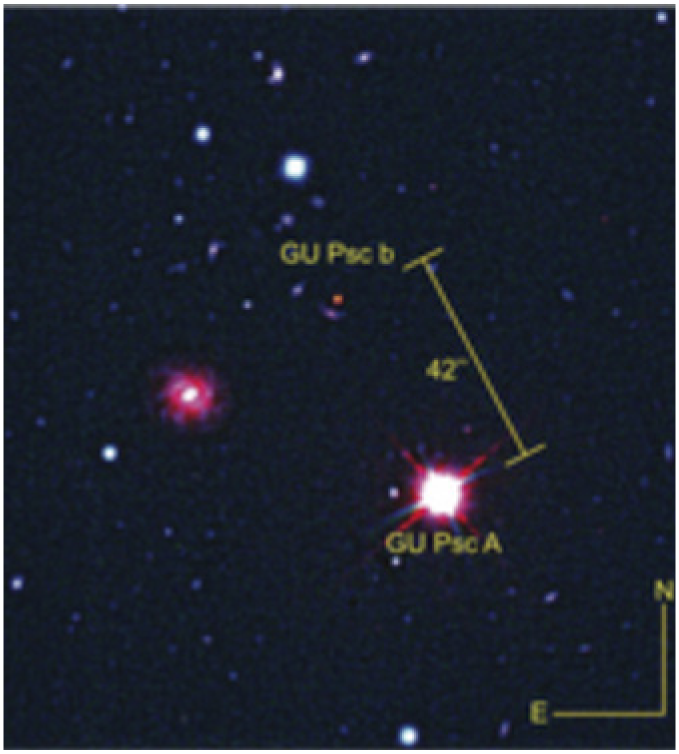


Figure 4 — The planet GU Psc b and its star GU Psc composed of visible and infrared images from the Gemini South Observatory and an infrared image from the CFHT. Because infrared light is invisible to the naked eye, astronomers use a colour code in which infrared light is represented by the colour red. GU Psc b is brighter in infrared than in other filters, which is why it appears red in this image.

evolution to determine its characteristics. The spectrum of GU Psc b obtained from the Gemini North Observatory on Maunakea was compared to such models to show that it has a temperature of around 800 °C. Knowing the age of GU Psc due to its location in AB Doradus, the team was able to determine its mass, which is 9- to 13-times that of Jupiter.

The team has started a project to observe several hundred stars and to detect planets lighter than GU Psc b with similar orbits. The discovery of GU Psc b, a rare object indeed, raises awareness of the significant distance that can exist between planets and their stars, opening the possibility of searching for planets with powerful infrared cameras using much smaller telescopes, such as the one at the Observatoire du Mont-Mégantic. The researchers also hope to learn more about the abundance of such objects in the next few years, in particular, using GPI instruments on Gemini, CFHT's upcoming instrument SPIRou, and the *James Webb Space Telescope*'s FGS/NIRISS.

PI update—Marie-Ève Naud received her Ph.D. and now is the scientific, education, and public outreach coordinator of iRex at the Université de Montréal. ✶

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

John Percy's Universe

Variable Stars I Have Known—And You Should, Too

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

Maybe I am biased, but I think that variable stars—stars that change in brightness—are the most interesting and important. In my last column, I reflected on my 60-year career as an astronomer. Here, I highlight a "Baker's dozen" variable stars that, for various diverse reasons, have made my "all-star" list. All of them are stars that you might want to point out at your next star party or mention at your next public presentation. I've previously highlighted Betelgeuse (Percy 2020) and EU Del (Percy 2019) in this column.

Algol, *Beta Persei*, is the prototype eclipsing-binary variable star. Every 2.867 days, the cool giant (K0IV) component eclipses the hot main-sequence (B8V) component, and the star fades from 2.1 to 3.4 magnitude for a few hours. In between these primary eclipses, there are very shallow secondary eclipses. The giant is the more evolved star, but has a lower mass. This is referred to as the "Algol paradox," because high-mass stars evolve faster than low-mass ones. The giant star must have lost mass in its previous evolution—a process causing the orbital period to slowly increase. Skilled amateur astronomers monitor the changing periods of this and hundreds of other eclipsing variable stars. Geminiano Montinari is credited with discovering the variability in 1667. John Goodricke (1764–1786) measured the period and proposed the eclipse mechanism to the Royal Society in 1783. Goodricke became deaf as a child and might well have ended up in an asylum. Instead, he received a good education and, together with his neighbour, Edward Pigott, made other notable contributions to variable-star astronomy before his untimely death at age 21. The Arabic name of this star, roughly translated as "the demon star," suggests that its variability may have been known centuries before. And there is strong evidence that Egyptian observers had noted the variability and measured the period 3200 years ago (Jetsu et al. 2013).

The *Crab Pulsar*, the spinning neutron-star remnant of a supernova observed in 1054 CE, is located at the centre of the Crab Nebula in Taurus. It emits radio pulses every 33.5028583 milliseconds. This period is slowly growing longer, as the pulsar radiates its rotational energy into space. The pulsar also emits optical pulses, so it qualifies as a variable star. At least three people claim—probably correctly—to have observed the pulses visually through a large telescope, prior to its radio discovery in 1968. The pulses are generated by the rotation of the pulsar and its super-strong magnetic field, so it would be classified as a rotating variable star. The first pulsar was observed earlier in 1968 by graduate student Jocelyn Bell and her supervisor, Professor Tony Hewish (Hewish, Bell et al. 1968). Hewish eventually received a share of a Nobel Prize for the discovery. Bell did not. One can argue whether this was unjustified or not, but it's a pity that the prizes can only be shared by up to three individuals.

Delta Cephei is the prototype Cepheid pulsating variable star; the variability was discovered by John Goodricke (see Algol, above). It varies between 3.48 and 4.37 in V magnitude with a slowly varying period of about 5.366208 days. Because it is bright and has two comparison stars conveniently placed (epsilon and zeta), it is an ideal variable star for beginners to observe. There is a finding chart in the *Observer's Handbook*.

Cepheids are important because there is a tight relation between their period and their average absolute brightness—now called the Leavitt Law, after Henrietta Leavitt (1868–1921) who discovered it. If the period and average apparent brightness of a distant Cepheid can be measured, then its absolute brightness can be inferred from the Leavitt Law. Then the distance can be calculated by the inverse-square law of brightness. This is one of the cornerstones of the cosmic distance scale. Together with the observed expansion rate of the Universe, it also gives one measure of the age of the Universe.

GW170817 was a gravitational wave (GW) burst observed at 8:41 a.m. ET on 2017 August 17 by three GW observatories around the world. Triangulation enabled them to locate (approximately) the position of the source on the sky. The shape of the GW signal indicated that it was caused by the in-spiral and merger of two neutron stars in a binary system. Several teams set out to look for an optical counterpart, and the first successful team was led by my young colleague, Professor Maria Drout. It was located in the outskirts of NGC 4993, a lenticular galaxy 120 million light-years away. Subsequent observations showed that the burst produced large amounts of heavy elements—those heavier than iron. This discovery marked the true birth of multi-messenger astronomy—combining data from GW observatories, and data from across the electromagnetic spectrum. Shortly after the discovery, Drout gave a presentation about her work to a teachers' workshop at the Dunlap Institute in Toronto. It conveyed the excitement of astronomical discovery better than any such presentation that I can remember!

Mira, "the wonderful" (omicron Ceti), is the prototype large-amplitude pulsating red-giant star. At maximum brightness, reached every 332 days, it can be as bright as 2nd magnitude; at minimum, it fades to 9th magnitude. A simple beginner's

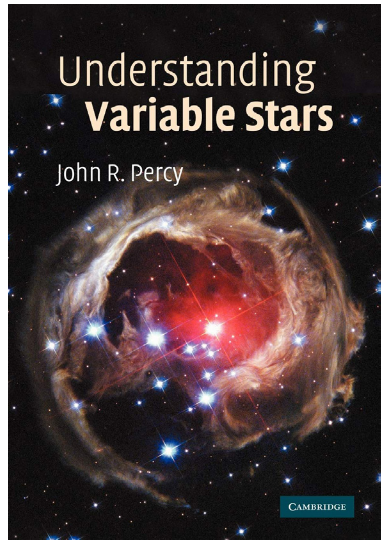


Figure 1 — Hubble Space Telescope image of V838 Monocerotis. The pulse of light, emitted when the star brightened in March 2002, moved outward through the nebula of gas and dust, ejected during the star's lifetime, illuminating successive layers of the nebula. Although the nebula looks large in this image, it is only about one arcminute across. Source: HST/NASA/ESA.

observation, then, is to go out and see whether Mira is visible in Cetus to the unaided eye. There is a finder chart in the *Observer's Handbook*. Mira is accompanied by a faint, hot white-dwarf companion in a 498-year orbit. The red giant, as it pulsates, ejects mass, some of which accretes on the white dwarf. Together, they plough through space at 130 km/s, creating a bow shock and tail. The variability of Mira was noted by David Fabricius in 1596, though it is possible that other observers had detected it much earlier. Together with Tycho's Supernova (1572) and Kepler's Supernova (1604), the discovery of the variability of Mira showed that stars were not unchangeable, despite what the Aristotelian model of the Universe required. So, Mira helped to usher in the Copernican Revolution.

Nova Cygni 1975 (V1500 Cyg) was discovered on 1975 August 29 and, within a day, it reached a maximum brightness of V = 1.69, making it the brightest nova since 1942. But it faded fast and is now at 20th magnitude. Japanese amateur astronomer Minoru Honda was credited with the discovery, though it was undoubtedly seen by others—including my 11-year-old daughter. She was at a summer camp up north, and knew how Cygnus was supposed to look, but didn't have access to a phone to tell me. So, she knew about it before I did. This nova, along with two bright novae in Delphinus (Percy 2019), helped me appreciate the important work that amateur astronomers do in discovering such objects. V1500 Cyg consists of a red-dwarf star, which is depositing material on a highly magnetized white-dwarf companion.

Polaris, the North Star, is the best-known star in the northern sky. It's not the brightest, as many people think. It ranks #47. But it's interesting—it helps us find north. Its angle above the northern horizon is equal to our latitude, almost. It's a triple star. The brightest component is a supergiant (F7Ib) and a 3.9696-day Cepheid pulsating variable star. The pulsation period is slowly increasing, as a result of the star's evolution; that's one way that astronomers can test their models of stellar evolution. In the 1980s, my graduate student Armando Arellano discovered that Polaris's pulsation amplitude had decreased significantly (Arellano Ferro 1983); it is now about ten times less than it was a century ago. Polaris is difficult to observe photometrically, so most recent studies have used radial-velocity (Doppler) observations to study the pulsation. Despite being the closest Cepheid, its distance has been controversial. The astrometric satellite *HIPPARCOS* gave 433 ly in the 1990s, but at least one other study gave 323 ly. The latest astrometric satellite *Gaia* gives 445.3 ly, which should settle the question.

Proxima Centauri, a faint red dwarf (M5.5Ve) in the Alpha Centauri triple system, is the closest star to the Sun. It's also a variable star—a flare star, and an 82.6-day rotating variable with starspots. It's therefore the nearest variable star to the Sun. More important: it undergoes small, complex, periodic fadings that indicate it has a system of exoplanets around it. And one of them is Earthlike: the temperature is such that water could exist on its surface in liquid form. Habitable planets must be numerous! Proxima Centauri is therefore a very exciting star that gets mentioned in many of my public talks!

RU Camelopardalis, the "reluctant Cepheid," is a rather obscure 9th-magnitude 22-day Population II Cepheid pulsating star. In 1965, however, it did something very unusual (though see Polaris, above), it stopped pulsating—almost. This was discovered at the Dunlap Observatory by my fellow graduate student Serge Demers and our supervisor, former RASC National President Don Fernie (Demers and Fernie 1966). There was a flurry of observations and publications that showed the period was still 22 days—but with some random "wandering"—and the amplitude varied between 0.0 and 0.3 magnitude on a time scale of hundreds of days. Observations are now much sparser, but data from the All-Sky Automated Survey for Supernovae show that this behaviour has continued. Since we still don't know why the pulsation stopped (almost) or why the period and amplitude vary, more sustained observations are needed. RU Cam reminds us that skilled amateurs can still contribute to astronomical research in many ways, such as by monitoring variable stars—like RU Cam—with unusual properties or behaviour.

Supernova 1987A was discovered on 1987 February 23 by University of Toronto astronomer, Ian Shelton, working at the U of T Southern Observatory in Chile. It was independently noticed by at least two other observers. SN1987A was the brightest supernova since Kepler's Supernova in 1604, reaching V = 2.9, even though it was about 160,000 light-years away in the Large Magellanic Cloud. Following its discovery, some of astronomy's most powerful instruments were trained on it, revealing much about the supernova process—the synthesis of heavy elements in the explosion, the nature of the recently discovered neutron star remnant left behind, and the interaction between the ejected gas and dust and the surrounding interstellar material. Neutrino observatories had already noted a pulse of neutrinos, coincident with its optical discovery. The supernova "victim" turned out to be Sanduleak-69 202—the first observed demise of a known, catalogued star. Following the discovery of SN1987A, there was great publicity and celebration in Toronto, much of it organized by the late Bob Garrison, a past President and Honorary President of the RASC.

V725 Sagittarii is one of the most truly fascinating variable stars that I have encountered during my 60-year career. It is an obscure 9th-magnitude variable star with a unique story: during the last century, it has transformed from a 12-day Cepheid pulsating variable star into a 90-day yellow-giant pulsating variable (Percy et al. 2006). That paper illustrates how different people can engage with and contribute to astronomical research: Percy and Wehlau were professional astronomers, Molak was a high school student, and Lund, Overbeek, and Williams were skilled amateur astronomers. This star is in a rare and peculiar phase of evolution, and clearly needs systematic, sustained observations (see my comment on RU Cam!).

V838 Monocerotis. In 2002, this previously unheralded star brightened by ten magnitudes to V = +6.75, emitting a pulse of light that moved outward through the surrounding gas and dust ejected during the star's lifetime, illuminating successive layers of the nebula. This "light echo" phenomenon produced a sort of "CT-scan" of the nebula. I was so intrigued by the images of V838 Mon that I used one on the cover (Figure 1) of my book Understanding Variable Stars (Cambridge UP, 2007). The cause of the outburst is still not known, though there is no shortage of hypotheses. ✶

Acknowledgements

This article has made use of the SIMBAD database of stellar information, operated at the CDS in Strasbourg, France.

References

Arellano Ferro, A. (1983). Period and amplitude variations of Polaris, *ApJ 274*, 755.

Demers, S. and Fernie, J.D. (1966). RU Cam: a Cepheid which has stopped pulsating? *ApJ 144*, 440.

Hewish, A., Bell, S.J. et al. (1968). Observations of a rapidly-pulsating radio source, *Nature, 217*, 709.

Jetsu, L. et al. (2013). Did the ancient Egyptians record the period of the eclipsing binary Algol – the Raging One? *ApJ 773*, A1.

Percy, J.R., Molak, A., Lund, A., Overbeek, D., Wehlau, A.F., and Williams, P.F. (2006). V725 Sgr: from population II Cepheid to red semiregular variable, *Publ. Astron. Soc. Pacific, 118*, 805.

Percy, J.R. (2019). My favourite constellation: Delphinus, *JRASC, 113,* 258.

Percy, J.R. (2020). What's up with Betelgeuse?, *JRASC, 114,* 134.

John Percy FRASC is Professor Emeritus, Astronomy & Astrophysics, and Science Education, University of Toronto, and a former President and Honorary President of the RASC.

Dish on the Cosmos

Biosignatures and the Phosphine Mystery

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

Four years ago, I wrote about the coming Square Kilometre Array (SKA), a new radio telescope being built across southern Africa and Australia that will eventually be the largest telescope on Earth. The SKA is a radio interferometer, which uses the timing of signals arriving at different antennae to improve the resolution of the overall telescope. After decades of planning, 2021 promises to be a major year for this new telescope, which will usher the next generation of radio astronomy.

This year, nations across the globe are committing to building the telescope. The principal SKA countries have already joined together through a treaty to commit to the construction and long-term support of the telescope, and Canada is considering joining this effort. The major challenge in building the SKA isn't the radio telescope itself, but rather the vast data rates the telescope will generate.

The massive jump in data rates is due to two reasons. First, the amount of data an interferometer generates depends on the numbers of telescope pairs in an array. Now, the largest arrays have approximately 50 antennae but the SKA will push this number up to into the hundreds, leading to a 30-fold increase in the data rate.

The other main challenge will come from the vastly larger data rates that can be generated by the radio receivers on each individual antenna, producing hundreds of millions of measurements per antenna each second. With these two drivers, the SKA will push an internet's worth of data between the antennae and the *correlator*, the large computer at the centre of the array that combines the signals of all the antennae. However, even with heavy processing, astronomers will still have to comb through terabytes of data in search of the next discoveries.

The SKA will not be open for science for another five years, but even now we are getting ready for the data challenges. To prepare, Australia and South Africa have built precursor telescopes, that are being used to test the designs that will eventually enable the SKA. The South African telescope is called MeerKAT, an expansion of the Karoo Array Telescope (KAT) where the Karoo is the name of an interior desert region in South Africa. The Australian telescope is called the Australia SKA Pathfinder or ASKAP. After years of solving the engineering challenges of these new telescope technologies, they are both starting to produce amazing new views of the radio sky.

Figure 1 shows an iconic image from the MeerKAT telescope, displaying the radio emission pointed toward the Milky Way Galactic centre. The bright region in the centre is the plasma in the environment near the central black hole. The most striking features, however, are the myriad of bubbles that are

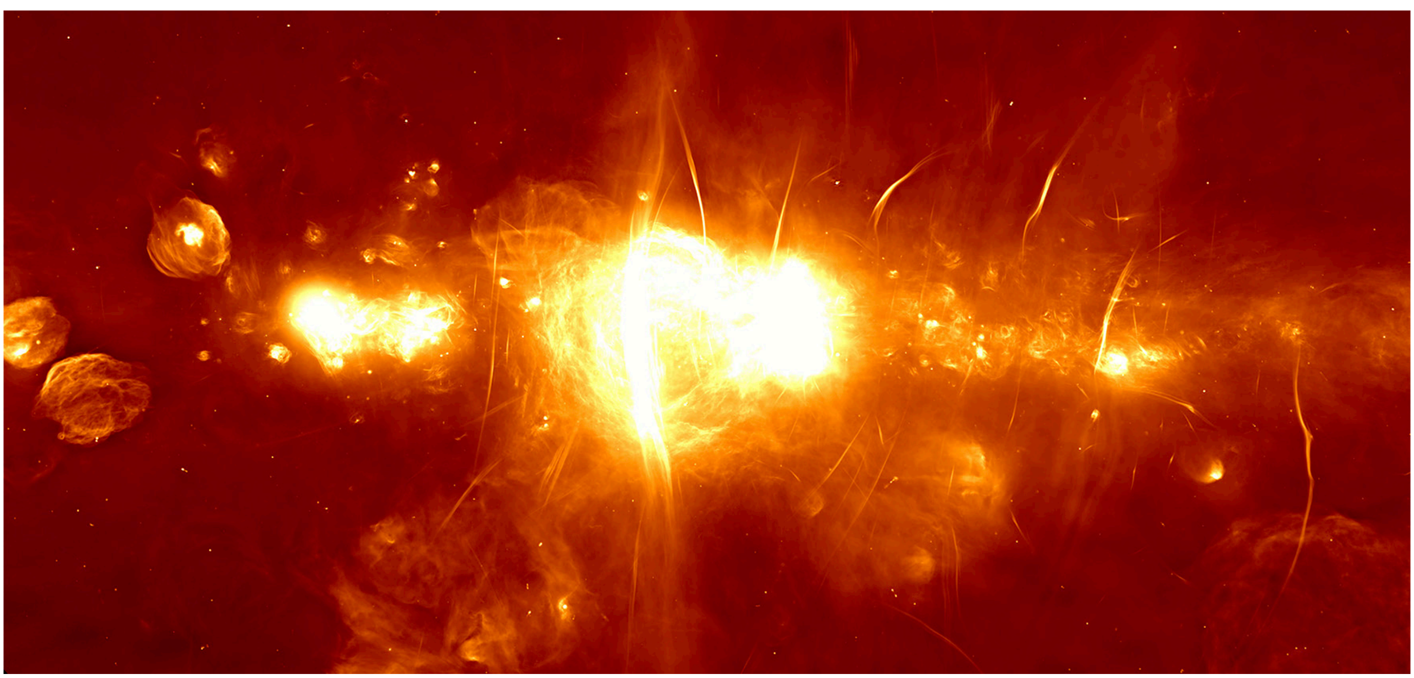


Fig 1 — Image of the centre of the Milky Way taken using the MeerKAT telescope. The image shows off the vastly improved quality that is enabled by the SKA precursor telescopes. The large bubbles are the remnants of supernova explosions and the long stripes show where high energy particles are confined in tubes of magnetic flux. Image Credit: MeerKAT, South African Radio Astronomy Observatory.

the remnants of supernova explosions detonating in the dense nuclear region. The other notable feature are the long stripes of emission. These are the images of tubes of magnetic flux that have trapped high-energy particles that give off radio light when trapped inside the tubes. This best-ever image of the galactic centre in radio dramatically improves on previous work thanks to high quality wavelengths of imaging and sensitivity of the 64 new antennae in the MeerKAT array. Radio images like this will become commonplace in the SKA era.

Where MeerKAT went deep to make new discoveries, ASKAP has developed the technology to go wide. Figure 2 shows a wide-area map of the radio sky made with ASKAP. While a telescope like MeerKAT would have to build up this image in a series of hundreds of individual images, ASKAP captured this image in just two snapshots of the sky.

The 4° x 6° field of view (96 times larger area than a full Moon) on ASKAP is made by placing a series of receivers in the focal plane of the ASKAP dishes. Each receiver looks at a slightly different part of the sky, and links up with the receivers on the other ASKAP antennae to produce interferometric images. With this wide-area snapshot capability, ASKAP has planned surveys of the radio sky that rely on seeing huge amounts of space. In this case, the telescope is tuned to observe the atomic hydrogen gas in galaxies. By surveying a galaxy cluster, ASKAP immediately sees every galaxy at once. The atomic gas is being measured using a radio spectral line of hydrogen with a known frequency, where the physics of the atom has tuned into a specific cosmic radio station. By comparing the observed frequency to the known frequency, astronomers are measuring the velocity of the gas relative to the telescope using the Doppler effect. These differences in

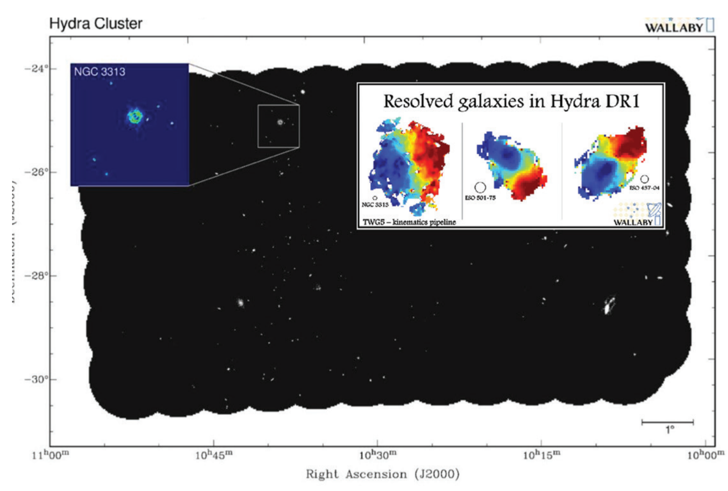


Fig 2 — Preliminary atomic gas map of the Hydra galaxy cluster made using ASKAP. Each individual point shows a galaxy's atomic hydrogen gas. Image credit: T. Westmeier. The inset panels zoom in on galaxies in the field of view. The maps show the velocity along the line of sight with one side of the galaxy coming toward us and one moving away from us. By measuring this rotation map carefully, we can infer the mass and therefore the amount of dark matter in a galaxy. Image credit:T. Westmeier and K. Spekkens

velocity are allowing astronomers to map out the velocity of galaxies as the move around giant clusters.

The MeerKAT observations are also being used to make maps of how individual galaxies are spinning. The inset panel on Figure 2 shows the velocity maps from individual galaxies extracted from ASKAP data as part of the WALLABY survey. The observations are showing how these galaxies have one side of the galaxy coming toward us and one side moving away, which is the telltale signature of galaxy rotation. However, each galaxy has a different velocity map, which can be used to tell us something about how the galaxy is rotating. In particular, since the galaxy rotation is maintained by gravitational force, the speed of rotation can be used to tell us about the true mass of the galaxy, including both the visible matter we can measure and the dark matter that is only detected through the gravitational effects.

Canadian astronomer Kristine Spekkens (Royal Military College / Queen's) is leading the effort to use these ASKAP data to carefully measure how each of these galaxies is rotating, which can be used to deduce a wealth of information about their internal structure and the amount of dark matter in each of the systems. The fraction of dark matter is a key measurement to make across a wide range of galaxies since it can illuminate exactly how dark matter behaves. The best models of dark matter that we have seem to have difficulty in predicting the number and types of galaxies that should form. The caution in that statement comes from the limited measurements we have on galaxies. Only the atomic gas reaches far into the outskirts of the galaxies, where the starlight fades away, making this the best tool for carefully measuring a galaxy's mass. Before ASKAP observations, galaxy mass measurements took painstaking efforts but the ability to measure thousands of galaxies in a single observation will allow Dr. Spekkens and her collaborators to test whether our dark-matter models really can't explain what we are seeing.

When not deciphering the mysteries of dark matter, Dr. Spekkens also represents Canada on the SKA Board of Directors. With the construction of the main part of the SKA due to begin this year, she is working with astronomers and government to define the Canadian role in this new, world-class telescope. It is a challenging time to contemplate building a new telescope. The past year has been challenging globally, and governments and people have had vast concerns from the COVID-19 pandemic and the damage to health and livelihood that the virus has wrought. While astronomers yearn for the new discoveries that the SKA would bring, we must seek a future that balances the quest for new knowledge against the broad needs of humanity. ✶

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

A Planetary Grouping: Mercury, Venus, and Jupiter

by David Garner, Kitchener-Waterloo Centre
(dgarner@celestialreview.space)

Since last September, many of us have been watching Jupiter getting closer and closer to Saturn. By late December, the two planets appeared to be touching.

This conjunction of Jupiter and Saturn happens about once every 20 years, but there has not been a conjunction this close since 1623 July 16. Quite a spectacle!

Jupiter and Saturn began moving apart after that but were still visible in the early evenings. By January, the two planets became lost in the glare of the Sun.

According to Jean Meeus (*Math Astronomy Morsels*), a planetary grouping refers to three or more naked-eye planets that can fit inside a circle with a diameter of at most five degrees. Generally, between any three of Mercury, Venus, Mars, Jupiter, and Saturn, this occurs about once every year or two.

For the first two weeks of February watch as Mercury, Venus, and Jupiter move closer and closer together. By this time, Saturn will have moved a bit farther west.

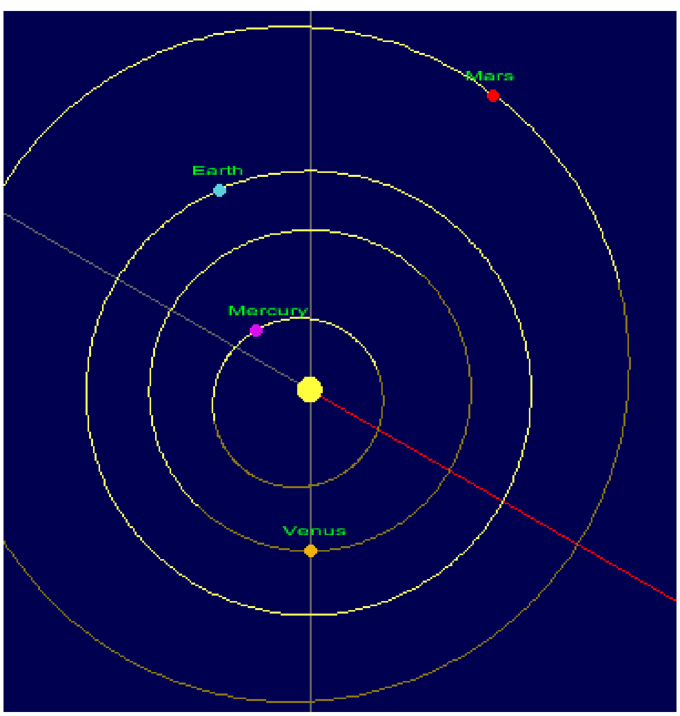


Fig 1 — Inner Planet positions on 2021 February 13.

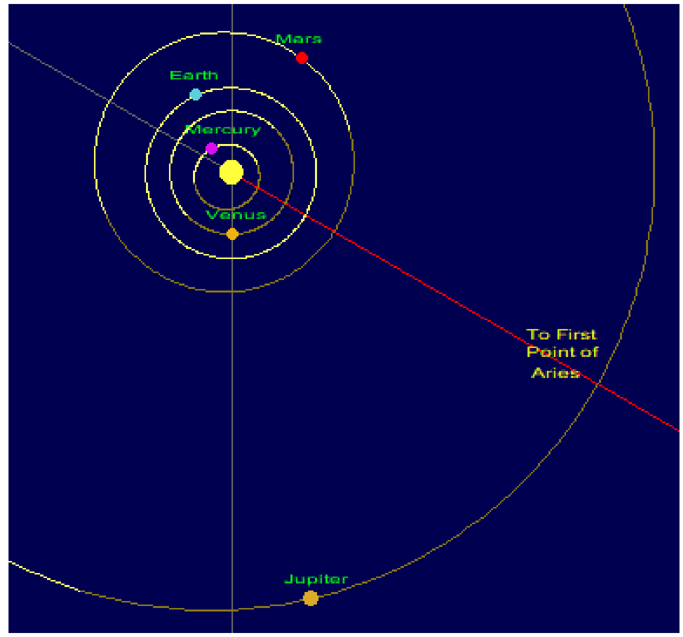


Figure 2 — Jupiter's position on 2021 February 13.

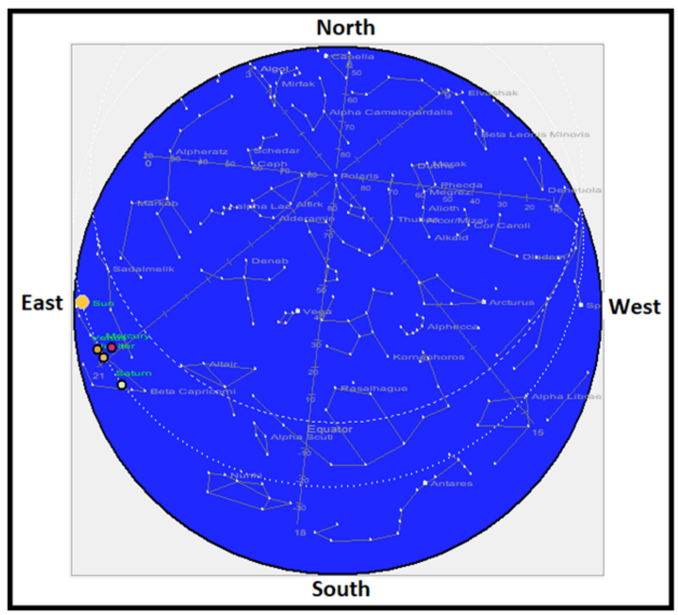


Figure 3 — Note the close Grouping of Mercury, Venus, and Jupiter. Saturn has moved farther west.

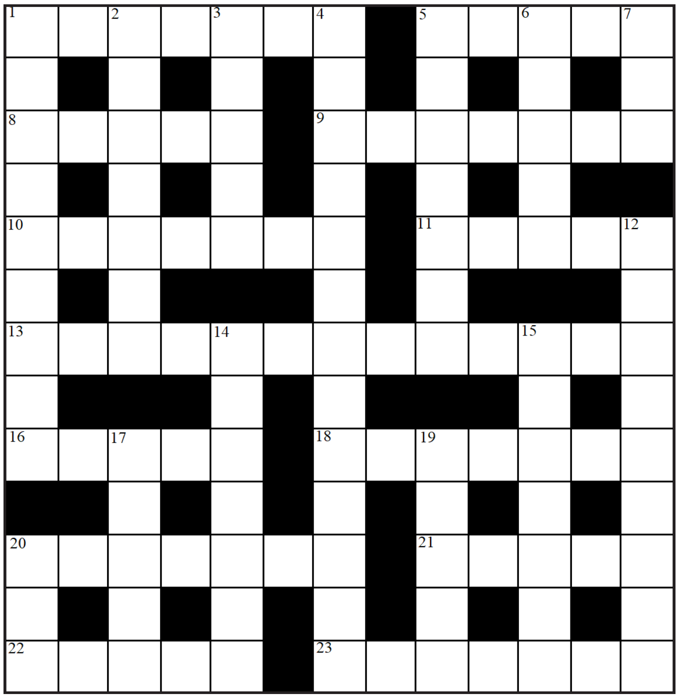
On the morning of February 13, for a few moments just before sunrise, watch as Mercury, Venus, and Jupiter will all fit within a circle of approximately 4° and about 10° angular distance west of the Sun.

As you can see in Figure 3, all three planets will be very close together. Keep an eye out! ✶

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

Astrocryptic

by Curt Nason



ACROSS

1. I care about Diddley's broken dish (7)
5. Crater among the top twenty chosen landing sites (5)
8. Bullish tech assistants are heard between you and I (5)
9. No coral formations seen in solar holes (7)
10. Check out that moraine; but not now, Al (7)
11. Mars prep program where you might get dates (5)
13. Northern deflection right where ice is for color, apparently (8,5)
16. Things get worse going where stars are highest (5)
18. Festive tea served around Neptune (7)
20. I followed fifty in a muddled queue from a stellar pony (7)
21. Sister puts potassium iodide on the teapot handle (5)
22. A real orbiter of Jupiter (5)
23. Perhaps a cobbler by marriage but also a comet discoverer (7)

DOWN

1. Initial planetary distance to stellar distance at light speed leads us to a crater (9)
2. Where maximum rotational velocity creates a torque (7)
3. Hark! There she is with Europa over Io (5)
4. Dog clinic cuts out a stellar blocker (9,4)
5. Repulsive point of the main sequence (7)
6. Orion's dogs help some people walk (5)
7. Who says it is a nebula? (3)
12. Radiate around and between the poles at a solid angle (9)
14. Hope turns back sick around Uranus (7)
15. Seeing relies on Vitamin A and a broken latrine (7)
17. Charioteer in United Artists film about an enterprising communications officer (5)
19. Pointless neural dysfunction about the Moon (5)
20. I hear and observe with it (3)

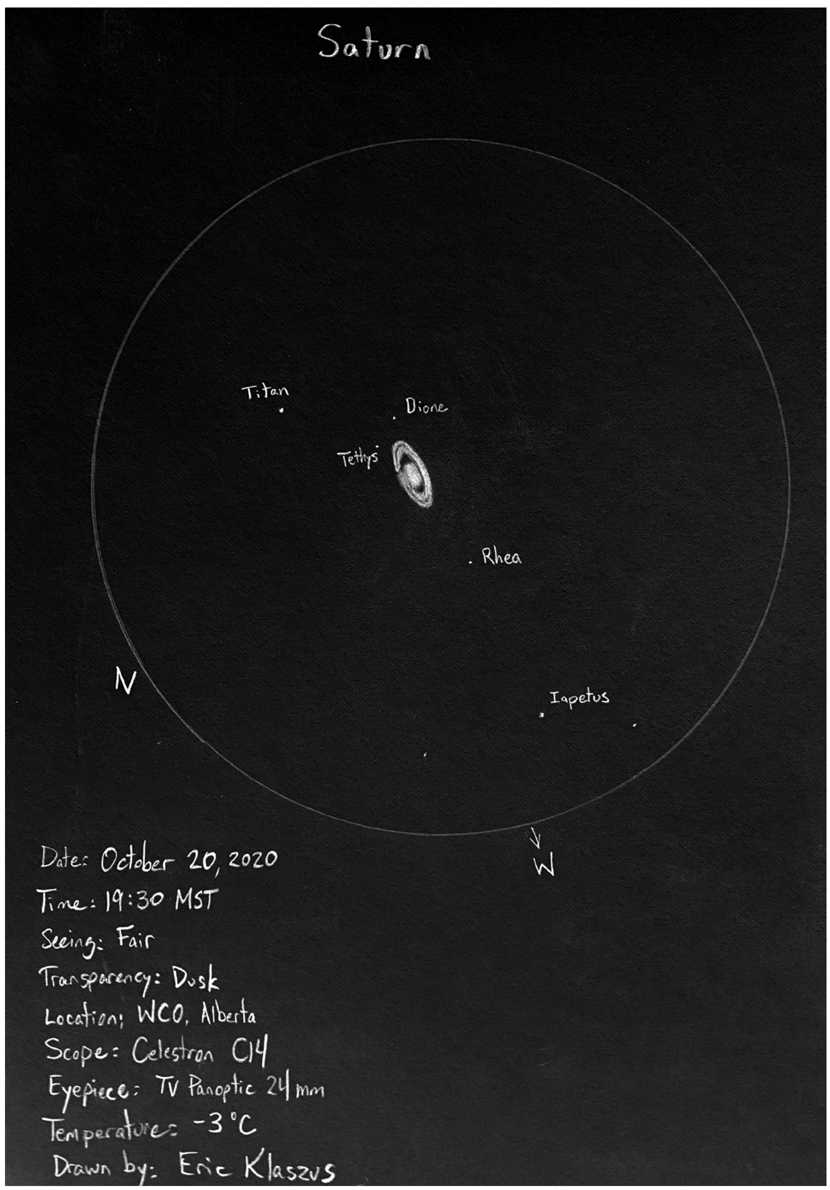
Answers to previous puzzle

Across: 1 PROTEUS (anag); **5** ARIEL (2 def); **8** ASHEN (2 def); **9** AEGAEON (anag+aeon); **10** EULER (homonym); **11** HARVEST (h+anag); **12** CHARON (char+on); **14** PARSEC (an(r)ag); **17** LASSELL (an(rev)ag); **19** ARCHE (anag); **21** BELINDA (be+Linda); 22 EARTH (anag); **23** NARES (N+Ares); **24** EUDOXUS (rev+ox+us)

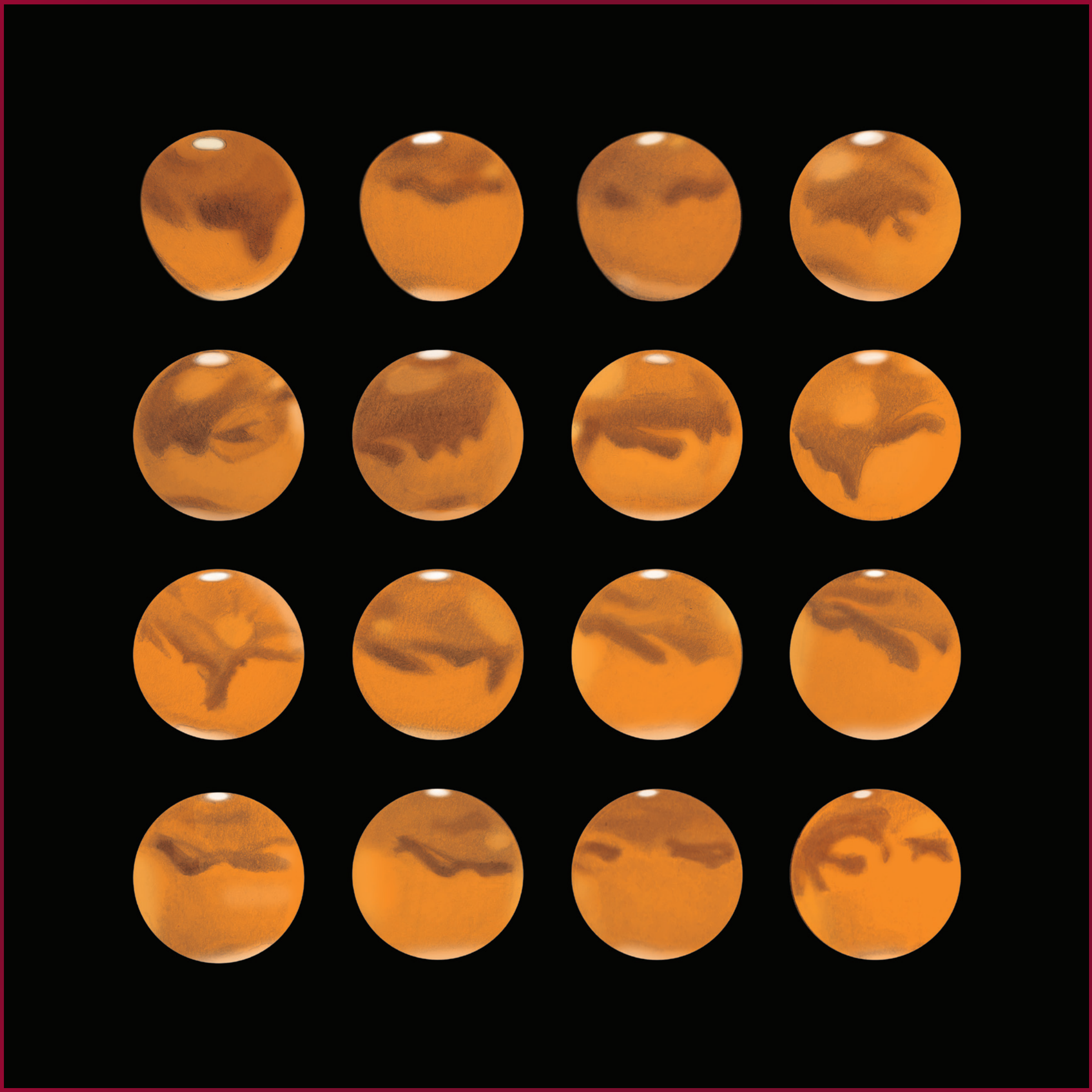
Down: 1 PHASE (anag); **2** OPHELIA (anag); **3** EJNAR (anag+r); 4 SKATHI (anag); 5 ALGERIA (anag); **6** IRENE (2 def); 7 LUNATIC (2 def); **12** CALIBAN (2 def); **13** OCEANUS (anag+us); **15** SYCORAX (an(co)ag); **16** ALSACE (anag); **18** SOLAR (anag); **19** AREND (anag); **20** ETHOS (anag)

Great Images

by Erik Klaszus



Saturn is a treat for most astronomers, and Eric Klaszus sketched our wonderful ringed planet from the RASC Calgary Centre's Wilson Coulee Observatory (WCO). He used graphite pencils on white paper, then scanned and inverted the sketch.



Journal

Halifax Centre member Michael Gatto set out this Mars opposition to capture as many sketches as possible, with the goal of capturing a full rotation of sketches. Michael states "I was grateful to get so many clear nights, and was thrilled with the interest and encouragement from RASC members from across Canada as I shared my progress online." Details; pencil sketches completed at the eyepiece of a hand-tracked Dobsonian built around an 8″ ƒ/7.5 Zambuto Optics mirror. Tak LE eyepieces giving powers of 200× to 300×, along with #80, #25, and ND filters. Scanned, then colour added in Procreate on an iPad. Completed between 2020 September 06 and 2020 October 25 from Cole Harbour, Nova Scotia.