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Journal

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PROMOTING ASTRONOMY IN CANADA

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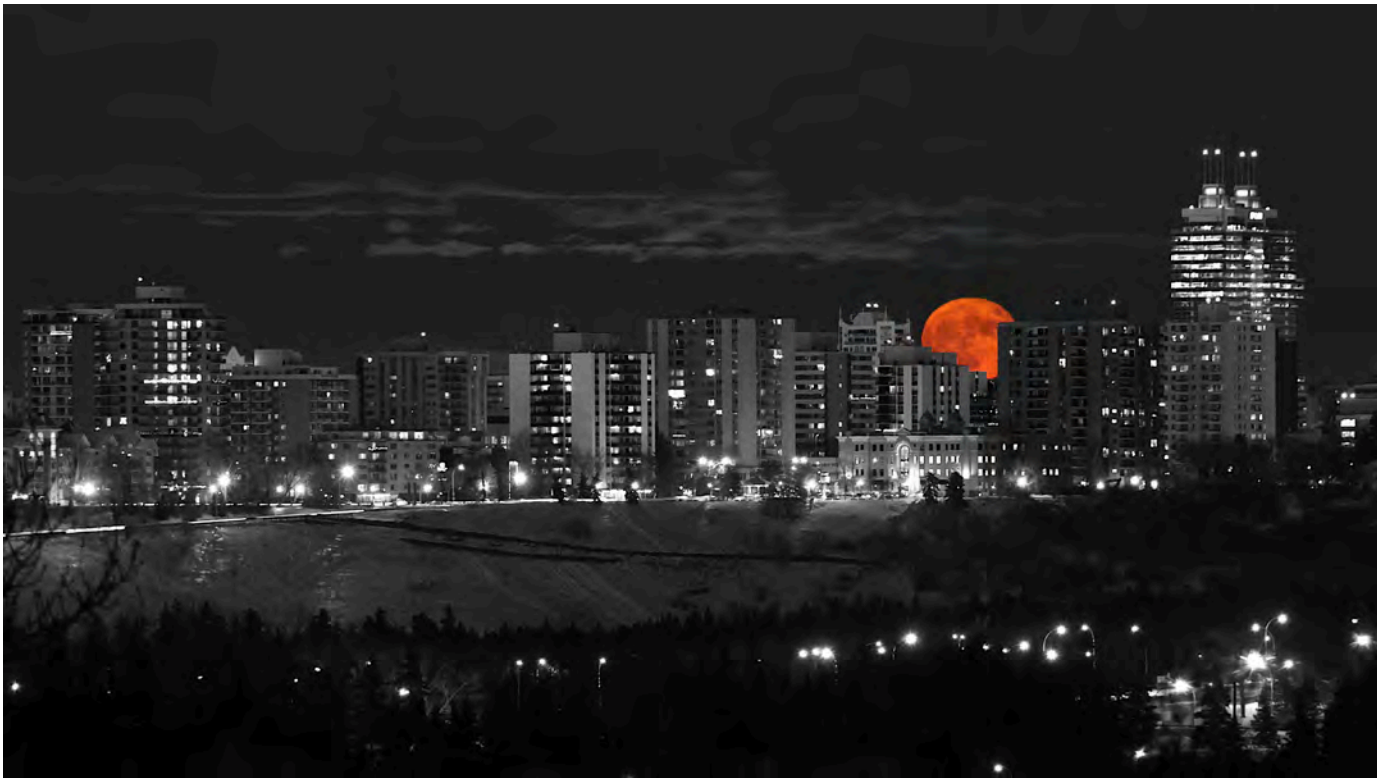
The Best of Monochrome



After the freezing rain on the weekend of 2013 December 14–15, Luca Vanzella of Edmonton caught some breaks in the clouds to the northeast to permit him to capture the Full Cold/Long Night's Moon rising. Taken from Valleyview Drive, through a gap in the trees, while standing in knee-deep snow on the banks of the North Saskatchewan River. The Moon is about 14.5 hours after full at an altitude of 0.8 degrees. Images captured with a Canon Rebel T3i with 75–300 zoom lens at 170 mm FL, ƒ/6.3, ISO 200. Vanzella used a 2-sec exposure for the foreground and a 1/80-sec exposure for the Moon. Images processed, composited, and cropped using GIMP.

Journal

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

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"This image was taken from my Bortle 5 backyard just outside of London, Ontario. I recently had my DSLR camera astro-modified by Night Sky Camera (they are offering a discount for RASC members) and this was my first night out with the new mod. I knew I wanted to try a target rich with H-alpha emission, which is why I went for NGC 7000. I love the contrast between the bright nebula and patches of dark starry sky." Katelyn Beecroft captured this beautiful image on 2021 November 23 with a Sky-Watcher Evostar 72ED with 1.0 field flattener on a Star Adventurer 2i tracker using her Canon t6i (modded) at ISO 1600. She guided with a ZWO 30-mm ƒ/4 guide scope with an ASI 120-mm mini guide cam. The final image is a stack of 75 90-second subs and was processed using DSS, Pixinsight, and 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.

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President's Corner

by Robyn Foret, Calgary Centre
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With our Earthly pursuits in jeopardy as we continue to create a safe environment in a world of 10 COVID variants being monitored and 2 Covid variants of concern (at the time of this writing), I thought a focus on other-worldly events would be in order.

Starting with commercial launches, the following companies are scheduled to launch satellites of all sorts, from scientific missions using CubeSats to Space Surveillance missions by the U.S. Dept. of Defence and, of course, numerous resupply missions to the ISS.

NASA, ESA, ROSCOSMOS, Arianespace, SpaceX, Northrup Grumman, CASC, ISRO, RVSN, ULA, Firefly Aerospace, Rocket Lab, Astra, MHI, VOX Space, Virgin Orbit, Relativity Space, LandSpace, KARI, Gilmour Space, ILS, CALT, Khrunichev, ABL, TiSPACE, Isar Aerospace, Orbex, Skyrora, and GK Launch Services all have scheduled orbital missions and the list grows even more when you add suborbital flights. This growing list of launch companies is a testament to the commercial viability of the industry.

There are some familiar names there but some interesting state and private operators too, notably:

- RVSN RF aka the Strategic Rocket Forces of the Russian Federation or the Strategic Missile Forces of the Russian Federation, a branch of the Russian Armed Forces.
- ISRO – the Indian Space Research Organization
- CASC – China Aerospace Science and Technology Corporation
- ULA – United Launch Alliance, a joint venture between Lockheed Martin and Boeing
- Astra – Alameda California-based company whose first successful mission to orbit occurred in November 2021
- Rocket Lab – a public American manufacturer specializing in launches of small satellites and CubeSats. Founded in and launching from New Zealand with HQ in California. Launching CAPSTONE, a 12-unit CubeSat, into a near-rectilinear halo orbit (NRHO), to verify the calculated orbital stability simulations for the planned lunar orbiting *Gateway* space station.
- Northrop Grumman — one of the world's largest weapons manufacturer and military technology providers — was awarded a Commercial Orbital Transportation Service (COTS) by NASA

- MHI – Mitsubishi Heavy Industries launching a Mitsubishi/JAXA designed rocket
- Relativity Space – first flight of the 3-D-printed rocket will launch with no payload in early 2022 (90% of the rocket is 3-D printed using a proprietary aluminium alloy)
- LandSpace – is one of six Chinese private space-launch companies
- KARI – Korean Aerospace Research Institute of South Korea launches *Nuri*, an indigenously developed Korean orbital launch vehicle. Using SpaceX as a role model, they are striving to develop relatively cheap and reliable rockets for the commercial launch market.
- Gilmour Space is set to launch *Eris*, a three-stage small-lift vehicle, from a new launch facility in Australia
- ILS – International Launch Services, exclusively sells commercial launch services using Angara and Proton lift vehicles from the Baikonur Cosmodrome in Kazakhstan and the Plesetsk and Vostochny Cosmodrome in Russia
- CALT – the China Academy of Launch Vehicle Technology is a state-owned civilian and military launch vehicle manufacture and a subsidiary of CASC
- Khrunichev is the manufacturer of the Proton and Rokot rockets and of the Russian modules of the ISS

Human spaceflight will continue to advance, too. SpaceX plans to send four people on an eight-day mission to the ISS. The mission is *Axiom Mission 1* or AX-1 and is the first private ISS mission and a new step forward in Space Tourism. Mark Pathy, CEO and Chairman of Mavrik, may become the first Canadian private Mission Specialist on the ISS.

In May, China is expected to launch three taikonauts to the *Tianhe* core module, the first module of the *Chinese Space Station*.

Boeing's *Starliner* is expected to conduct a second un-crewed test flight with a possible crewed test flight before year's end.

Missions to the Moon are planned for 2022, too. SpaceX will launch the IM-1 lander on a Falcon 9 Block 5 rocket, as early as February 2022. The Intuitive Machines lunar lander is designed to deliver small commercial payloads to the lunar surface. NASA's Space Launch System, Artemis 1, and the first lunar mission for the Orion multi-purpose crew vehicle, should also take place sometime in 2022.

With SpaceX raising the bar with respect to cost-effective launch vehicles, others are chasing them and 2022 will see the Ariane 6 fly with per-satellite launch costs in line with Falcon9; Blue Origin plans to launch the New Glenn rocket with a reusable first stage; and ULA plans to launch the Vulcan Centaur which is intended to replace the Atlas V and Delta IV Heavy. Raising the bar even more, SpaceX expects to conduct the first orbital test flight of the reusable *Starship* in 2022.

It looks like the Space Race is back in full force and with the promise of space-based commerce becoming reality, the days of only super-powers holding the keys to the next frontier are numbered. ✶

News Notes / En manchette

Compiled by Jay Anderson

Earth has a new buddy

"Just friends." That media phrase describes our latest companion: a tiny new moonlet that has settled into a centuries-long relationship with the Earth, travelling together around the Sun. The new arrival, a near-Earth asteroid named Kamo`oalewa, could be a fragment of our moon according to a paper published in *Nature Communications* Earth and Environment by a team of astronomers led by the University of Arizona.

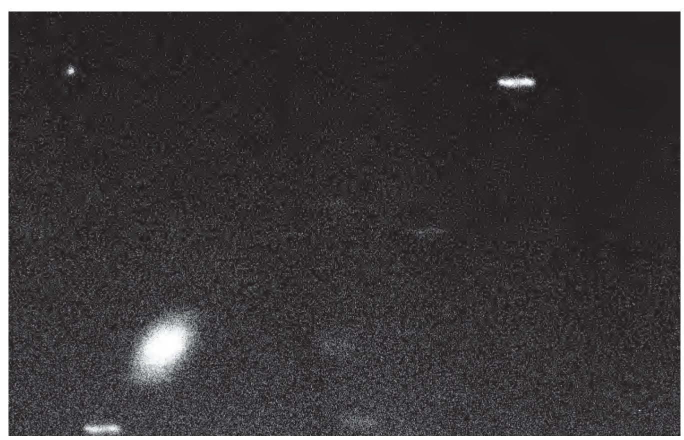

Figure 1 — An image of Kamo`oalewa (in the top left corner) acquired by the Large Binocular Telescope.

Kamo`oalewa is a quasi-satellite—a subcategory of near-Earth asteroids that orbit the Sun but remain relatively close to Earth. Little is known about these objects because they are faint (mag. 23) and difficult to observe. Kamo`oalewa was discovered by the PanSTARRS telescope in Hawaii in 2016, and the name—found in a Hawaiian creation chant—alludes to an offspring that travels on its own. The asteroid is roughly the size of a Ferris wheel—between 46 and 58 metres in diameter—and gets as close as about 14.5 million kilometres from Earth.

Our newly discovered travelling companion is one of five quasi-satellites that have been discovered so far, but it is the most stable, in a relationship with Earth that may last for centuries more. Its orbit varies between 38 and 100 lunar distances; its light curve reveals a rotation period of about 28 minutes. In its annual orbit, Kamo`oalewa spends approximately half of the time inside the Earth's orbit, which causes it to move ahead of our planet; it then crosses outside Earth's orbit, causing it to fall behind.

Due to its orbit, Kamo`oalewa can only be observed from Earth for a few weeks every April. Its relatively small size means that it can only be seen with one of the largest telescopes on Earth. Using the UArizona-managed Large Binocular Telescope on Mount Graham in southern Arizona, a team of astronomers led by planetary sciences graduate student Ben Sharkey found that Kamo`oalewa's spectrum is reddened from 0.4 to 2.2 microns, a colour that is slightly redder than typical asteroid spectra. The research team concluded that the best match is with lunar silicates such as those collected during NASA's Apollo missions.

The team can't yet be sure how it may have broken loose. The reason, in part, is because there are no other known asteroids with lunar origins.

"I looked through every near-Earth asteroid spectrum we had access to, and nothing matched," said Sharkey, the paper's lead author.

The debate over Kamo`oalewa's origins between Sharkey and his adviser, UArizona associate professor Vishnu Reddy, led to another three years of hunting for a plausible explanation.

"We doubted ourselves to death," said Reddy, a co-author who started the project in 2016. After missing the chance to observe it in April 2020 due to a COVID-19 shutdown of the telescope, the team found the final piece of the puzzle in 2021.

"This spring, we got much needed follow-up observations and went, 'Wow it is real,'" Sharkey said. "It's easier to explain with the Moon than other ideas."

Kamo`oalewa's orbit is another clue to its lunar origins. Its orbit is similar to the Earth's, but with the slightest tilt. Its orbit is also not typical of near-Earth asteroids, according to study co-author Renu Malhotra, a UArizona planetary sciences professor who led the orbit analysis portion of the study.

"It is very unlikely that a garden-variety near-Earth asteroid would spontaneously move into a quasi-satellite orbit like Kamo`oalewa's," she said. "It will not remain in this particular orbit for very long, only about 300 years in the future, and we estimate that it arrived in this orbit about 500 years ago," Malhotra said. Her lab is working on a paper to further investigate the asteroid's origins.

Kamo`oalewa is about 4 million times fainter than the faintest star the human eye can see in a dark sky.

"These challenging observations were enabled by the immense light-gathering power of the twin 8.4-metre telescopes of the Large Binocular Telescope," said study co-author Al Conrad, a staff scientist with the telescope.

Other co-authors on the paper include Olga Kuhn, Christian Veillet, Barry Rothberg, and David Thompson from the Large Binocular Telescope; Audrey Thirouin from Lowell Observatory, and Juan Sanchez from the Planetary Science Institute in Tucson.

Compiled with material provided by the University of Arizona

Perseverance adds another notch to its belt

A new paper from the science team of NASA's Perseverance Mars rover details how the hydrological cycle of the now-dry lake at Jezero Crater is more complicated and intriguing than originally thought. The findings are based on detailed imaging the rover provided of long, steep slopes called escarpments, or scarps, in the delta, which formed from sediment accumulating at the mouth of an ancient river that long ago fed the crater's lake.

The images reveal that billions of years ago, when Mars had an atmosphere thick enough to support water flowing across its surface, Jezero's fan-shaped river delta experienced late-stage flooding events that carried rocks and debris into it from the highlands well outside the crater.

At the time the images were taken, the scarps were to the northwest of the rover and about 2.2 kilometres away. Southwest of the rover, and at about the same distance, lies another prominent rock outcrop the team calls "Kodiak." In its ancient past, Kodiak was at the southern edge of the delta, which would have been an intact geologic structure at the time.

Prior to Perseverance's arrival, Kodiak had been imaged only from orbit. From the surface, the rover's Mastcam-Z and RMI

Figure 2 — From its landing site, "Octavia E. Butler Landing," NASA's Perseverance rover can see a remnant of a fan-shaped deposit of sediments known as a delta (the raised area of dark brown rock) with its Mastcam-Z instrument. Credits: NASA/JPL-Caltech/ASU/MSSS.

images revealed for the first time the stratigraphy—the order and position of rock layers, which provides information about the relative timing of geological deposits—along Kodiak's eastern face. The inclined and horizontal layering there is what a geologist would expect to see in a river delta on Earth.

"Never before has such well-preserved stratigraphy been visible on Mars," said Nicolas Mangold, a Perseverance scientist from the Laboratoire de Planétologie et Géodynamique in Nantes, France, and lead author of the paper. "This is the key observation that enables us to once and for all confirm the presence of a lake and river delta at Jezero. Getting a better understanding of the hydrology months in advance of our arrival at the delta is going to pay big dividends down the road."

While the Kodiak results are significant, it is the tale told by the images of the scarps to the northeast that came as the greatest surprise to the rover science team.

Imagery of those scarps showed layering similar to Kodiak's on their lower halves. But farther up each of their steep walls and on top, Mastcam-Z and RMI captured stones and boulders.

"We saw distinct layers in the scarps containing boulders up to 5 feet [1.5 metres] across that we knew had no business being there," said Mangold.

Those layers mean the slow, meandering waterway that fed the delta must have been transformed by later, fast-moving flash floods. Mangold and the science team estimate that a torrent of water needed to transport the boulders—some for tens of kilometres —would have to travel at speeds ranging from 6 to 30 kph.

"These results also have an impact on the strategy for the selection of rocks for sampling," said Sanjeev Gupta, a Perseverance scientist from Imperial College, London, and a co-author of the paper. "The finest-grained material at the bottom of the delta probably contains our best bet for finding evidence of organics and biosignatures. And the boulders at the top will enable us to sample old pieces of crustal rocks. Both are main objectives for sampling and caching rocks before Mars Sample Return."

Early in the history of the Jezero Crater's former lake, its levels are thought to have been high enough to crest the crater's eastern rim, where orbital imagery shows the remains of an outflow river channel. The new paper adds to this thinking, describing the size of Jezero's lake fluctuating greatly over time, its water level rising and falling by tens of metres before the body of water eventually disappeared altogether.

While it's unknown if these swings in the water level resulted from flooding or more gradual environmental changes, the science team has determined that they occurred later in the Jezero delta's history, when lake levels were at least 100 metres below the lake's highest level. And the team is looking forward to making more insights in the future: The delta will be the starting point.

Compiled with material provided by NASA.

A clever way to find a planet

Spotting a planet in another galaxy is hard, and even though astronomers know that they should exist, no planetary system outside of the Milky Way has been confirmed so far. Because the light from another galaxy is packed into a tiny area on the sky, it is very difficult for telescopes to distinguish one star from another, let alone a planet orbiting around them. And the usual techniques to find exoplanets in our galaxy don't work as well for planets outside of it.

This limitation doesn't apply when using X-rays to survey a galaxy instead of visible light. Because there are fewer objects that shine brightly in X-ray light, an X-ray telescope like ESA's *XMM-Newton* spacecraft can more easily distinguish between objects when observing a galaxy. Those objects are therefore easier to identify and study, and it might be possible to find a planet around them.

Some of the brightest objects that can be studied in external galaxies are the so-called X-ray binaries. They consist of a very compact object—a neutron star or black hole—that is eating material from a companion, or "donor" star orbiting around it. The infalling material is accelerated by the intense gravitational field of the neutron star or black hole and heated to millions of degrees, producing a lot of bright X-rays. Astronomers expect that, theoretically, planets transiting such a source would block these X-rays, causing a dip in the observed X-ray light curve.

"X-ray binaries may be ideal places to search for planets, because, although they are a million times brighter than our

Figure 3 — A composite image of M51 with X-rays from NASA's Chandra *and optical light from the NASA/ESA* Hubble Space Telescope *contains a box that marks the location of the possible planet candidate. X-ray: NASA/CXC/SAO/R. DiStefano, et al.; Optical: NASA/ESA/STScI/Grendler*

Sun, the X-rays come from a very small region. In fact, the source that we studied is smaller than Jupiter, so a transiting planet could completely block the light from the X-ray binary," explains Rosanne Di Stefano from the Center for Astrophysics, Harvard & Smithsonian, in the United States, and first author of a new study published in *Nature Astronomy*.

Rosanne and colleagues searched in *Chandra* and *XMM-Newton* data of three galaxies for such X-ray transits, dips in the light that could be explained by planets. And they found a very special signal in the Whirlpool Galaxy (Messier 51) that they decided to study in more detail. The dip occurred in X-ray binary M51-ULS-1 and completely blocked the signal for a few hours before it came back again.

Now the game of carefully crossing off possible explanations began before the researchers could even consider the option of an extragalactic planet. "We first had to make sure that the signal was not caused by anything else," says Rosanne, whose team argues against a number of possibilities in their new publication. "We did this by an in-depth analysis of the X-ray dip in the Chandra data, analysing other dips and signals in the XMM data, and also modelling dips caused by other possible events, including a planet."

Could the X-ray dip be caused by small stars like a brown or red dwarf? No, they argue, the system is too young for that, and the transiting object too large.

Could it be a cloud of gas and dust? Not likely, the team says, because the dip indicates a transiting object with a well-defined surface, which would not be the same for a passing cloud. Even if the planet had an atmosphere, it would still have a more well-defined surface than a cloud.

Could the dip be explained by variations in brightness of the source itself? The paper's authors are confident that this is not the case, because although the light from the source completely disappeared for a few hours before it came back, the temperature and light colours stayed the same.

Lastly, the team also compared the dip to another blockage of the light caused by the donor star passing in front of the compact star. This was partly observed by *XMM-Newton* and the event caused a much longer black-out, which was different from the dip caused by a possible planet.

"We did computer simulations to see whether the dip has the characteristics of a planet transiting, and we find that it fits perfectly. We are pretty confident that this is not anything else and that we have found our first planet candidate outside of the Milky Way," adds Rosanne.

The team also speculates about the characteristics of the planet based on their observations: it would be the size of Saturn, orbiting the binary-star system from tens of times the Earth-Sun distance. It would make one full orbit roughly every 70 years and be bombarded with extreme amounts of radiation, making it uninhabitable by life as we know it on Earth.

This long orbit of the planet candidate is also a limitation for the study because the event can't be repeated any time soon. That's why the team remains careful to say that they found a possible planet candidate, for which the broader community might find other explanations, although they have not been found after careful research by the team. "We can only say with confidence that it doesn't fit any of our other explanations," Rosanne clarifies.

Still, this is an exciting step forward in the quest to find a planet outside of the Milky Way. This is the first planet candidate that would orbit a known host system, as compared to candidates found with gravitational lenses. This would also be the first time that a planet is found orbiting an X-ray binary. The existence of those planets is consistent with the fact that planets are found around pulsars (rapidly rotating neutron stars), and some of these pulsars have been part of an X-ray binary in the past.

"The first confirmed planet outside of our Solar System was found around a pulsar, an object typically observed in X-rays. I am excited that X-rays now also play an important step in the search for planets beyond the border of our galaxy," says Norbert Schartel, XMM-Newton Project Scientist for ESA.

"Now that we have this new method for finding possible planet candidates in other galaxies, our hope is that by looking at all the available X-ray data in the archives, we find many more of those. In the future we might even be able to confirm their existence," says Rosanne.

Compiled with material provided by ESA.

A magnetic tunnel for the Solar System

A Dunlap Institute astronomer has discovered that our Solar System may be surrounded by what she describes as a magnetic tunnel that can be seen in radio waves.

Dr. Jennifer West, Research Associate at the Dunlap Institute for Astronomy and Astrophysics, is making a scientific case that two bright structures that are seen on opposite sides of the sky—previously considered to be separate—are actually connected and are made of rope-like filaments. This connection forms what looks like a tunnel around our Solar System.

The April 2022 *Journal* deadline for submissions is 2022 February 1.

See the published schedule at

rasc.ca/sites/default/files/jrascschedule2022.pdf

"If we were to look up in the sky," explains West, "we would see this tunnel-like structure in just about every direction we looked—that is, if we had eyes that could see radio light."

Called "the North Polar Spur" and "the Fan Region," we've known about these two structures for a long time (Figure 4). "Since the 60s," West says. But most scientific explanations have focused on them individually. West and her colleagues believe they are the first astronomers to connect them as a unit.

Made up of charged particles and a magnetic field, the structures are shaped like long ropes, and are located about 350 light-years away from us. They are about 1000 light-years long. "That's the equivalent distance of travelling between Toronto and Vancouver two trillion times," West explains.

West (a former member of the Winnipeg Centre member) has been thinking about these features on and off for 15 years — ever since she first saw a map of the radio sky. More recently, she built a computer model that calculated what the radio sky would look like from Earth as she varied the structure of the surrounding magnetic field. This modelling allowed West to "build" a structure around us, until it matched what the sky looked like through our radio telescopes. It was her insight on what the starting magnetic field might look like that led her along the path that eventually brought the model in line with the data.

"A few years ago, one of our co-authors, Tom Landecker, told me about a paper from 1965, from the early days of radio astronomy," West says. "Based on the crude data available at this time, the authors (Mathewson & Milne), speculated that these polarized radio signals could arise from our view of the Local Arm of the Galaxy, from inside it." She continues, "That paper inspired me to develop this idea and tie my model to the vastly better data that our telescopes give us today."

To further explain this, West uses the Earth's map as an example. The North Pole is on the top and the Equator is through the middle—but of course, we can always re-draw that map with a different perspective. The same is true for the map of our galaxy. "Most astronomers look at a map with the north pole of the galaxy up and the galactic centre in the middle," she explains. "An important part that inspired this idea was to remake that map with a different point in the middle."

"This is extremely clever work," says Dr. Bryan Gaensler, a professor at the Dunlap Institute and an author on the publication. "When Jennifer first pitched this to me, I thought it was too 'out-there' to be a possible explanation. But she was ultimately able to convince me! Now I'm excited to see how the rest of the astronomy community reacts."

In popular terms, West's model places the Earth inside a "tunnel" of galactic magnetism (Figure 5). By calculating how the radio emission from this configuration would appear from our viewpoint, she was able to recreate the North Polar Spur and the Fan Region in the model and determine approximately the distance to these structures.

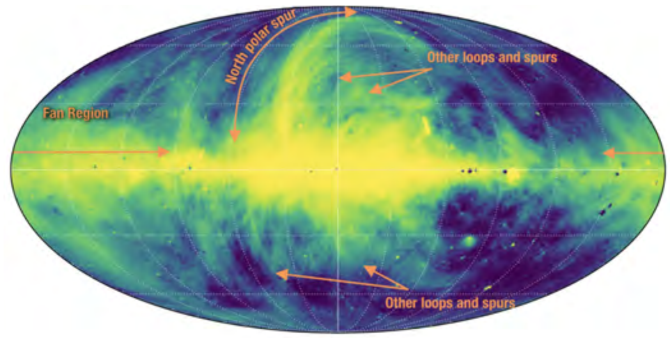

Figure 4 — The galaxy seen in radio waves in the conventional view with the galactic centre in the middle of the image. Credit: Haslam et al. (1982) with annotations by J. West.

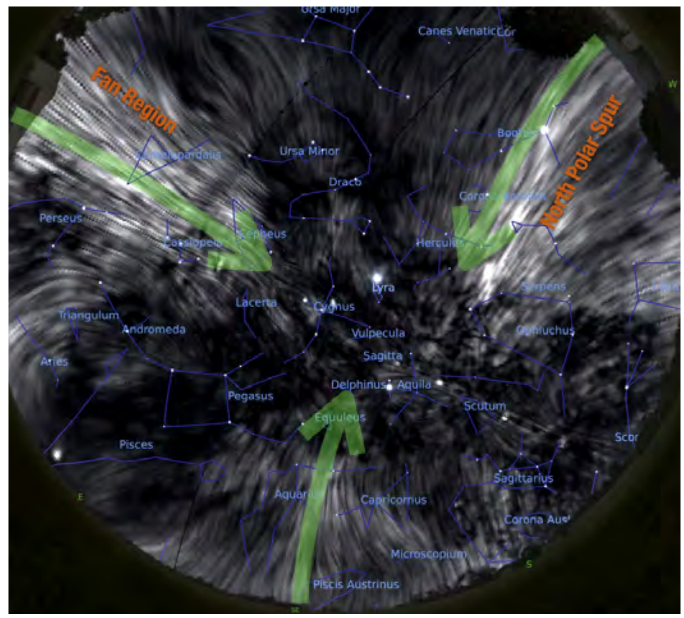

Figure 5 — The sky as it would appear in radio-polarized waves. The Van-Gogh-like lines show magnetic-field orientation. Credit: Haslam et al. (1982) with annotations by J. West.

An expert in magnetism in galaxies and the interstellar medium, West looks forward to the next possible discoveries within this research.

"Magnetic fields don't exist in isolation," she explains. "They all must to connect to each other. So a next step is to better understand how this local magnetic field connects both to the larger-scale galactic magnetic field, and also to the smaller scale magnetic fields of our Sun and Earth."

In the meantime, West agrees that the new "tunnel" model not only brings new insight to the science community, but also a ground-breaking concept for the rest of us, on the ground.

"I think it's just awesome to imagine that these structures are everywhere, whenever we look up into the night sky." ✶

Compiled with material provided by the Dunlap Institute for Astronomy and Astrophysics

Featured Articles / Articles de fond

RASC Halifax Centre's David M.F. Chapman Honoured with Asteroid (10047) Davidchapman

by Mary Lou Whitehorne, FRASC

Minor Planet (10047) Davidchapman (1986 QK2) has been named by the International Astronomical Union, in recognition of Dave Chapman's many contributions to the promotion of astronomical science.

So, who is this Chapman fellow, anyway? I first met him in 1985 or 1986, I can't be sure which year it was. At the time he was the Halifax Centre Librarian, but was resigning the position to head to the United Kingdom for work or study. I was a brand new member so the details didn't stick. All that stuck was that I was suddenly the new Librarian!

Chapman has been an active RASC life member for over 50 years. When he returned to Nova Scotia from overseas, he resumed his activity in the Centre and has remained deeply involved ever since. Currently he is retired from his career as a physicist working in underwater acoustics at Defense Research & Development Canada.

Dave has held many roles in the RASC, both locally and nationally, applying his skills and knowledge for the advancement of astronomical science as well as for the benefit of the RASC. A few continuing themes have been his work to constantly improve the Society's publications, observing program, awards program, education and outreach program, mentoring new members, and fostering productive and mutually beneficial partnerships with external organizations. All of this, plus his skillful use of social media, has expanded awareness of the RASC across Nova Scotia and Canada, and has contributed substantially to the thriving success of Halifax Centre and Society initiatives.

There are too many of Dave's contributions to go into great detail about many of them. One stands out in particular for its broad reach and high impact: the establishment of the Kejimkujik National Park and National Historic Site as an official RASC Dark-Sky Preserve (DSP). The careful and thoughtfully detailed work setting up this DSP set the bar for all DSPs to follow! This collaboration with Parks Canada includes Indigenous astronomy programming coupled with modern science in what is now known as the "two-eyed seeing" approach. It's a very big part of the annual Dark Sky Weekend at Kejimkujik National Park, during which the Park is invariably full to capacity with visitors keen to experience the night sky in such a richly fulfilling and mind-broadening way.

Chapman has worked assiduously on many other files. He was Editor of the *Observer's Handbook* (2012–2017), has served as Halifax Centre's Librarian, Vice President, President, Observing Chair, and is well known as the Centre's "Chief Lunatic." If you are not a keen lunar observer in Halifax Centre, it might be best to keep quiet about it! Dave has also fostered a productive relationship with the Acadia First Nation and continues to work on developing the Mi'kmaw Moons project with his research partner, Cathy LeBlanc of Acadia First Nation.

Along with all this have been major contributions to RASC publications, plus chairmanship of the national Awards and Observing Committees. Dave is a frequent speaker at Centre meetings, a popular guest on radio and television, and a participant in essentially every other Halifax Centre event, especially if it involves public education and outreach.

David Chapman also holds the Simon Newcomb Award, Service Award, and is a Fellow of the RASC. Now he can add an asteroid to the list. The RASC and the Halifax Centre are very fortunate to have outstanding members such as Dave Chapman, who give freely and energetically to further the work of the Society. A fuller accounting of his many and varied contributions can be found in his 2015 Service Award nomination, in JRASC here: rasc.ca/sites/default/files/ServiceAwards_2015.pdf

In conclusion, Dave Chapman has certainly earned the distinction of a named asteroid, and I am delighted that this honour has come his way. His love of the stars is deep and unflagging, as is his passion to bring the stars to the people around him. When he is not working on one of his many astronomy projects, he can be found out under the night sky, observing. Frequently, his observing takes place at Kejimkujik National Park, and may be accompanied by a bottle of Dark as Keji ale. What could possibly be better? ✶

A rare image of Dave Chapman when he is not doing astronomy, but enjoying a paddle on Nova Scotia's scenic Terrence Bay. Photo by M.L. Whitehorne

Apollo Geological Training in Canada, 1970–1972

by Christopher Gainor, Victoria Centre
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Humanity's first exploration of another celestial body took place over four years from December 1968 to December 1972 when Apollo astronauts flew to the Moon. In 9 flights that flew to or near the Moon, 12 astronauts explored the lunar surface, and another 12 flew to the vicinity of the Moon, 3 of them twice. After *Apollos 8* and *10* orbited the Moon, six of the seven Apollo flights that followed included exploration of the lunar surface. The exception was *Apollo 13*, whose planned landing in 1970 was cancelled when its Service Module lost much of its oxygen and power supplies on the way to the Moon.

Apollo began in 1961 when U.S. President John F. Kennedy set a national goal of landing humans on the Moon before the end of the decade. While the main purpose of Apollo was to challenge the Soviet Union in space exploration as part of the Cold War, the National Aeronautics and Space Administration (NASA) also sought to gain scientific knowledge from the Apollo flights.

The scientific program for the astronauts who travelled to the lunar surface featured geological sampling and exploration of each landing site. The first two landings focused on proving the ability to land on the Moon, and the subsequent missions were dispatched to areas of scientific interest. The astronauts' work on the lunar surface also included emplacement of instruments such as seismometers, magnetometers, and laser reflectors that operated after the astronauts returned to Earth.[1]

All but one of the astronauts who flew on Apollo lunar expeditions were pilots and engineers, and the other was a professional geologist who took pilot training. To obtain the most scientific value from each landing, all the astronauts were trained in geology, and this training included field trips to places where the geology was believed to resemble what would be found on the Moon.

NASA astronauts began their studies of geology in 1964 with class work and field trips around the United States. When crews were named for flights to the Moon, they got more geological training and field trips. Astronauts and their instructors prepared for their lunar geological work in Arizona, Texas, New Mexico, Oregon, Nevada, California, Idaho, Colorado, Minnesota, Alaska, and Hawaii. Early geology field trips also took place outside the U.S. in Iceland and Mexico. The *Apollo 14* astronauts supplemented their geology field trips in the U.S. with trips to Germany and Mexico, and the crews of *Apollos 15*, *16*, and *17* trained for their lunar traverses in Canada, in addition to locations around the United States. This article will focus on the Apollo geology training that took place in Canada.[2]

Suffield, Alberta

The first geological training session for NASA astronauts in Canada took place in July 1970 when the crew of *Apollo 15* and 11 other astronauts flew to Medicine Hat in southeastern Alberta, and then went on to the nearby Defence Research Establishment Suffield. The 14 astronauts explored a 94-metre-wide crater created by an explosion of 450 tonnes of TNT to help them learn what to expect in and around impact craters.

The 2,700-square-mile Suffield lands were acquired by the Canadian government in 1941 and were used by the British government for wartime training and chemical weapons research. After the war, the generally flat prairie land was turned over to the Defence Research Board (DRB), now

Figure 1 — Astronauts, geologists, and others inside the Dial Pack crater at Defence Research Establishment Suffield in Alberta minutes after the crater was created in an explosion on 1970 July 23. © Her Majesty the Queen in Right of Canada as represented by the Minister of National Defence

known as Defence Research and Development Canada. Canadian Forces Base Suffield was established in 1971, and the British Army has since used part of the lands for infantry and tank training.

In 1960, the Canadian, British, and U.S. governments set up a joint research program that included three large 450-tonne TNT explosions at the Defence Research Establishment Suffield. After a series of explosions of various sizes, including two 450-tonne blasts in 1964 and 1968, the third large explosion, known as Dial Pack, took place on 1970 July 23. A number of experiments took place in conjunction with the explosions, including tests of their effects on various structures, vehicles, aircraft, and equipment.[3]

The first large explosion, which took place in 1964 and was known as Snowball, led to cooperation with the U.S. Geological Survey (USGS), which had responsibility for training astronauts in geology and later for analyzing the findings of the Apollo landings. According to DRB geologist Gareth Jones, extensive scientific studies following the Snowball blast revealed complex geological structures that caught the interest of the former Dominion Astronomer, Carlyle S. Beals, who had developed a strong research interest in impact craters. Beals alerted the Dominion Observatory and the American Astronomical Society to the findings from Snowball, which in turn drew the attention of USGS geologist Eugene M. Shoemaker, a well-known expert on craters and lunar geology. The USGS took part in subsequent research related to explosions at Suffield, including Dial Pack. USGS geologists likely persuaded NASA to dispatch astronauts to the Dial Pack test.[4]

Fourteen astronauts witnessed the 1970 Dial Pack explosion from a distance of three kilometres after having been briefed on the science of impact craters by geologists Gareth Jones of the DRB and David Roddy of the USGS. They included the prime crew of *Apollo 15*, Commander David R. Scott, Lunar Module Pilot (LMP) James B. Irwin, and Command Module Pilot (CMP) Alfred M. Worden, and their backup crew of Richard F. Gordon Jr., Vance D. Brand, and Harrison H. Schmitt. *Apollo 16* Commander John W. Young and LMP Charles M. Duke Jr., also viewed the explosion, along with astronauts Fred W. Haise, Gerald P. Carr, William R. Pogue, Anthony W. England, Robert A. Parker, and Joseph P. Allen.[5]

About 10 minutes after the explosion, the astronauts and two geologists who accompanied them walked inside the crater, and "examined the overturned flap, backwash and glass beads and walked around the crater at the edge of the continuous ejecta blanket." Later on, the astronauts watched films of the explosion.[6] Scott later told reporters that the crater had many features that bore similarities to impact craters on the Moon. The debris included large angular rocks and small glass beads inside the ejecta.[7]

Figure 2 — Charles Duke (left) and John Young (right) during a geology field trip at Sudbury, Canada. 1971 July 7–9. NASA Photo S71-39840

A year and three days later, Scott, Irwin, and Worden departed the Kennedy Space Center for the plains of Hadley between the Hadley Rille and the Apennine Mountains. Their flight was the first of three J-series missions with the Lunar Roving Vehicle that allowed extended exploration of the lunar landing sites. In 1972, astronauts Young and Duke flew to the Moon on *Apollo 16*, and Schmitt on *Apollo17*.

Sudbury Basin, Ontario

The landing crews of *Apollos 16* and *17* trained in Sudbury, Ontario, prior to their flights, and these field trips are far better known than the training session in Alberta. Accompanied by instructors and other astronauts, *Apollo 16* Commander Young and LMP Duke came to Sudbury in July 1971, and *Apollo 17* LMP Schmitt and Commander Eugene A. Cernan trained there in May 1972.

The oval-shaped basin of 60 km by 27 km containing nickel, copper, palladium, and other minerals that are the basis of Sudbury's mineral wealth was originally a crater caused by the impact about 1.85 billion years ago. There are many fractures, faults, and shatter cones—fan-shaped features in rocks—in and around the basin similar to those caused by violent impacts on the Moon. And while impact breccias—rocks containing a variety of different types of rocks created by impacts—are not often seen on much of the Earth due to the effects of weathering and other natural processes, they are plentiful in the Sudbury area and on the Moon.

The metallic ores in the Sudbury area were first recognized during railway construction in 1883, and scientific research began a few years later. Mining and smelting in the basin began early in the 20th century and continues to this day. For many years, the origin of the basin was a matter of controversy, with volcanic origin being a popular theory. By the 1950s, research showed that the basin had been created by a single catastrophic event, and in 1964, research with brecciated rocks and shatter cones pointed to a gigantic impact from space that was estimated to have taken place between 1.6 and 1.9 billion years ago.[8] At the time the Apollo astronauts visited the Sudbury area, many of the locations they visited had been laid bare of vegetation by logging and the effects of pollution from smelters in the area.

Apollo 16 Training

On Tuesday, 1971 July 6, *Apollo 16* astronauts John Young and Charlie Duke arrived in Sudbury along with the flight's backup commander, Fred Haise, and astronaut Anthony W. England, who would be the spacecraft communicator in Mission Control during their traverses on the lunar surface (*Apollo 16* CMP Ken Mattingly did not make the trip). Their party of 20 included geologists and other staff, notably William R. Muehlberger, a University of Texas geologist who served as principal geology investigator for *Apollos 16* and *17*, and Bevan M. French, a geologist from NASA's Goddard Space Flight Center who had begun studying the geology of Sudbury five years earlier as part of his work on craters and other impact structures. That evening, the astronauts were briefed for two hours by geologist Michael Dence of the Department of Energy, Mines and Resources in the Canadian government about the history of the Sudbury Basin and the plan for their walking traverses over the following three days.[9]

Early the next morning, the astronauts and geologists set out for the Kelly Lake area on the edge of Sudbury. The geologists included Dence and Don Phipps and J. Guy Bray from the International Nickel Company, Inco, that owned most of the mines and smelters in Sudbury at the time. A *Sudbury Star* reporter wondered whether Young, Duke, and Haise were really astronauts given their "unconventional gear" of "Straw hats, blue jeans, and army boots" in place of spacesuits. The astronauts did wear backpacks simulating the portable life-support systems they would carry on the Moon, and Hasselblad cameras attached to their chests similar to those they would use on the lunar surface. They also carried geology tools and bags to prepare for their geology work on the Moon.

The astronauts spoke by two-way radio with England, who sat in a tent that stood in for the Mission Control Center at the Manned Spacecraft Center in Houston. They described the rocks they picked up and the geological formations they encountered, including shatter cones, during their four-hour walk along crater-like formations near Kelly Lake.[10] "The crew was able to recognize all of the [geological] units but had some difficulty interpreting some of the breccias," a NASA history of geological training for the Moon noted. The astronauts collected about 45 kg of rocks for later analysis in Houston, and after the traverse they held a two-hour debriefing session with geologists.[11]

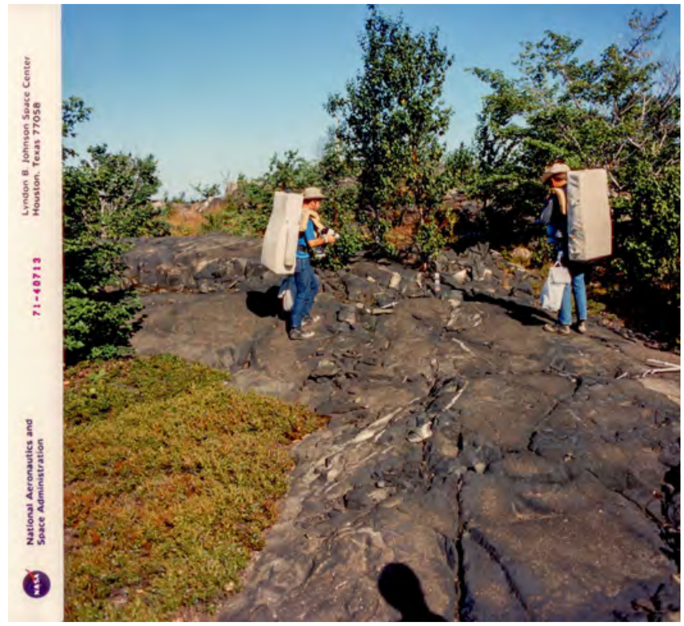

Figure 3 — Astronauts John Young (left) and Charles Duke (right) training at Creighton near Sudbury, Ontario, on 1971 July 9. NASA Photo S71-40713

In the afternoon, the astronauts and geologists moved to the shore of Lake Wanapitei northeast of Sudbury for a "one-hour exercise" to examine a "more recent and much smaller impact structure that produced impact breccias that are now intermingled with glacial deposits." [12]

On July 8, the astronauts spent four and a half hours in a traverse near High Falls, northwest of Sudbury off Highway 144 near Windy Lake. The traverse included sampling of some igneous rocks and overlying glacial deposits, and down into a variety of breccias and other rocks created by impact. Then a three-hour debrief of the astronauts' work on the traverse took place on site. "Another two hours was spent stopping at outcrops along Highway 144 to provide a general cross-section of the Sudbury Basin." That evening, the astronauts went underground on a visit to the Creighton Mine, and later they discussed the origin of the ores from that mine. [13]

The next morning featured a two-and-a-half-hour traverse at Creighton, where the astronauts found a variety of brecciated rocks resulting from the impact that created the basin. The traverse was followed by a 90-minute debrief session, and then the NASA group left Sudbury with many photos and more than 90 kg of rocks gathered by the astronauts.

In a detailed memo on the trip to Sudbury, French praised the choice of Sudbury for training and the contributions of Canadians from Inco and other organizations. "I was especially impressed with the high quality of the geological training and geological effectiveness of the astronauts in an area of extremely complex geology," he wrote, adding that the performances of Young and Duke were comparable to what would be expected from trained geologists, thanks to the high quality of training they had received. French said witnessing the simulated sample collection gave him perspective on the work of the astronauts on the lunar surface, and he added that the simulation helped geologists who would be working with astronauts and controllers during the lunar traverses better understand how individual astronauts would approach their geological work. "The general conclusion of the participants in the *Apollo 16* exercise was that it was extremely successful, and a return visit for the *Apollo 17* crew is a distinct possibility," French concluded.[14]

The Reasons Sudbury was Chosen

The astronauts' visit to Sudbury got a great deal of attention in Canadian media, and the astronauts and geologists spoke to journalists, expressing a desire to visit Canada again. "We got a good look at the formations we'll probably be seeing on the Moon," Young said.[15]

The forbidding appearance of much of the area at the time due to deforestation and pollution was a major topic of news coverage of the astronauts' visit. "It's not that Sudbury looks like the moon—although the city has been the frequent brunt of comparisons to the lunar surface—it's just that the rocks are out of this world," was the way Lydia Dotto of the *Toronto Star* explained the reason for the visit.

Figure 4 — Astronaut John W. Young, Apollo 16 *commander, collecting samples at the North Ray Crater geological site during the third EVA on the lunar surface. The Lunar Roving Vehicle (LRV) is parked at upper left. NASA Photo AS16-117-18825*

The astronauts and geologists appeared to be prepared for the controversy. At the end of the Kelly Lake traverse, Duke told reporters: "The area looks nothing like the Moon, but the rocks are a good analogy to the impact-type rocks we'll find on the Moon."[16] Muehlberger also denied that the astronauts came to Sudbury for the view. "If that was what we wanted, NASA would have taken them to better locations in the world for that type of viewing."[17]

Their message didn't get to the Ontario Legislature, where Sudbury Liberal MPP Elmer Sopha said the astronauts should have gone to the Gobi Desert rather than Sudbury because the publicity around their visit gave an "erroneous image" of Sudbury. New Democrat MPP Elie Martel (Sudbury East) said he would "hope like hell" that the mining companies and provincial government take the hint that the pollution that was affecting the area should be cleaned up. Mayor Joe Fabbro's major comment was that the astronauts were very welcome in Sudbury.[18]

Years later, another factor in the decision to visit Sudbury became known. Geologist Don Wilhelms of the U.S. Geological Survey wrote that impact breccias are rarely found on Earth, and the *Apollo 14* astronauts had been shown this type of rock when they visited the Ries Crater in Germany in August 1970 prior to their flight. Wilhelms, who consulted for NASA, recalled that "certain incidents on the trip caused [Director of Flight Crew Operations] Deke Slayton to forbid future European excursions." Sudbury then was chosen because of its impact breccias and because it was "[c]loser to home."[19]

Sudbury on the Moon

The *Apollo 16* astronauts launched from the Kennedy Space Center on 1972 April 16 for a landing site in the highlands of the Moon named after the famed French mathematician Rene Descartes. The landing site was chosen because it promised lunar samples created by volcanic processes rather than as the result of impacts early in the Moon's history. *Apollo 16*'s Lunar Module *Orion* carried the second Lunar Roving Vehicle to the Moon, which was driven by Young and Duke. Mattingly piloted the Command and Service Module *Casper*.

Five days later, after a landing delayed by a problem with *Casper*'s main engine, Young and Duke began the first of three moonwalks. As he took his first lunar step at the Descartes landing site, Young promised: "*Apollo 16* is gonna change your image."[20] Young and Duke quickly learned the wisdom of those words when they found that Descartes landing site and the Cayley Formation were covered with breccias that were created by impacts similar to what had created the Sudbury Basin, not the volcanic rocks that they expected.

When Young gathered an "absolutely beautiful" rock on his and Duke's third and final lunar traverse at North Ray Crater, he said: "It looks like a Sudbury breccia, and that's the truth. I

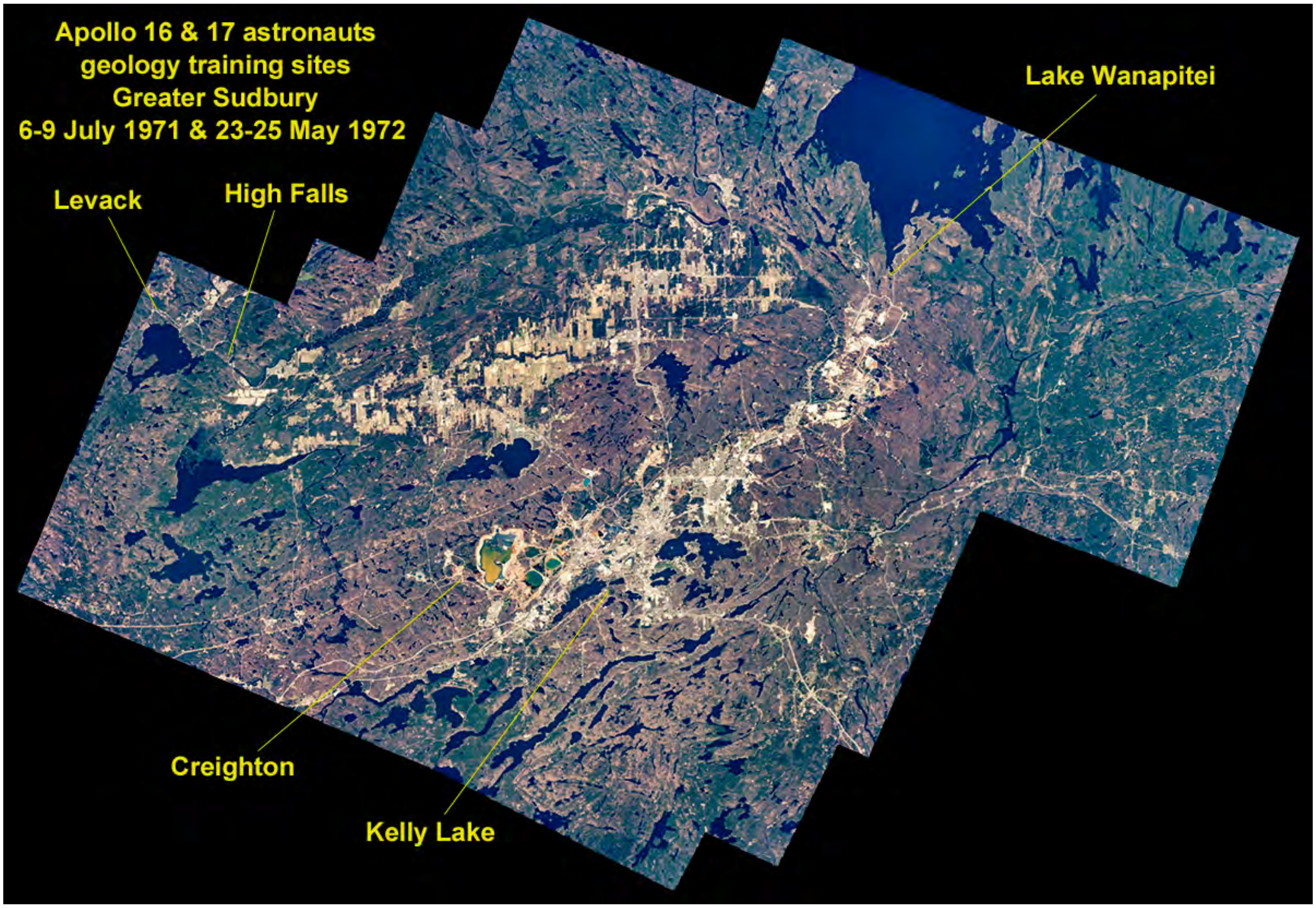

Figure 5 — Locations of geological field trips in the Sudbury area. Graphic by Andrew Yee, photo by Chris Hadfield.

can't believe it." Less than a half hour later, the two astronauts found a shatter cone nearby similar to what they had seen at Kelly Lake.[21]

In their 20 hours walking on the lunar surface, the two astronauts collected 95.8 kg of samples, drove 26.7 km with their rover, left behind a set of instruments that operated for 7 years, and kept Young's promise of a changed image. "Now we know that almost all lunar craters were created by impacts and their impact basins dominate the lunar crust," Wilhelms later wrote. "The *Apollo 16* mission thus caused a major revision in our view of lunar history," French said.[22]

Apollo 17 Training

Less than a month after *Apollo 16* returned to Earth, Sudbury welcomed astronauts preparing for the sixth and final Apollo expedition to the lunar surface, *Apollo 17*. The Sudbury field trip for that flight had been under consideration since the successful *Apollo 16* trip there the previous summer, but the unexpected turn with Young and Duke's exploration of Descartes and its relationship to the geology of the Sudbury Basin put Sudbury firmly on the training schedule for *Apollo 17*.[23]

On Tuesday, 1973 May 23, *Apollo 17* Commander Eugene Cernan and LMP Harrison Schmitt, the only professional geologist who would land on the Moon in Apollo, flew into Sudbury along with backup astronauts and *Apollo 15* veterans Scott and Irwin, and two astronauts from their support crew, Robert A. Parker, who would communicate with Cernan and Schmitt from the control centre during their traverses on the lunar surface, and C. Gordon Fullerton. As usual, they were accompanied by geologists headed by Muehlberger, French, and other NASA personnel. That evening, Dence briefed the astronauts on the geology of the Sudbury Basin as he had done the previous July for the *Apollo 16* astronauts.[24]

While some of the *Apollo 17* training covered the same ground in Sudbury as *Apollo 16*, the format of this visit was different. On the morning of May 24, the astronauts carried out an aerial reconnaissance flight of two and a half hours over the Sudbury Basin in a NASA Gulfstream aircraft. For this flight, they were accompanied by *Apollo 17* CMP Ronald E. Evans, who returned to the U.S. immediately after the flight.

In the afternoon, the astronauts visited the south shore of Lake Wanapitei to examine the variety of breccias and impact structures located there, and later visited Hanna Lake in the

Kelly Lake area. Cernan and Schmitt did not conduct a full rehearsal of their lunar traverses like Young and Duke did, but simply hiked around the area and examined points of geological interest.[25]

On May 25, the astronauts and geologists revisited the Windy Lake, High Falls, and Onaping Falls area that had been previously studied by the *Apollo 16* crew, with an additional stop at Whitewater Lake on the way back to Sudbury. Afterward, the astronauts and geologists spent two hours discussing their findings before the astronauts flew back to Houston that evening.[26]

The visit of the *Apollo 17* astronauts did not draw the same degree of media interest and controversy as the *Apollo 16* visit. The fact that Cernan wasn't allowed to drive a rental car because the vehicle was taken out in the name of someone else in the NASA party drew some press coverage.[27]

Apollo 17 lifted off from Kennedy Space Center on 1972 December 7, and Cernan and Schmitt landed in the valley of Taurus-Littrow. Like the crews of *Apollos 15* and *16*, they spent three days exploring the area with the help of another Lunar Roving Vehicle. The goal was to find a variety of lunar samples from early and late in the history of the Moon. Unlike *Apollo 16*'s crew, Cernan and Schmitt did not refer to Sudbury from the lunar surface, but they reported that they were keeping an eye out for shatter cones.[28]

The 382 kg of Apollo lunar samples and the data from the six Apollo experiment packages have helped scientists better understand the history of the Moon and of the Earth. One of the big lessons geologists learned concerned the importance of impacts in the history of the Moon.[29]

Conclusion

Many changes have taken place in Sudbury in the decades since the Apollo astronauts visited, including measures by governments, companies, and scientists to restore the vegetation whose loss had been inaccurately linked to the astronaut field trips.[30] Others have seen Sudbury become a centre of scientific research.

Fifty years after the visit of the *Apollo 16* astronauts, geologist Mike Dence said it was fortunate that they visited Sudbury in the 1970s before the vegetation in the area was restored to reverse the impacts of logging, mining, and acid rain, an effort that won recognition from the United Nations. "Most of that area has now been overgrown very considerably. It is now woods, and it's very difficult to work out exactly where we went with the astronauts," he told the *Sudbury Star*. "The rehabilitation of the Sudbury landscape has gone that far—after 50 years, most of it is lost in the woods."[31]

Research and scientific debate about the exact nature of the impact that created the Sudbury basin is still continuing. Recent work is suggesting that the impact resulted from a comet rather than from an asteroid as was earlier believed. Bevan French, who accompanied the Apollo astronauts to Sudbury, has recently resumed the geological research into the Sudbury impact that he began in 1966.[32]

David Pearson, a professor in the school of environment at Laurentian University in Sudbury, took part in the *Apollo 17* field trip. In 2019, he told TVOntario that the two astronaut visits served as a catalyst for the establishment in 1984 of Science North science centre in Sudbury, where Pearson served as founding director. In 1999, the Sudbury Neutrino Observatory, now the SNOLAB underground physics laboratory, was established at the 2070-m level of the Creighton Mine that had been visited by Young and Duke of *Apollo 16*. "I think that their visits and the publicity of their visits created an interest in science in children in Sudbury and gave the city a different vision of its place."[33]

Fifty years after Apollo, NASA is gearing up for a return to the Moon in this decade in the Artemis program, which will have Canadian participation. In September 2021, Canadian astronaut Joshua Kutryk and NASA astronaut Matthew Dominick visited an impact crater at Mistastin Lake in Labrador, and geological training will likely ramp up as Artemis missions get under way.[34]

Canada has a strong tradition of research into meteor impacts, as shown by people like C.S. Beals, Ian Halliday, and Gareth Jones, among others.[35] Their research at places like Sudbury and Suffield helped establish the importance of impacts in the history of Earth, and played a role in the work of the Apollo astronauts of establishing the importance of impacts in the history of the Moon and elsewhere in the Solar System and beyond.[36] ✶

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Endnotes

1 The story of Apollo exploration of the Moon is told in Andrew Chaikin, *A Man on the Moon: The Voyages of the Apollo Astronauts* (New York: Viking, 1994). The author's book *Arrows to the Moon: Avro's Engineers and the Space Race* (Burlington: Apogee Books, 2001) tells the story of Canadians who were involved in Apollo, including the Canadian geologists who worked with Apollo lunar samples, 191–192. Transcripts of the conversations between Apollo astronauts on the Moon and

controllers on Earth are available online at the *Apollo Lunar Surface Journal* at www.hq.nasa.gov/alsj/main.html.

2 William Phinney, *Science Training History of the Apollo Astronauts* (Washington, D.C.: National Aeronautics and Space Administration, NASA SP-2015-626). Other sources of information on geology in Apollo are Don E. Wilhelms, *To a Rocky Moon: A Geologist's History of Lunar Exploration* (Tucson: University of Arizona Press, 1993); Donald A. Beattie, *Taking Science to the Moon: Lunar Experiments and the Apollo Program* (Baltimore: Johns Hopkins, 2001); and Bevan M. French, *The Moon Book* (Harmondsworth, England: Penguin Books Ltd., 1977).

3 G.H.S. Jones, *The Suffield Craters as Analogues of Impact Structures: Suffield Special Publication No. 177*, Department of National Defence, 1995. Chapter 6 of this report covers the Dial Pack explosion, and the wider report contains valuable background on the explosions that took place at Suffield from 1960 to 1970. See also J.D.R. Pattman, *Operation Dial Pack 1970 Canadian Project A7 Thermal Radiation Measurements* (Defence Research Board of Canada, Report DREO 642, 1971).

4 Jones, *The Suffield Craters*, 4-1; J.L. Locke, "Carlye Smith Beals 1899-1979," *JRASC Vol. 79, No. 6* (December 1979), 325–332; C.S. Beals and Ian Halliday, "Impact Craters of the Earth and Moon," *JRASC, Vol. 61, No. 5* (October 1967) 295–313. Beals served as President of the Royal Astronomical Society of Canada and was the only Canadian to serve as president of the American Astronomical Society. For more on Shoemaker, see David H. Levy, *Shoemaker by Levy: The Man Who Made an Impact* (Princeton: Princeton University Press, 2000).

5 Doug Ward, "Apollo 15 Crew Views Canadian Crater Blast," *Roundup* (Houston: *NASA Manned Spacecraft Center, Vol. 9, No. 20*, 1970 July 31) p. 1; Carolyne Bittinger, "Astronauts Here for Blast," *The Medicine Hat News* (Medicine Hat, Alta., 1970 July 22) p. 1; Frank Mackey, "Blast Goes Without a Hitch," *The Medicine Hat News* (1970 July 23) p. 1; Frank Mackey, "Blast 'complete success,'" *The Medicine Hat News* (1970 July 24) p. 3. A DRB spokesperson was quoted as saying that scheduling problems prevented Apollo astronauts from being present at the 1968 Prairie Flat explosion at Suffield. Scott had flown on *Gemini 8* and *Apollo 9*, Young had flown on *Geminis 3* and *10,* and *Apollo 10* in lunar orbit. Gordon had flown on *Gemini 11* and in lunar orbit as Command Module Pilot on *Apollo 12*, and Haise had flown around the Moon on *Apollo 13*. Brand later flew on *Apollo-Soyuz* and the *Space Shuttle*, and Carr and Pogue later flew on *Skylab*. England, Parker, and Allen were scientist astronauts who flew on board the *Space Shuttle* after having acted as spacecraft communicators during Apollo moonwalks.

6 Phinney, *Science Training History*, pp. 238, 239, 243.

7 Ward, "Apollo 15 crew."

8 Michael R. Dence, Eugene L. Boudette, and Ivo Lucchitta, "Guide to the Geology of Sudbury Basin, Ontario, Canada," Interagency Report 43 (United States Department of the Interior Geological Survey, May 1972), pp. 1–8; and Bevan M. French, *Sudbury Structure, Ontario: Some Petrographis Evidence for an Origin by Meterorite Impact* (Greenbelt, MD: NASA Goddard Spaceflight Center, February 1967).

9 Phinney, *Science Training History*, 247; French, *The Moon Book*, 155. The astronauts and U.S. geologists flew from Houston to Sault Ste. Marie, Michigan, and then drove to Sudbury. See Lydia Dotto, "Walking on rocks 'not a fun trip' say U.S. moon men in Sudbury," *Toronto Star*, 1971 July 8.

10 Charles Kruse, "U.S. Astronauts Turn Rock Hounds, Prepare for Apollo 16 Moon Mission," *The Sudbury Star*, 1971 July 8. See also "Sudbury Basin Rocks Give Clues to Apollo 16 Mission," *Inco Triangle, Vol. 31, No. 4*, July 1971. The Manned Spacecraft Center was renamed after former president Lyndon B. Johnson in 1973.

11 Phinney, *Science Training History*, p. 247.

12 Ibid. The crater at Lake Wanapitei is estimated to be about 37.2 million years old, much younger than the Sudbury structure.

13 Ibid.

14 Dr. B.M. French, NASA Memorandum to Dr. Louis S. Walter, "Travel to Sudbury, Canada for Apollo 16 Field Simulation, July 6–10, 1971," 1972 March 3.

15 "To Return to City After Apollo Trip," *Sudbury Star,* 1971 July 10.

16 Dotto, "Walking on rocks."

17 "U.S. Astronauts Here Training for Study of Craters on Moon," *Sudbury Star*, 1971 July 7. In his Memorandum on the visit to Sudbury, French praised the work of a public relations person from NASA Headquarters and the "well briefed" astronauts, who "adroitly" answered questions about the Sudbury landscape.

18 "Sopha Stands Alone In NASA Criticism of Area Moon Trek," *Sudbury Star,* 1971 July 10. See also "Associating Sudbury With Moon Irks MPP," *Sudbury Star*, 1971 July 10, and "Well Said, Elmer, Moonscape Indeed," *Sudbury Star*, 1971 July 12.

19 Wilhelms, *To a Rocky Moon*, p. 290. The author has been unable to learn what the incidents were.

20 *Apollo Lunar Surface Journal, Apollo 16*, The First EVA, "Back in the Briar Patch."

21 *Apollo Lunar Surface Journal, Apollo 16*, The Third EVA, "Station 11 and North Ray Crater," and "House Rock."

22 Wilhelms, *To a Rocky Moon*, p. 308. French, *The Moon Book*, p. 108.

23 Lydia Dotto, "2 astronauts going to Sudbury to see the rocks," *The Globe and Mail*, 1972 May 23; "Sudbury Terrain Again Draws Apollo Astronaut Geologists," *The Sudbury Star*, 1972 May 23.

24 Phinney, *Science Training History*, p. 252. Scott and Irwin were later replaced on the *Apollo 17* backup crew for disciplinary reasons by Young and Duke. Fullerton also served as a spacecraft communicator for *Apollo 17* and later flew in the *Space Shuttle* program.

25 "Astronauts Again Study Sudbury Rocks," *The Sudbury Star*, 1972 May 24; Phinney, Ibid.

26 "Sinuous, Hackley' Describes Area Rock," *The Sudbury Star*, 1972 May 25; "Astronauts Return After Area Study," *The Sudbury Star*, 1972 May 26; Ian Ross, "Sudbury was a mineral training ground for NASA astronauts," *Northern Ontario Business*, posted 2016 May 27, www.northernontariobusiness.com/regional-news/sudbury/sudbury-was-a-mineral-training-ground-for-nasa-astronauts-372020; and Phinney, ibid.

27 E. H. Hausmann, "Astronaut can't drive rental car in Sudbury," *Toronto Star*, 1972 May 24.

28 *Apollo Lunar Surface Journal, Apollo 17*, The Third EVA, "Geology Station 9 at Van Serg," and "EVA-3 Closeout."

29 For an in-depth discussion of Apollo's findings, see Chapter 18 of Wilhelms, *To a Rocky Moon*, and French, *The Moon Book*.

30 In 1972, Inco brought the 381-metre-tall Superstack at Copper Cliff into operation. By spreading smelter emissions over a much wider area than before, it reduced damage from the emissions in the Sudbury area. Other work began at that time to restore forests in the area. In 2017, Vale Canada Ltd., which now owns the mines and smelters, announced that it will take the Superstack out of operation and replace it with smaller and more efficient stacks. For more on the restoration of the Sudbury area, see Colleen Romaniuk, "The Drift 2020: The Sudbury story," *Northern Ontario Business*, 2020 February 28. www.northernontariobusiness.com/drift-2020-/the-sudbury-story-2127705.

31 Colleen Romaniuk, "It's been 50 years since NASA's Apollo 16 astronauts walked on Sudbury," *The Sudbury Star*, 2021 July 9, p. 1.

32 Tia Ghose, "Comet Strike to Blame for Canada's Iconic Sudbury Basin," *Scientific American*, www.scientificamerican.com/article/comet-strike-to-blame-for-canada-s-iconic-sudbury-basin Posted 2014 November 19. See also Kevin O. Pope, Susan W. Kieffer, and Doreen A. Ames, "Empirical and theoretical comparisons of the Chicxulub and Sudbury impact structures," *Meteoritics & Planetary Science 39, No. 1* (2004), 97–116. Bevan French, interview with author, 2021 18 October. See also French, *The Moon Book*, p. 155.

33 Claude Sharma, "That's no moon: Before these NASA astronauts went to space, they went to Sudbury," TVOntario website, 2019 July 22. www.tvo.org/article/thats-no-moon-before-these-nasa-astronauts-went-to-space-they-went-to-sudbury .

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OΣΣ 254 Cas/ WZ Cas: A Unique Coloured Double-star System with a Carbon Star Component of Variable Colour

By François Chevrefils and Michel Duval
RASC Members

OΣΣ 254 Cassiopeiae is a coloured double star indicated in the section on Coloured Double Stars (Autumn Stars) of the RASC *Observer's Handbook* (OH). It is discussed further in the online Supplement of the OH for Coloured Double Stars (www.rasc.ca/handbook/supplements).

Its characteristics are indicated in Table 1.

Its component A is a variable star (WZ Cas) of magnitude varying from 6.5 to 8.5 according to recent visual observations of the American Association of Variable Stars Observers (AAVSO) (see Figure 1, where dates on the horizontal axis go from March 2018 to July 2019). At its minimum magnitude it is reported to be very red (R) and beautiful (!!).

It is a carbon star of spectra C5 to C9 III, i.e. its colour varies from orange to deep red, and its temperature from ~4200 K to ~2500 K, respectively (see online Supplement of the OH for spectra of colour and temperature). It has a period of ~186 days and its variable type is semiregular. It has a carbon atmosphere and is at a distance of ~2861 light-years.

Component B of the double star is a pale blue (B) star of spectrum: A0, Class III (T ~10,000 K).

A photo of OΣΣ 254 Cas/ WZ Cas, obtained with an 8-inch telescope, is shown in Figure 2 (south is up). Component A (WZ Cas) is the brightest orange star in the centre. Component B is the blue star on its right.

This combination of a coloured double star (OΣΣ 254 Cas) and a carbon star of variable colour (WZ Cas) is unique for the following reasons:

- there are very few variable stars in the lists on double stars, e.g. only three have been found so far in the book on double stars for small telescopes by Sissy Haas (2006), none of which are components of a coloured double star.
- WZ Cas is among the few variable carbon stars of magnitude high enough to easily perceive their colour visually (most of them are of minimum magnitude lower than 12).
- regular observers of coloured double stars tend to not verify if one of their components is a variable star, while regular observers of variables tend to not verify if they are components of a coloured double star.
- present types of double stars include regular doubles, tight doubles (for optical tests), and coloured doubles (as described in the OH). When other double-star combination systems similar to OΣΣ 254 Cas/ WZ Cas are found, a new category of "coloured double stars of variable colour and brightness" may need to be created.

The OΣΣ 254 Cas/ WZ Cas double-star system is an interesting and relatively easy target for amateur astronomers and public star parties, where changes in the double colours from deep red/blue to orange/blue can be followed at its minima and maxima of magnitude, which will occur according to Figure 1 during the observation seasons of Cassiopeia in autumn and winter, respectively.

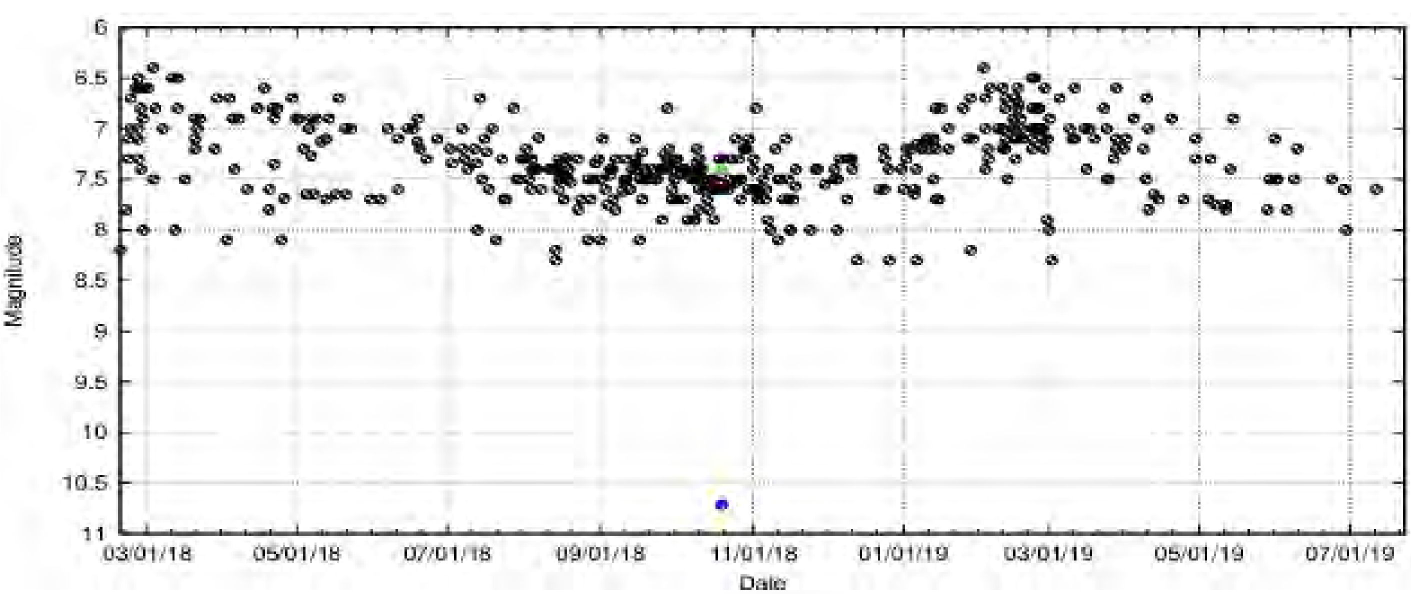

Figure 1 – AAVSO Light Curve of WZ Cas

		RA (2000)		Dec		Magnitudes		Sep.	Colour		Beauty
Double Star	SAO	h	m	°	′	A	B	″	A	B	—
OΣΣ 254 Cas	21002	00	01	+60	21	7.6v	8.7	57	R	B	!!

Table 1

Light curves for WZ Cas after 2019 are available from aavso.org. WZ Cas is near bright star β Cas.). ✶

Figure 2 — OΣΣ 254 Cas Double Star System

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François Chevrefils is a long-time amateur astronomer in Montréal, Québec (since 1969). He has presented over a hundred seminars to astronomy clubs throughout the greater Montreal region. He is the author of a reference work in three volumes and ~ 900 pages on stars and constellations for amateur astronomers, in the process of being completed and finding a publisher. He can be reached by postal mail at 2 - 5880 Ch Côte St-Antoine, Montréal QC H4A 1S5, Canada.

Michel Duval is in charge of the section on Coloured Double Stars of the RASC Observer's Handbook *(since 2009). He is the principal author of several research papers in the JRASC (since 2005), concerning the transits of Venus and Mercury against the Sun, the black-drop effect, and the diamond ring effect during eclipses of the Sun. He can be reached at duvalmn@videotron.ca.*

Great Images

By Blair MacDonald

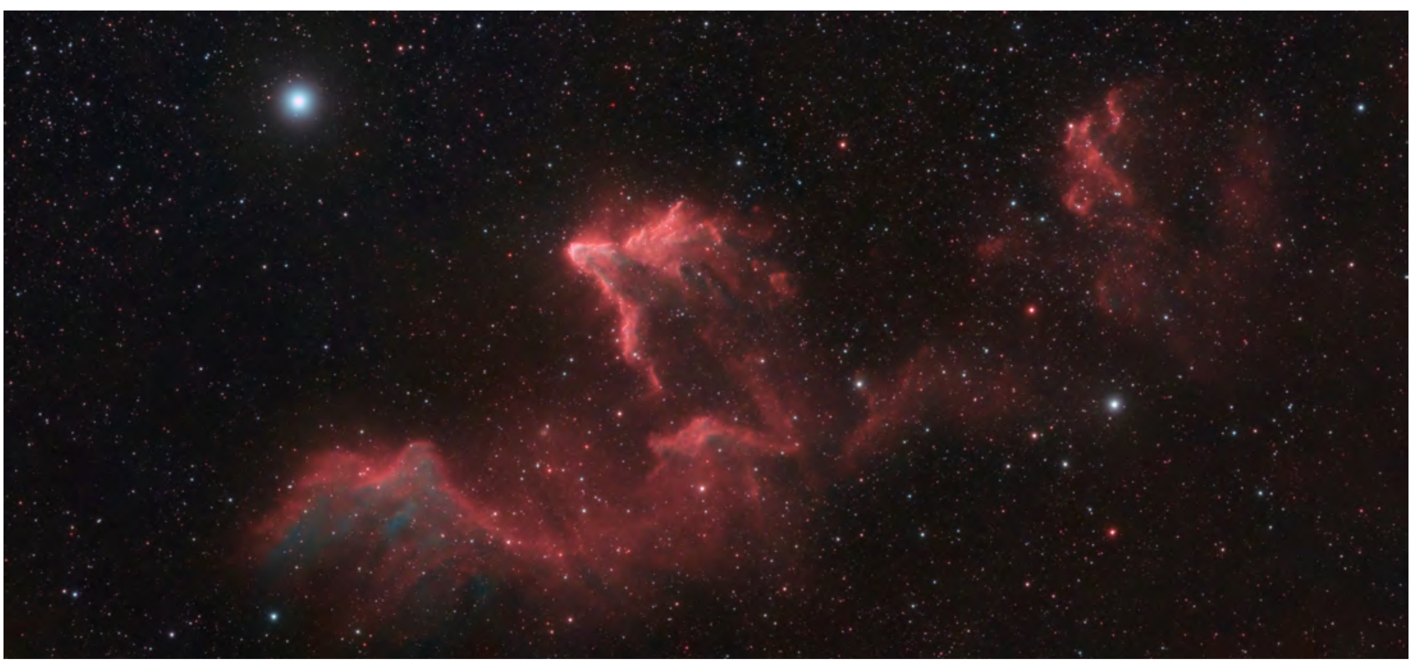


Figure 1 – Blair MacDonald writes, "First shot from our cottage in Marion, Nova Scotia, on 2021 July 31. The Ghost of Cassiopeia, or IC 63, is being shaped by radiation from the star Navi (Gamma Cassiopeia) at upper left." The image represents 5 hours (20 x 15 min) of data, using a Sky-Watcher Esprit 120 f/7 APO refractor with an Optalong L-enhance light-pollution filter.

Figure 1 – Rick Stankiewicz used some of that astronomer's patience to capture Comet Leonard (C/2021 A1). "The clouds just about wiped me out … but I waited for some 'sucker holes' to capture something/anything, and I got lucky!" he said. Rick imaged the comet from Peterborough, Ontario, using a Canon 60D and a Canon 200-mm lens at ISO 3200, ƒ/2.8 for 10 seconds on an iOptron SkyTracker Mount.

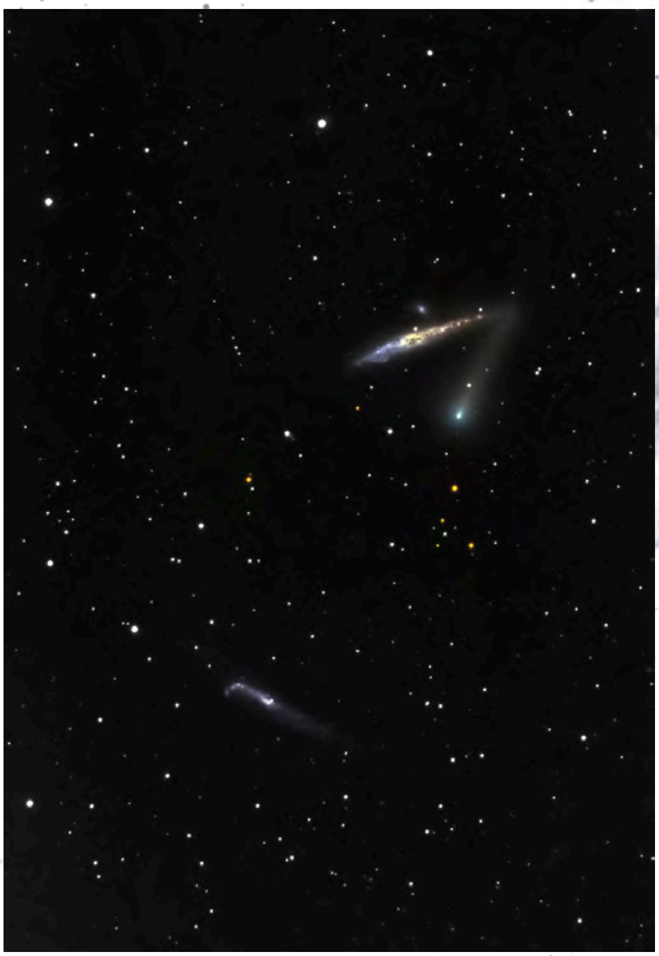


Figure 2 – Shelley Jackson had planned for a month to capture this image of NGC 4631 (the Whale), NGC 4627 (small companion galaxy), and NGC 4656 (the Hockey stick/Crowbar). On the morning of 2021 November 24, her patience—along with a bit of luck—paid off. "Things were working just in time for me to start imaging and after 15 minutes, clouds shrouded the view. I was very lucky to capture this once-in-eternity joining of the comet with such a great trio of galaxies," she said. Shelley used an 81mm WO GT apo triplet, with a field flattener/.8 reducer, a 50-mm guide scope, ZWO 120 mono guide camera, Sky-Watcher AZ EQ5 pro and Sky-Watcher EQR 6 pro mounts (she also imaged the galaxies before the arrival of Comet Leonard), Atik mono CCD cam cooled to 0 °C, Pegasus focus cube, and Pegasus Falcon Auto rotator filters (RGB). She captured the image under Bortle 6/7 skies from her backyard in Sarnia, Ontario. The final image was stacked and processed with PixInsight. Combined RGB for galaxies = 120×60 + an additional 30×30 sec to capture the comet with the galaxies.

Figure 3 – This spectacular image of the Lobster Claw Nebula (Sharpless 157) and the Bubble Nebula (NGC 7635) taken by Dave Dev from his backyard in Woodbridge, Ontario, over several days from August through to November 2021 using his Sharpstar 94-mm APO with an ASI 2600 mono camera. He used eight hours on each narrowband filter (Hα, OIII, and SII) for the final image, which was processed using PixInsight.

Figure 4 – On November 19, we were treated to a partial lunar eclipse. Daniel Biron stayed up into the wee hours of the morning in Repentigny, Québec, capturing this beautiful image of our nearest neighbour as it glided through Earth's shadow. Daniel used a Celestron C6 with an ƒ/6.3 reducer/corrector and a vintage Celestron 30-mm Ultima with a Google Pixel 4a Smartphone.

AAVSO

Your Monthly Guide to Variable Stars – Series Two

by Jim Fox, AAVSO

Introduction

Even before recorded history, mankind has been fascinated by the night sky. Hunter/gatherers were familiar with patterns of stars that would foretell when game would be migrating. Later, farming cultures knew other patterns would alert them to the proper time to plant their crops. Even after written records became available, certain patterns that we now call constellations were used to illustrate tales of real or mythic heroes, the forerunners of today's graphic novels. But those early people were not aware that the stars themselves had stories to tell. Some of those stories involve stars that change brightness—variable stars.

In a previous series, I suggested a variety of variable stars that are easy to find and observe. Intended for new variable-star observers or the public, those stars could be observed by the unaided eye or with binoculars. They provide a brief introduction to the many stars whose brightness changes from time to time.

This new series is intended for amateur astronomers who already have some familiarity with the night sky. I hope to pique your interest in variable stars by describing stars that are representative of some of the many mechanisms by which stars change their brightness or are particularly interesting (at least, to me). While some of them are bright enough to be visually observed with binoculars throughout their cycle of variability, others will require a telescope of moderate size during the dimmest segment of their period. The stars can be found in a convenient sky atlas, and I will provide J2000 coordinates in case a star is not already plotted therein.

Estimating the brightness of a star is easy. Find two nearby stars of known brightness, one that appears brighter and one that appears dimmer than the target star. Then estimate the fractional brightness of the target compared to the two references. Is it halfway between? A quarter? Really close to one of them? Apply this fraction to the difference between the references to arrive at the target's brightness estimate. With a little practice, you should be able to estimate a star's brightness within a tenth of a magnitude. You can submit such observations for inclusion in the International Database of variable-star measurements that is maintained by the American Association of Variable Star Observers (AAVSO).

While I include a convenient, noninverted (north at top) chart of comparison stars nearby the featured variable, full charts that include other comparisons can be found on the website of the AAVSO at https://aavso.org. In their "Pick A Star" menu box, simply type in the star's name (or abbreviation) and click "Create a finder chart." Note that magnitudes are shown to the nearest tenth with the decimal point omitted so as not to be confused with a star; so, a star labelled 59 will be of magnitude 5.9, for example.

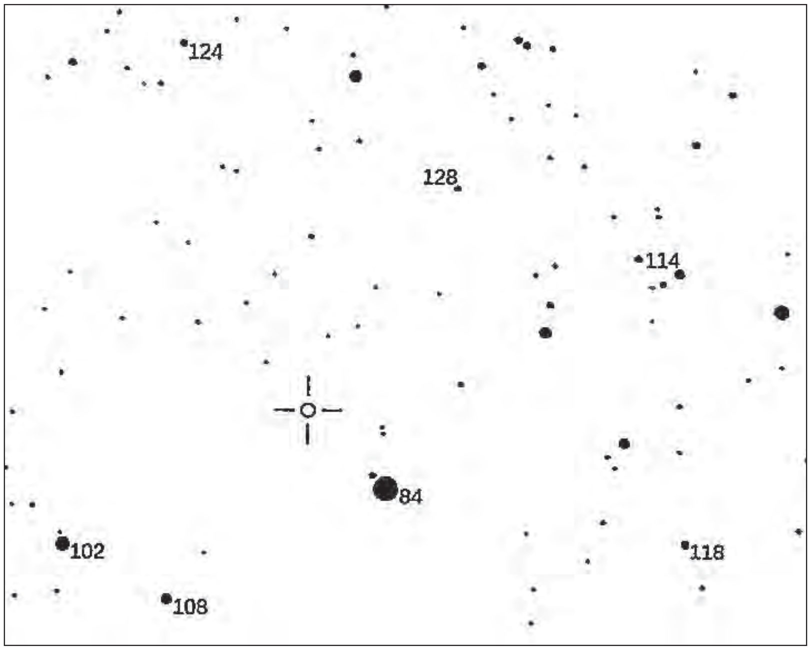
In his book *Starlight Nights*, Leslie C. Peltier points out that, unlike deep-sky objects, variable stars are not just *there*, they are *happening* and as you observe them from night to night, you can watch them ***happen!*** However at the beginning of Chapter 9, Peltier counsels, "I feel it is my duty to warn any others who may show signs of star susceptibility that they approach the observing of variable stars with utmost caution. It is easy to become an addict and, as usual, the longer the indulgence is continued the more difficult it becomes to make a clean break and get back to a normal life." As I lead you on a journey of variable-star observing, do not hesitate to become "addicted"—it will be exciting!

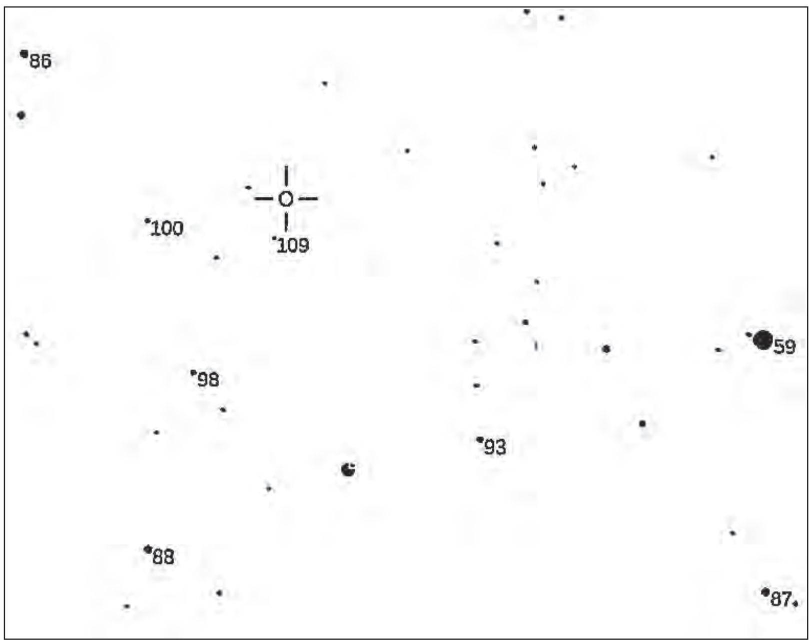
For more information on these (and many other) variable stars, I recommend *Understanding Variable Stars* by John R. Percy (2007) or diving into the pages of the AAVSO website.

January – T Tauri (T Tau)

Located between the Pleiades and Hyades star clusters in the constellation of Taurus, T Tauri was discovered in 1852 by John Russel Hind, an asteroid hunter at the time who is credited with discovering ten asteroids in the mid-19th century. The nearby reflection nebula, NGC 1555, is illuminated by the star and is known as "Hind's Nebula," but is a challenge to observe. Since it is illuminated by T Tau, it also varies in brightness, making it a variable nebula! In 1981 an infrared companion star was discovered about half an arcsecond south of the visible star. We now know that T Tau is actually a triple-star system.

This star is the namesake of a class of very young stars. T Tauri stars have only recently emerged into optical visibility from the surrounding nebula of their origin. As such, they probably





are less than 10 million years old and are pre-main-sequence in their evolution. So, these stars offer us a glimpse into the earliest stages of stellar evolution. Most likely, our Sun went through a T Tauri stage some 4.5 billion years ago.

Brightness changes in T Tauri stars may be due to their "growing pains" as they grow in size by accretion or have instabilities in their atmospheres or have partial obscuration by the remnants of the clouds from which they formed. T Tauri varies by a few tenths of a magnitude on a daily basis, residing in the range of magnitude of 9.3 to 10.7 but has no well-defined period. Stars of this class are defined spectroscopically, particularly by the presence of lithium in the atmosphere, it being an indicator of stellar youth.

You can find T Tau at 04h 21m 59s, +19°32′06″, 1.6° west of Epsilon Tauri and 1.5° southwest of Omega2 Tauri, near the 8.4-magnitude star SAO 93887 labelled as 84 on the accompanying chart. Chart is not inverted with north up and east left. T Tau is the highlighted open circle. Chart courtesy AAVSO.

February – VY Canis Majoris (VY CMa)

First noted as a variable in Jerome Lelande's *Star Catalogue of the Paris Observatory*, VY Canis Majoris was noted as magnitude 7 in 1801. Lelande is also credited with a pre-discovery observation of Neptune in 1795. VY CMa was reasonably well observed during the 19th century but fell out of favour in the 20th century, until 1970, when Lief J. Robinson released a study of the star on 2000 photographic plates in the Harvard College observatory collection. It has been a popular variable ever since.

One of the largest stars known, the outer atmosphere of VY CMa would extend out past the orbit of Jupiter if it replaced the Sun in our Solar System. The star is also a triple system imbedded in a dense nebular cloud. This, combined with its deep red colour, makes it challenging to estimate its brightness. The most reliable visual procedure is to make brief glimpses of the star and comparisons since fixed staring at red objects tends to make them seem brighter.

Most of the radiation from VY CMa is in the infrared and microwave portions on the spectrum. In fact, the star is an example of a natural MASER (Microwave Amplification by Stimulated Emission of Radiation), the microwave equivalent of the more commonly known LASER. The star acts as a "pump" to excite silicon molecules in the surrounding nebula.

Varying between magnitudes 7.4 and 9.6, VY CMa has an irregular period around 950 days. It can be found in southern Canis Major at 07h 22m 58s, –25°46′03″, where it makes a nearly right triangle with Delta and Eta Canis Majoris. It is 26′ northeast of 5.9-magnitude SAO 173529 labelled 59 on this chart. Chart is not inverted with north up and east left. VY CMa is the highlighted open circle. Chart courtesy AAVSO. ✶

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

Observing

My Minimal Set—Observing With Only Two Eyepieces and Some Barlows

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

"So this is the set?" my friend Shane asked me, "Yeah, I've pared down to observing with just two eyepieces." Minimalism—I'm sure you've also read about people who live with only a toothbrush and a change of clothes, but you can relax as this is not that sort of article. The idea here is about observing better and more often than an astronomical tale of frugality.

New observers often ask about purchasing eyepiece setss. This seems logical because manufacturers advertise this way, and you can get complete "beginner sets" or accumulate expensive sets in nearly every millimetre of focal length from 2.5 mm on up. So when newcomers ask, they are surprised when I mention that, while I've collected many eyepieces, I typically observe with only two or three eyepieces and some Barlow lenses. Sure, on special occasions, such as some all-too-rare good seeing or a planetary opposition, I break out the specialized high-power glass, but for the most part, I just use a low-power and a mid-power eyepiece plus Barlows to give specific magnifications.

Why bother with Barlows?

I actually don't care for Barlows too much because of the futz factor of sliding eyepieces in and out and that can create a barrier to observing with all available powers, this is especially true when the weather turns cold. However, I was getting out observing and missing certain powers despite bringing four or five eyepieces along in a large toolbox converted into an eyepiece case. I had a 7 mm but felt a 6 mm was too close to justify the expense, and I couldn't find a 4 mm I was happy with, not to mention I had hoped to step up from 70-degree apparent fields to something like 80 degrees or greater. So a few years ago I set my sights on getting one medium-power eyepiece with a wide field and eyeglass-friendly eye relief with the specific purpose of using it in Barlows. After some experimenting, my "minimalist" set now includes two eyepieces and three Barlows: a 12.5-mm 84-degree, plus 1.6×, 2×, and 3× Barlows, and a 40-mm 70-degree for lowest-power widest-field observing. My current telescope is a 100-mm *f*/7.4 refractor selected to optimize light weight and quality optics that I refer to as the "4-inch." *To calculate power (×), the 740-mm focal length of the refractor is divided by the eyepiece focal length or that provided by eyepiece plus Barlow

* Note that powers are approximate, and this set gives slightly higher powers as these Barlows provide greater magnification than specified

In the 4-inch I have found this set provides a nice range of powers for the majority of my observing sessions. The 40 mm gives just under 20×, and is perfect for wide-field rich-field telescope (RFT), low-power views, while the 12.5 mm gives 60× and 100×, 130× and 185× using the Barlows I have, which provide slightly higher powers according to my testing. For large objects, the 40 mm gives a near 4-degree true field, while the 12.5 and 60× begins to reveal subtle detail in smaller objects, with 130× being the most useful power for revealing subtle detail in smaller, deep-sky objects and in planets.

It is not coincidental that this set of powers matches closely what well-known observer and author Stephen O'Meara used in his 4-inch scope when writing his Deep Sky Companion books, *The Messier Objects, The Caldwell Objects*, and *Hidden Treasures*. O'Meara typically begins with an object's description using 23×, moves to 72×, then 130×, and on some occasions 189×, or even more. After experimenting with a variety of powers, I've concluded that O'Meara's set seems to provide the best observing experiences.

What about exit pupil?

Readers of the RASC *Observer's Handbook* won't be surprised by these magnifications, since a quick read of Roy Bishop's article on telescope exit pupils, pages 50 to 53, provides guidance for exit pupils resulting in a similar range of powers. Bishop provides specific guidance on making these selections based on what observers in the field have found useful: a high-power range in the 0.5- to 1-mm range, medium range in the 1- to 2-mm exit-pupil size, with low power occupying the 2- to 4-mm range, plus a Richest Field Telescope lowest usable power in the 4- to 7-mm range. A comparison with my selections shows similar exit pupils; however, I sometimes prefer slightly lower powers than the next observer due to my interest in observing large, extended objects.

What do you need to consider to get down to a minimal set?

Use exit pupils as a guide. To determine exit pupils, divide the eyepiece focal length by the telescope focal ratio. In my case 40 mm / f7.4 = 5.4-mm exit pupil. This works great with nebular filters, as well as giving about the widest field for a mid-sized refractor. I found O'Meara's next jump too much for me; he typically transitions from 23× to 72×; however I found a 10 mm at 74× gave too much magnification. Instead I moved to a 12.5 mm for 60× and a wider field. The 1.6× Barlow takes this to 100×, which unfortunately maxes out my seeing conditions on far too many nights. More useful on better evenings is 130×, achieved by placing the 12.5 mm in a 2× Barlow, which

Figure 1 — My "minimalist" set now includes two eyepieces and three Barlows: a 40-mm wide-angle (70°); a 12.5-mm 84°, plus 1.6×, 2×, and 3× Barlows.

Eyepiece	Exit Pupil	Power
40 mm	5.4 mm	20×
12.5 mm	1.7 mm	60×
12.5 / 1.6× Barlow	1 mm	100×
12.5 / 2× Barlow	0.8 mm	130×
12.5 / 3× Barlow	0.54 mm	185×

Figure 2 — Used set with a zoom eyepiece— a 30 mm, a 12 mm, and a zoom eyepiece. WALER = Wide Angle, Long Eye Relief, original design by Glenn Speers of Antares, no longer for sale on the retail market.

seems to yield higher power, as all my Barlows do, than the numbers alone suggest. A real sweet spot for observing is 130×, allowing plenty of resolution while limiting intermittent poor seeing—this power is often my highest usable for deep-sky objects before light begins running out on my small 4-inch scope. I also find that around 130× is when fine planetary detail begins to reveal itself. For some objects, or when seeing improves, I reach for the 3× Barlow. This works out to about 185×, taking me close to the maximum "usable" limit of 200×, which is a power that functions as a well-known ceiling on good nights, also the typical limit given for a 4-inch telescope. The ability to maximize the seeing on most nights, combined with shorter cool-down times, is why many observers keep a 4-inch or smaller scope handy or, like this observer, opt to observe solely with a small scope.

I have owned other telescopes and found the powers above are the most useful regardless of telescope type. I used a set of three eyepieces and a Barlow to get similar powers with my first 8-inch Dobsonian, later a 6-inch Maksutov, and more recently, when looking through my observing friend's 12-inch reflector.

But these eyepieces and Barlows are expensive, right?

You don't need to buy the most expensive eyepieces. I have a similar set I purchased used, with a zoom eyepiece instead of Barlows, which can be had for less than the cost of only one decent mid-range eyepiece. The differences between these older used eyepieces and the more recent ones is the benefit of new coatings, however, I still use my original 2× Barlow. Many observers likely own enough eyepieces to get them close to a similar set and, during cold months, keeping things simple might help you get out under the stars more often. ✶

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

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

Binary Universe

Hopping Through the Sky

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

Star-Hop Maker (SHM) is a very interesting planning software tool. But know it has a misleading name: it does not make "star-hopping" charts!

I was intrigued when I first learned of this product. I imagined that SHM would generate a star-hopping plan showing the best way to get from a starting point to a target object some distance away, presumably a faint galaxy. Classic star-hopping has the observer starting at a bright star, visible to the naked eye, then viewing fainter stars, asterisms, other obvious sights or markers, all within the grasp of a finder scope, a short distance from one another. But I learned quickly SHM does not do that. *Star-Hop Maker* produces *object-hopping* plans. It helps you hop from galaxy to galaxy or from galaxy to double star to variable star to some other deep-sky object. That's a sky-tour plan.

I read about *Star-Hop Maker* on Cloudy Nights in late September 2021. A user had just coughed up 21 Euros for the software admitting he didn't "have much time to plan observations." He was hoping the SHM would "make it easy." Someone suggested it looked "like a great way to set up a night of observing." When another user noted there was a 30-day trial version, I quickly downloaded version 1.1.0 and installed it on my 64-bit Windows 10 laptop.

www.starhopmaker.com

Learning *Star-Hop Maker*

I found SHM quirky and unusual and I experienced some head scratching. It reminded me of other planning apps like *SkyTools* (see *JRASC* April 2015) and *AstroPlanner* (*JRASC* October 2016). It suggests a radically different way of working and it took me a while to get up to speed. It sports a busy interface, a bit patchwork, not fully Windows compliant, which all takes some time getting used to.

Thankfully, it uses a classic menu style with commands File, View, etc. There are orientation videos and a brief user guide. Unfortunately, the document was written for an earlier version, so it further complicates the user's acclimation.

The main screen (see Figure 1) is bewildering, with many panels and floating windows that cover much of the stellar atlas! Immediately I ran into issues. The program needs to be shown on a single large high-resolution monitor or a multi-monitor computer. My 1366 by 768 pixels laptop display was too small. The "Information Area" bar under Menu was too wide, so I turned it off. I dismissed the "Events" panel on the left. Curiously there is no on-screen legend for the chart symbols, but I found them described in the Help menu.

I learned there are two strategies for using the program: preparing ahead of time; or winging it in the field.

Figure 1 — The busy main screen of Star-Hop Maker *with information bar and various panels.*

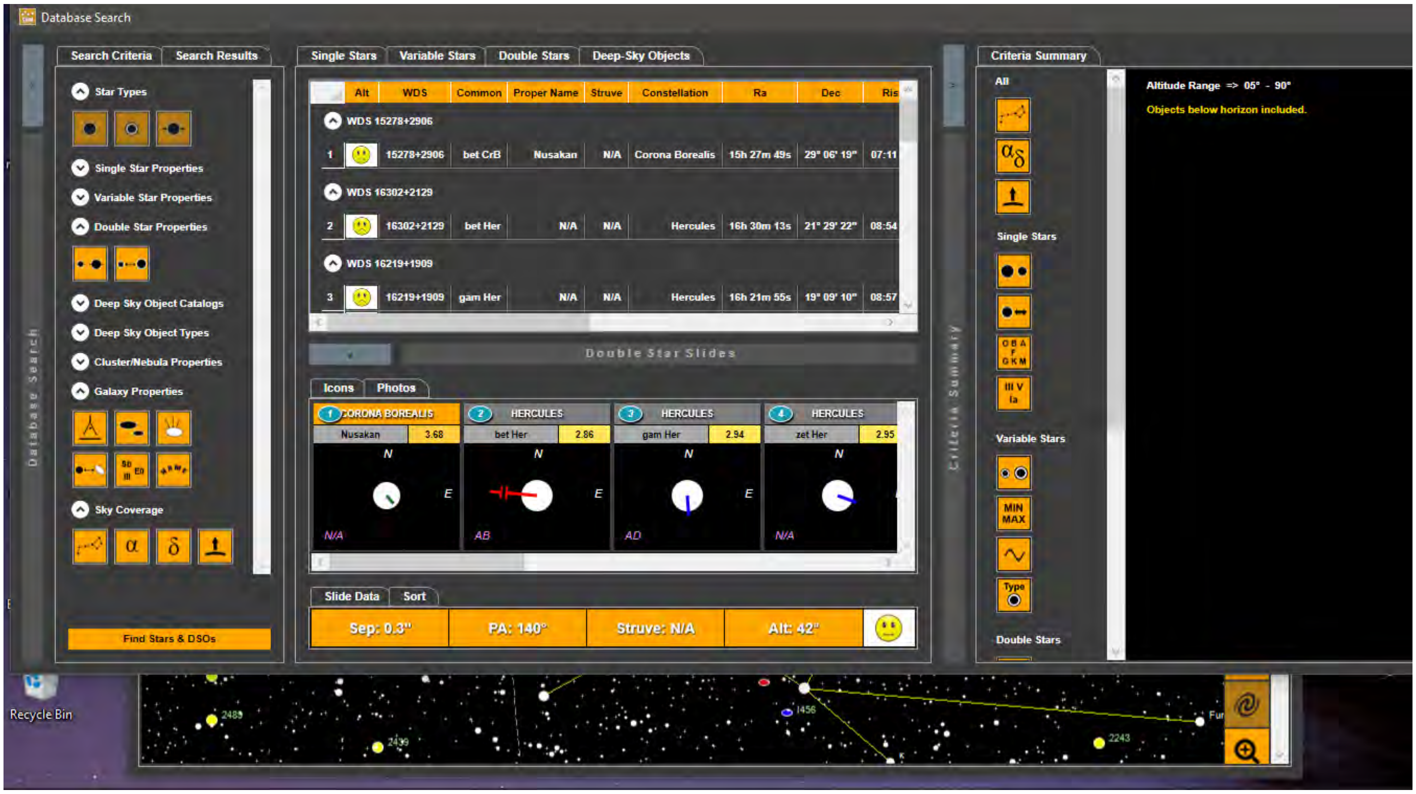


Figure 2 — The Database Search window with criteria controls, candidate targets, and summary section.

Preparing in Advance

If you wish to plan an observing session ahead of a clear evening, you should use the Prepared Star-Hop Creator. I fancied making a plan for a Messier Marathon, to visually show an optimized route through the single evening. However, I encountered a curious limit, that objects cannot be 30 degrees away from one another.

I considered a less ambitious use case: an observer working on their RASC Messier Certificate with a few more targets to bag, objects in Sagittarius, Scutum, Aquarius, and Capricornus. I'd make an object-hopping plan to knock off the targets in a good sequence. I opened the Database Search window.

The search (Figure 2) gives access to the rich database that includes galaxies, nebulae, clusters, double stars, and variable stars. You can filter on type of object as well as object properties. You can also limit candidate objects to an altitude range. For my example project, I instructed the Database Search to show me all classes of Messier Catalogue objects in four constellations.

The objects meeting the criteria are shown in the centre of the search window, in a tabular list with details such as Rise time, and in a unique slides panel with graphical notes or survey images.

I noted you could tell the search tool to select objects when no magnitude was provided in the database, a feature I wish other programs supported!

When filtering is complete, the candidate items need to be copied from the search window to the Prepared Star-Hop (PSH) window (Figure 3). On a small screen, this requires window wrangling. Fortunately, elements of some windows can be temporarily collapsed. Then it is a simple matter of dragging to the Object List of the PSH window.

I had started with number 75 for my little campaign and had a good list of M objects. On the atlas screen I felt the route a bit jumpy, so I activated the AI Star-Hop Path Creator. This "artificial intelligence" feature used algorithms to form a better route between the objects. I spotted a very long hop from Scutum to the east edge of Aquarius, so I searched along the way for some double stars from the RASC program. I also noted NGC 7009 from the Finest NGC list. I added those objects to the plan.

The list had a good mix of interesting targets, and the software drew the path on the Sky-Chart display, an easy-to-follow visual presentation of my planned route (Figure 4). The program told me where the next object was and how far away.

Making a List on the Fly

An alternative way to "object hop" around the sky, perhaps with computer at the telescope, centred on a particular constellation, viewing things ad-hoc, is to use the Blind Star-Hop (BSH) feature. In general, you add nearby objects of interest from the Sky-Chart. This can be done by right mouse clicking,

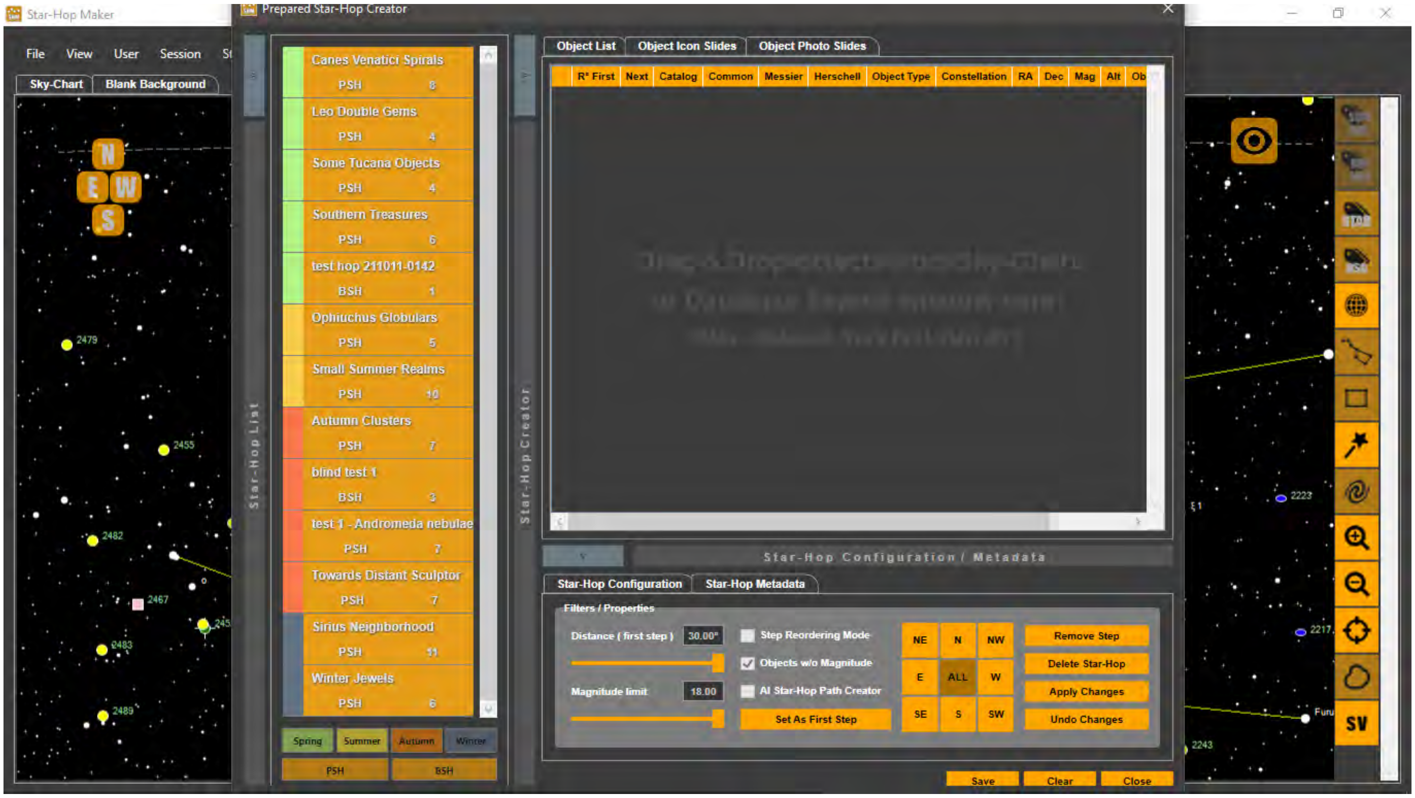


Figure 3 — Readying a plan with the Prepared Star-Hop Creator *window.*

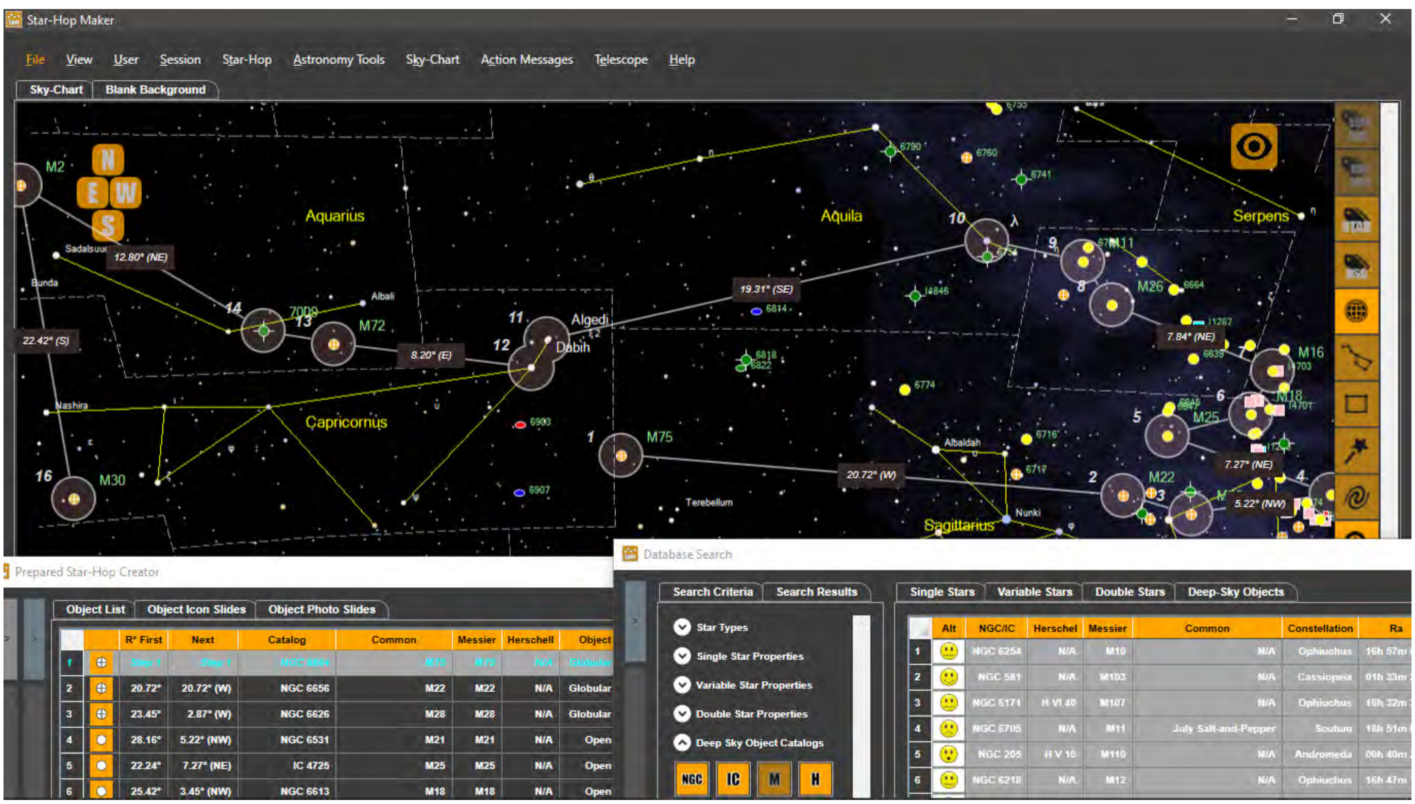


Figure 4 — Visual plan or route to view target deep-sky and double-star targets.

but a better approach is to drag a rectangular box over a region of interest. The Object Selection tool should identify deep-sky objects (DSOs) and stars within the selection zone.

Run With It

Either using your own prepared star-hops, saved blind star-hops, or provided plans, you activate the *Star-Hop Runner*

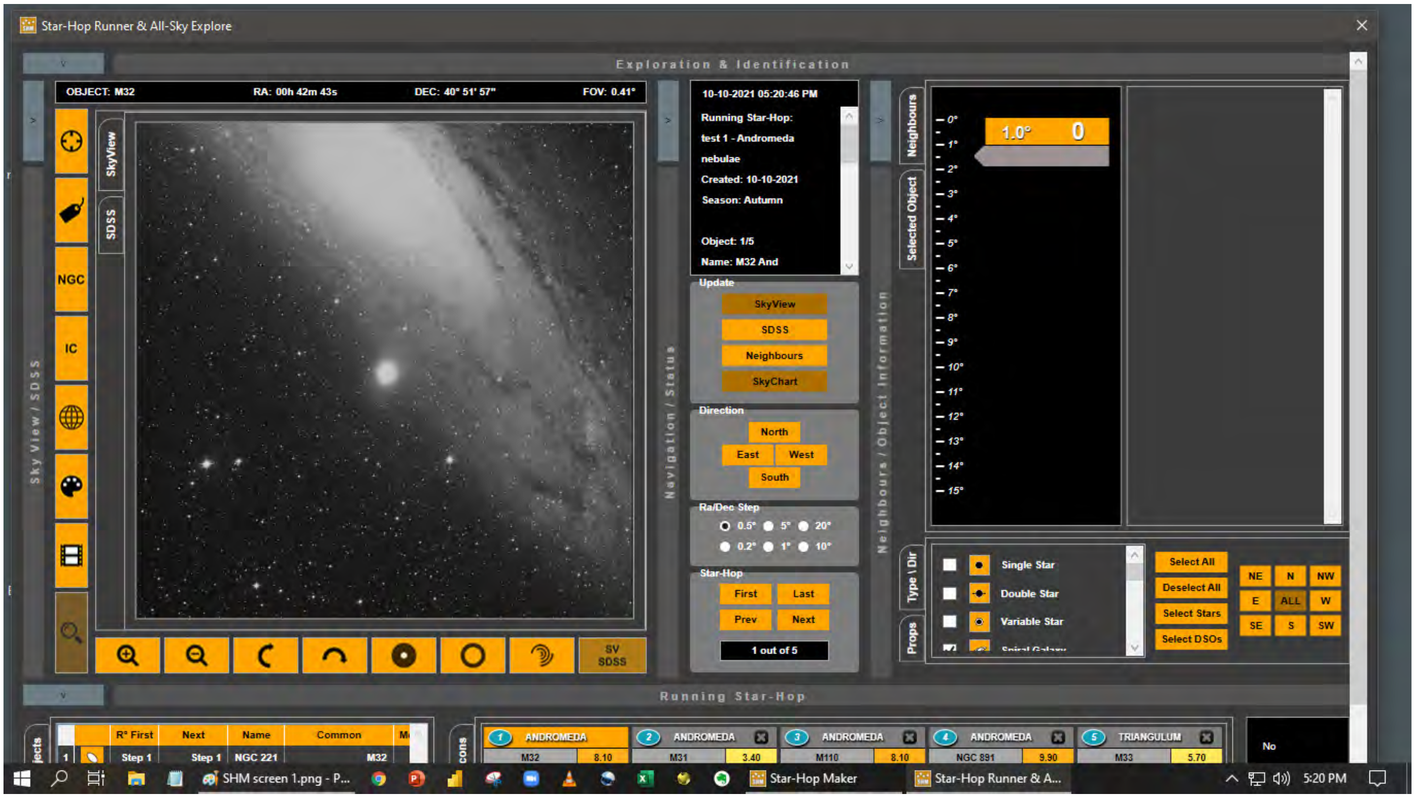


Figure 5 — Executing a plan with the Star-Hop Runner *window with SDSS image showing Messier 32.*

screen (Figure 5) to get the software to serve as your tour guide. And you're on your way.

This is a very large display that overflowed my laptop screen again. But it is robust, with many interesting features, including Sloan Digital Sky Survey images. You may use the Observation Log window to record notes and details as you view your targets. The application can be operated in an adjustable red-light mode so you can stay dark adapted at the telescope.

Other Options

I tried some of the export options and print command but was disappointed as none showed the distance and angle data.

There is an Android app that serves as a companion to the main tool and I did not test it. It appears to present your pre-built observing plan for you to simply follow.

Object-Hopping Approach

Star-Hop Maker is a rich and powerful planning tool and I believe it shows great promise. It is unique in its visual approach. And it is a little mind-boggling what the developer has done so far. If he continues to be responsive and proactive and attracts early adopters, I think this will prove a very useful tool for object hoppers.

But it is young, not far from version 1.0. I spoke to the developer in October 2021, and he sounded enthusiastic, but I've seen no updates in the interim. I'll keep an eye out for 2.0.

The Object Selection tool was frustratingly inconsistent. The map projection is peculiar and cannot be adjusted. I had trouble with the magnitude options but that might be due to limitations applied to the database in trial mode. The interface frequently uses multiple tabs without highlighting or colouring so you cannot tell which is active. The SkyView image in the Runner window can be flipped but disappointingly not rotated freely. And for the Prepared Star-Hop window to be most useful, every alpha star in every constellation should be included.

I think *Star-Hop Maker* can be very effective if you like viewing everything in one constellation or you have patchy clouds forcing you to aim into slow-moving sucker holes. Or perhaps when planning for a star party to visit proximal showpiece objects. It is very intriguing the thought of visual charts literally showing you the way to view your deep-sky targets.

Bits and Bytes

Stellarium continues to experience rapid development and changes. In version 0.21.1, they mucked with the Bookmarks feature. But that's what you get with beta software. ✶

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

CFHT Chronicles

Hello 2022

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

2021 was quite the year for us at CFHT. Exciting science despite COVID, staff working from home and the office, and a new director. The consistent anchor through the entire year was the CFHT staff which gets the job done despite whatever mayhem the world brings.

We anticipate the announcement of our new executive director before my next column, so I will provide all the details next time around. We hope to have someone in place in the first half of 2022.

Taking stock of the previous year is a tradition of nearly everyone, myself included. Let's look at some of CFHT's science highlights in 2021 before we dive into 2022…

Spectacular "Honeycomb Heart" Revealed in Iconic Stellar Explosion

A unique "heart shape," with wisps of gas filaments showing an intricate honeycomb-like arrangement, has been discovered at the centre of the iconic supernova remnant, the Crab Nebula. Using SITELLE at the Canada-France-Hawaii Telescope (CFHT), astronomers mapped the void in unprecedented detail, creating a realistic three-dimensional reconstruction.

The Crab Nebula, also known as Messier 1, exploded as a dramatic supernova in 1054 CE, and was observed over the subsequent months and years by ancient astronomers across the world. The resulting nebula—the remnant of this enormous explosion—has been studied by amateur and professional astronomers for centuries. However, despite this rich history of investigation, many questions remain about what type of star was originally there and how the original explosion took place.

Thomas Martin, the researcher at Université Laval who led the study, hopes to answer these questions using a new 3-D reconstruction of the nebula. "Astronomers will now be able to move around and inside the Crab Nebula and study its filaments one by one," said Martin.

The team used the powerful SITELLE spectrograph at CFHT on Maunakea to compare the 3-D shape of the Crab to two other supernova remnants. Remarkably, they found that all three remnants had ejecta arranged in large-scale rings, suggesting a history of turbulent mixing and radioactive plumes expanding from a collapsed iron core.

Astronomers use computer simulations of supernova explosions to estimate what patterns the ejected materials make as they expand into a supernova remnant. Each possible explosion is associated with a specific pattern or fingerprint. The honeycomb pattern observed by the team resembles the fingerprint caused by the collapse of a heavier iron core. Co-author Dan Milisavljevic, an assistant professor at Purdue University and supernova expert, concludes that the fascinating morphology of the Crab seems to go against the most popular explanation of the original explosion.

"The Crab is often understood as being the result of an electron-capture supernova triggered by the collapse of an oxygen-neon-magnesium core, but the observed honeycomb structure may not be consistent with this scenario," Milisavljevic said. "Future work mapping the Crab's chemical distribution of elements is needed to address this inconsistency."

The team created a 3-D reconstruction of the Crab Nebula made of 406,472 data points represented as tiny cubes, which can be viewed on our website at www.cfht.hawaii.edu/en/news/HeartofTheCrab/

SPIRou's Planetary Exploits

SPIRou thrived in 2021 with astronomers announcing discoveries about AU Mic b and Tau Boötis b. SPIRou observations enhanced our understanding of these two planets. In both cases, the results lend credence to the current theory of planetary formation. Astronomers believe large planets form deeper in the debris disk surrounding their star at distances similar to the giant planets in our Solar System. These more-distant areas are richer in gases and materials, allowing the planet to grow larger in size. At some point during their evolution, planets like AU Mic b and Tau Boötis b migrate inward due to gravitational interactions with the gas disk or other planets in their system, a different evolution than we see at home.

In 2020, Peter Plavchan and his co-authors announced the discovery of AU Mic b using the TESS telescope. AU Mic b transits its host star every 8.46 days. The observations constrained the radius to four times the radius of the Earth and determined an upper limit on the mass at <0.18 Jupiter masses. To better understand AU Mic b and the entire system, it is critical to determine not only the radius of the planet measured by Plavchan and his team, but the mass and the density as well.

A second team used SPIRou to follow up Plavchan's discovery of AU Mic b by measuring mass, density, and orbital tilt of the planet. Unlike TESS, which utilizes the transit method, SPIRou detected the minute gravitational pull induced by the close-in planet on its host star, AU Mic.

Astronomers use SPIRou to detect the periodic wobble induced by planets orbiting their host star—known as the radial velocity. These tiny wobbles in the star's spectra are used to measure the mass of the planet due to its gravitational influence on its star. Simultaneously, SPIRou performs polarimetric analysis of the star's light, enabling the detection and characterization of the host star's magnetic field. The characterization of magnetic activity, like that detected in AU Mic b, removes wobbles in the star's velocimetric data that potentially shield planets from detection.

Using SPIRou spectra, the team measured the mass of AU Mic b to be approximately 17× the mass of Earth. Combining the TESS and SPIRou data, the team estimated the density of the planet and found it to be only slightly larger than that of water, ~4× lower than the Earth's density, and surprisingly similar to Neptune and warm at ~300 °C.

"To put in human terms at 22 million years old, AU Mic b is a couple of months old." says Dr. Baptiste Klein, lead author on the SPIRou AU Mic b paper focusing on the planet's characteristics. "Finding a Neptune-like planet orbiting so close to its star in a planetary system this young puts challenging constraints on our current models of how planets form and migrate."

Through observations of AU Mic as the planet transited, the team constrained the tilt of the planet's orbital plane and found it aligned with the equatorial plane of its host star, a result confirmed with ESPRESSO at the European Southern Observatory. AU Mic b's position close to the star and aligned orbit perfectly illustrate the predictions of current theory; giant planets form far away from the star and migrate closer due to gravitational interactions between the newly formed planet and the surrounding protoplanetary disk.

"The SPIRou observations revealed that the orbit of AU Mic b is prograde and aligned with the stellar rotation axis," says Dr. Eder Martioli, lead author on the SPIRou AU Mic b paper focusing on the planet's orbital plane. "These observations are strong evidence that this planet was formed in the protoplanetary disk that evolved into the current debris disk around AU Mic."

Tau Boötis b

Astronomers using SPIRou at CFHT measured the atmospheric composition of the hot Jupiter Tau Boötis b and uncovered some surprises—Tau Boötis b is a scorching hot world that orbits its host star in three days. It is 6.24× more massive than Jupiter and 8× closer to its parent star than Mercury is to the Sun, thus classifying it as a hot Jupiter. Its host star, Tau Boötis, is located 51 light-years from Earth, is 40% more massive than the Sun, and one of the brightest-known planet-bearing stars in the sky. The planet's atmospheric composition has been studied a handful of times before, but never with an instrument as powerful as SPIRou.

The team's detailed analysis shows the atmosphere of the gaseous planet contains carbon monoxide, an expected result. Surprisingly, the team did not detect water, a molecule that was anticipated to be prevalent and should be easily detectable with SPIRou.

"Hot Jupiters like Tau Boötis b offer an unprecedented opportunity to probe giant-planet formation," said co-author Björn Benneke, astrophysics professor and Stefan Pelletier's Ph.D. supervisor at Université de Montréal. "The composition of the planet gives clues as to where and how this giant planet formed. For example, the low amount of water on Tau Boötis b could mean that our own Jupiter is drier than we had previously thought."

The key to revealing the formation location and mechanism of giant planets is imprinted in their atmospheric composition. The extreme temperature of hot Jupiters allows most molecules in their atmospheres to be in gaseous form and detectable with current instruments, enabling astronomers to precisely measure the content of their atmospheres.

"It is the first time we got such precise measurements on the atmospheric composition of a non-transiting exoplanet. This work opens the door to studying in detail the atmospheres of a large number of exoplanets, even those that do not transit their star," explains Ph.D. student Caroline Piaulet, also a co-author of the study.

The team assumed the composition of Tau Boötis b would be similar to the composition seen in the Solar System. Based on those Solar System models, they expected to see large quantities of water vapour in the planet's atmosphere along with carbon monoxide. Water vapour should be easy to detect with an instrument such as SPIRou.

"We expected a strong detection of water, with maybe a little carbon monoxide," explains Pelletier. "We were, however, surprised to find the opposite, carbon monoxide, but no water."

The team worked hard to make sure the results could not be attributed to problems with the instrument or the analysis of the data.

"Once we've convinced ourselves the content of water was indeed much lower than expected on Tau Boötis b, we were able to start searching for formation mechanisms that could explain this," says Pelletier.

The analysis of Pelletier and colleagues allowed them to conclude that Tau Boötis b's atmospheric composition has roughly five-times as much carbon as that found in the Sun, quantities similar to that measured for Jupiter. ✶

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.*

SAVING US: A Climate Scientist's Case for Hope and Healing in a Divided World

by Katharine Hayhoe

xii + 307 pp. One Signal Publishers. $Can 36.00.

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

You might wonder why I am reviewing a book on climate change in this astronomical journal. Certainly because climate change is now the most important challenge for the most important planet in the Solar System—ours. I'm writing this review during COP26 and devastating floods in BC! We also know that climate science is something that applies to thousands of planets beyond Earth. It's mainstream astronomy.

Equally important: I am reviewing this book because it contains a multitude of good and interesting advice on communicating science to the public, something we astronomers are actively involved in—and could benefit from learning more about.

Last but not least: I am reviewing it because the author, Katharine Hayhoe, graduated in Physics and Astronomy from my university. She was my undergraduate research collaborator. We co-authored two papers on variable stars together. Her father Doug Hayhoe was also a student in my senior astrophysics course, at the beginning of my professorial career. He went on to play important and respected leadership roles in school science education in Ontario. He was my much-valued advisor on science education, and on matters of science and religion.

In the last year of her undergraduate program, Hayhoe was inspired by a course in climate science, and decided that this was an area in which she could make a difference. She then obtained an M.S. and Ph.D. in atmospheric science from the University of Illinois at Urbana-Champaign. Now she is the Endowed Professor in Public Policy and Public Law, and the Paul W. Horn Distinguished Professor, at Texas Tech University. She is also chief scientist for The Nature Conservancy, a United Nations Champion of the Earth, one of *Time* magazine's 100 Most Influential People, and climate ambassador for the World Evangelical Alliance. As a member of the Intergovernmental Panel on Climate Change, she is also, in a small way, a Nobel Peace Prize Laureate. At the same time, she has endured the worst kind of abuse, just for working on our behalf.

Figure 1 — Katharine Hayhoe received a B.Sc. in Astronomy and Physics at the University of Toronto before embarking on a career as a leading climate scientist and communicator. Photo: Artie Limmer/Nature Conservancy.

This book is not just about climate change, it is also very much about communication. According to the *New York Times*, Hayhoe is "one of the nation's most effective communicators on climate change." She does this by connecting with people at a personal level, by focusing on things that are important to them, whether their kids' health, or hobbies like skiing or knitting, talking *with* them and not *at* them. And you cannot do this unless you actually set out to talk to them about climate change—something she thinks we do not do enough of, for whatever reason—maybe fear, maybe guilt. A primary goal of this book is to teach us how to do it.

The parallels between communicating climate change and communicating COVID-19 are uncanny. For me as a scientist and educator, it has been disheartening to see so much rejection of data and evidence, and of scientists and doctors, many of whom are toiling on the front line on our behalf. This book helps to understand where the roadblocks occur, and how we can overcome them. Facts are only part of the equation. At least COVID-19 has made people a bit more familiar with graphs, models, and predictions.

Lecturing, by itself, doesn't work. That's also true in university teaching! Much of the book describes Hayhoe's interactions and conversations with a wide variety of audiences and people, from academics, politicians, and businesspeople, to neighbours, friends, and family. Each of these conversations provides an example of her basic approach—how to communicate effectively by finding common ground, areas of common interest, value, and concern. Climate change affects almost every aspect of our lives!

Hayhoe's writing style is powerful, engaging, and personal—certainly not pedantic. That's something that a good astronomy book can benefit from. Dava Sobel's best-selling, award-winning astronomy books are fine examples. Not surprisingly, the present book is endorsed by the likes of Alan Alda, Margaret Atwood, and the patriarch of the Eastern Orthodox Church, who states that "*Saving Us* provides the transition from the mind to the heart."

Saving Us is an exemplary book of its kind. It has explicit and implicit lessons for us astronomy communicators. How is the best way to communicate with people about controversial topics such as space aliens, astrology, and young-Earth creationism? And although many people are excited by the gee-whiz topics of astronomy—exoplanets, black holes, cosmology—many more relate to the "softer," more personal topics—the beauty of the night sky, the connections between astronomy and the arts, astronomy in different cultures, the lives of astronomers, and astronomy and spirituality now and in ancient times (think Stonehenge and the pyramids in the Old and New Worlds). These broader perspectives are especially useful when understanding the holistic nature and value of Indigenous science. How often, at the beginning of an astronomy talk, do we find some of these common interests by telling our audience who we are, and asking who they are?

Although Hayhoe emphasizes that presenting facts and data is not sufficient, especially when dealing with skeptics, facts are not neglected. Correct facts are essential to counter "fake news." Science literacy is necessary (though not sufficient). Therefore all of us science educators and communicators have a part to play, even if we are not climate scientists.

The book touches on almost every aspect and application of climate change—physical and mental health and disease, safety and security, energy and transportation, agriculture and food, economics and politics, and general quality of life. These applications are so numerous and varied and profound that it's easy to find areas of common interest and concern, whether on the decreasing length of the snowmobiling season, or the decline of (name your favourite species). The book is divided into 5 sections, and 22 chapters, each divided into 1- or 2-page sections—something my personal reading style appreciates. There are almost 50 pages of notes, for those who want more details or references.

Hayhoe knows her audiences. It is tempting, as she points out, to simply divide people into "believers" and "deniers" —just one more example of how people are dividing themselves, or being divided into "tribes." These divisions would suggest that communication is not necessary for the first group, and not possible for the second. Rather, she prefers a classification (developed by others) into Alarmed, Concerned, Cautious, Disengaged, Doubtful, and Dismissive (currently 7 percent). The majority of Americans are worried. She describes different strategies that can be used for each of these groups, even the Dismissive.

Hayhoe is a pro at using mass media and social media to communicate, accurately and effectively. She is a master of "the art of persuasion." Her TED talk on climate change has been viewed over 5 million times. Her manner is super-engaging and super-positive and super-sincere. I urge you to track down one of her Youtube presentations, or her interview with Steve Paikin on Ontario's TVO on 2021 October 6. At the same time, she willingly and effectively talks with smaller groups, whether service clubs, or church groups, or kids at a science centre. She maintains that she learns something at each of these. Throughout the book, she reminds us that she did not become a great science communicator overnight. The secret is self-reflection, and a desire to do better. That works for astronomy communication, too.

Hayhoe is an evangelical Christian. That term should not be confused with a fundamentalist Christian who, among other things, may take the Bible literally, creating the well-known conflicts with aspects of science such as evolution, and the age of the Earth and universe. If evangelicals disagree with climate science, it`s probably politics, not religion. As Hayhoe has shown, people of faith can be as receptive to understanding climate change as any atheist. In fact, this audience may appreciate, more than most, that climate change disproportionately affects the poor and marginalized. She is to be commended for connecting, so effectively, with this large and powerful segment of our population.

What to do about climate change? As we are all aware, the justifiably alarmist messages that we receive tend to paralyze us. Fear is natural. It's a product of evolution. But it's there to provoke us to action. Hayhoe offers some positive suggestions, and some hope—hence the subtitle of this book. There are frequent references in the book to what's known about human behaviour, which affects, of course, how people react to our messages. She reminds us of all the well-known ways that we and our communities can effectively combat climate change. She tells us how to start the conversation and start the action—and "well begun is half done." She explains about carbon pricing, and cap-and-trade. She even discusses the controversial topics of carbon capture and geoengineering (such as by "solar radiation management"), topics that I personally find quite intriguing. Will this be the "silver bullet"? One of the strongest proponents of these solutions is Harvard's David Keith (aka Dr. Cool), another Canadian and another former undergraduate research student of mine.

As we have often been told, a large problem can often be solved most effectively by dividing it into smaller parts so, in this book, we hear about a variety of approaches and solutions that have been used successfully, by governments, communities, or individuals to address climate change. These can resonate, especially if they are local, and can be shown to work.

Obviously much needs to be done at the institutional level. While writing this review, I was pleased to learn that my university is divesting from its investments in fossil fuels. The Canadian Astronomical Society has an active Sustainability Committee. Astronomers are frequent fliers! My department is actively considering how to cut down on long-distance air travel, such as by inviting distant colloquium speakers to attend and present virtually.

This book's subtitle is "a climate scientist's case for hope and healing in a divided world." If anyone can provide a recipe for such hope and healing, it's Katharine Hayhoe. To quote from her article in *The Globe and Mail* on 2021 November 19, though: "if we wait for hope, we will never find it. But when we go out and look for hope … raise our voices to call for change … take action together … that's when we find that hope is all around us." ✶

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

Skyward

Imagination and the Astronomical League

by David Levy, Kingston & Montréal Centres

"A Dragon lives forever, but not so girls and boys."

Three quarters of a century ago, during the Second World War, the famous Harvard astronomer Harlow Shapley, along with Charles Federer, founding editor of *Sky and Telescope* Magazine, launched an association of astronomy clubs across the United States. It is called the Astronomical League, and it thrives to this day with more than 100 astronomy clubs. Unlike the national Royal Astronomical Society of Canada, the League is designed to be a more loosely structured organization. According to Carroll Iorg, its current president, one of its most critical and central goals is to inspire the next generation to enjoy the night sky. If that goal should fail, the possibility exists that there may be no astronomy for future generations.

As part of this vital goal, the Junior Astronomical League, a new subset of the Astronomical League, is now meeting every second Sunday over Zoom. But there is something more. My next book will be devoted to those young stargazers. It actually began as a typewritten saga I wrote in 1958 when I was 10 years old, and of all the 40 plus books I have written, this is Wendee's favourite. I am now completing a second edition of this book, in which a small group of children go on a stargazing adventure with Clipper, a magic beagle, and with Eureka, an enchanted reflector telescope. They go past the Moon and planets, the stars, the distant superclusters of galaxies, and even the great voids in distant empty space.

In its final chapter, this book explores the theme articulated in the last verse of Peter, Paul, and Mary's eminent song *Puff*. "A dragon lives forever, but not so girls and boys." The children, now grown, go to university. When they complete their college education, the young woman, adept at math and physics, becomes an astronomer, but the young man goes on to become a lawyer. He marries, has children who are now grown themselves, and unhappily gets a divorce. To recover he decides to take a vacation trip to Arizona. Driving his rented car one evening, he pulls off the road, gets out of his car, and looks at the stars. As childhood memories flood back, a second car pulls off. The young woman astronomer gets out of her car. The two cannot believe they are reuniting, and they catch up for hours. Then there is a break in their conversation. As the couple looks up silently at the stars, the magic beagle, and the telescope, appear and take shape. In that one ultimate celestial adventure, the magic of the night has returned. ✶

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.*

Dish on the Cosmos

Dark Matter Mysteries

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

Dark matter remains one of the big mysteries in physics and astronomy today. Even the name is a mystery: we aren't even sure that dark matter is actually "matter!" This column typically focuses on questions uniquely accessible by using radio telescopes. But in the chase for understanding dark matter, radio telescopes are just one of a vast range of tools scientists are employing to figure out what the signatures of dark matter actually mean.

The phrase dark matter refers to a model for explaining a set of astrophysical observations that we cannot explain using our standard set of physics. The fundamental assumption in the study of astrophysics is that the physical laws that operate here on Earth are the same as the laws throughout the rest of the cosmos. Using those laws, we simply cannot explain the full collection of different observations built up and confirmed over decades without something else that we don't understand being included. By hypothesizing several different explanations for these "dark matter" signatures, we try to constrain the properties of whatever is causing these anomalies.

Dark matter is so named because one of the simplest explanations that works for almost all the measurements is that dark matter is actually matter that does not interact with light (or more precisely any sort of electromagnetic radiation at all). Light is the primary way we gather information about the rest of the Universe. If dark matter doesn't interact with light, the matter is perfectly invisible. Indeed, there is little evidence that dark matter interacts with anything at all, except for the only way dark matter has been detected: through its gravitational effects.

While there were clues to the existence of dark matter since it was first conjectured in the 1930s, the major work that highlighted the "dark matter problem" was led by Vera Rubin through her work studying the rotation of galaxies. Galactic rotation, here meaning the orbital motion of stars and gas around the centre of disk galaxies, is a sensitive measure of the mass distributions in galaxies.

In astrophysics, the only way we have of measuring the masses of objects is to study the orbit of something around the object whose mass we want to measure. Just as GPS satellites can give a great measurement of the Earth's mass and the orbit of Earth can provide an estimate of the Sun's mass, the galactic rotation of star around the galactic centre can measure the

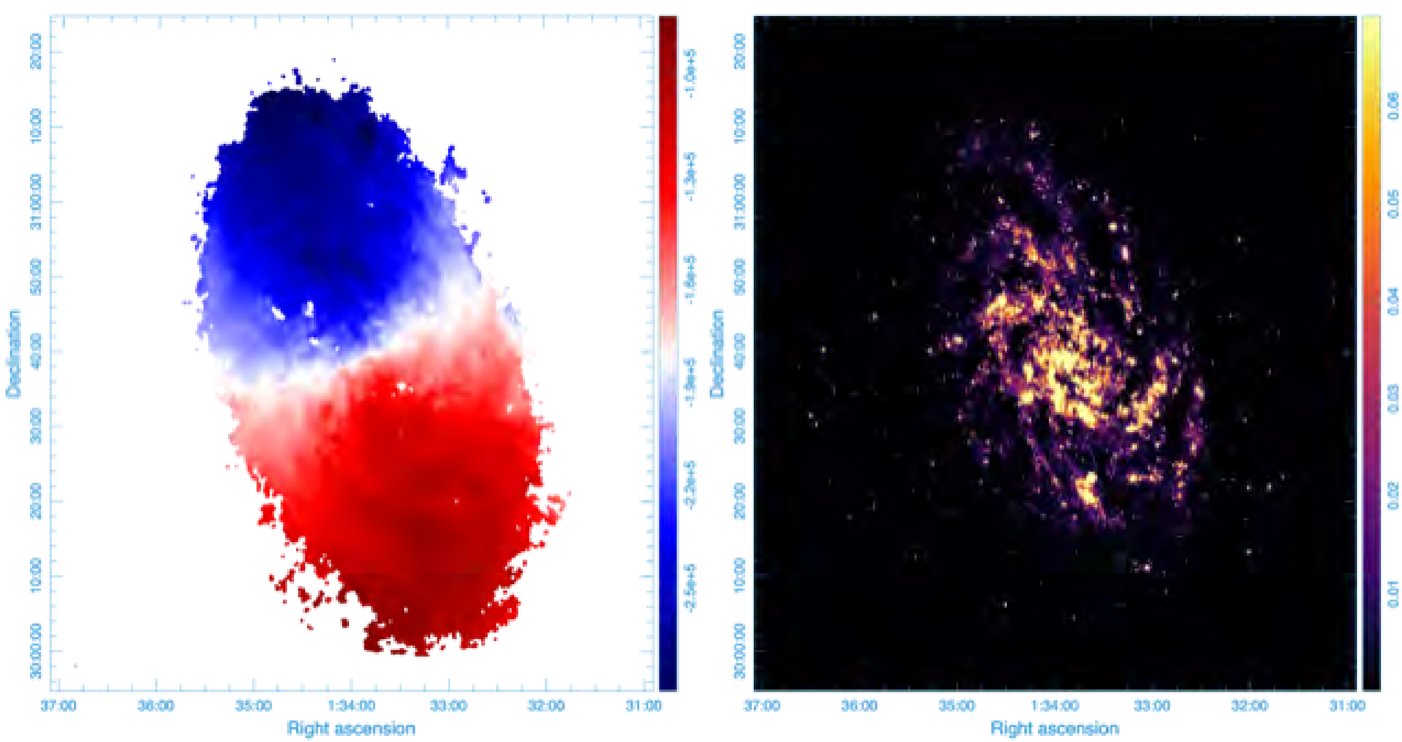


Figure 1 — Two views of the Triangulum Galaxy (M33). The left panel shows the projected gas velocity of the galaxy as measured from the Doppler shift of the atomic hydrogen gas (velocity scale given in m/s). The telltale signature of galaxy rotation can be seen with the northern part of the galaxy coming toward us and the southern part moving away from us. The right panel shows the far-ultraviolet emission from stars in M33, illustrating the extent of the stellar disk, which becomes tenuous and hard to detect well inside the radius where the gas can be measured.

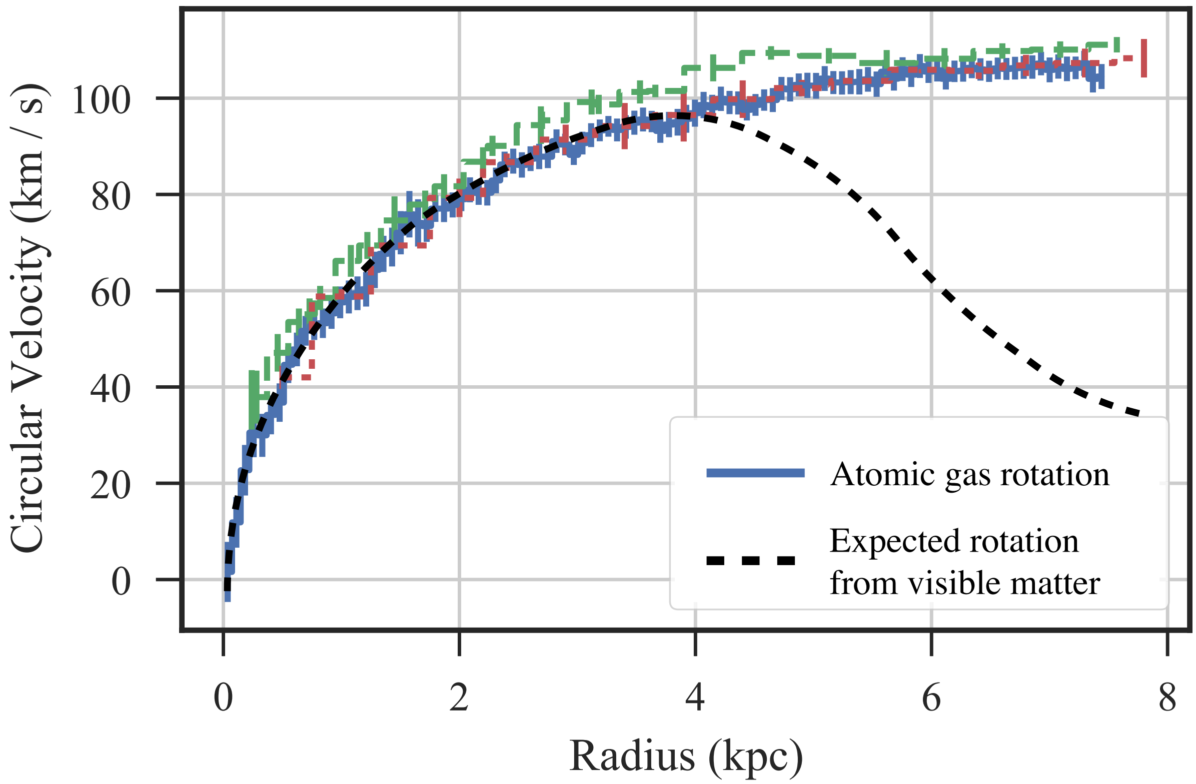


Figure 2 — Rotation curves of M33 adapted from Koch et al. (2018, MNRAS, 479, 2505). The coloured curves show several different measurements of the gas rotation velocity. The black dashed line is a schematic representation of the expected rotation velocity if there were no dark matter in the system and the rotation was driven entirely by the visible matter.

mass of that galaxy. There is a subtlety: in the case of orbits around the Earth or the Sun, there is only one massive, nearly spherical object inside the orbit under study. For galaxies, there is no dominant central object around which the stars are orbiting. While it is true that all galaxies appear to host a supermassive black hole at the centre, this black hole is actually far less massive than the combined mass of gas and stars in the centre. Indeed, orbits of stars appear to be determined by the collective gravity of all the other stars in the system and, as Rubin concluded, some other source of gravity that is likely the dark matter.

Rubin's actual observations were to measure the rotation speeds of galaxies far from their centre. While most of the matter was in the central regions of Rubin's targets, there was still enough matter out there that she could measure its motion toward or away from her telescope using the Doppler effect. Rubin used the large Palomar telescopes to make her original measurements using optical light. She concluded that the outer parts of galaxies were spinning faster than they should, given the amount of starlight she also observed. In these outskirts of galaxies, the motions expected based on the visible matter should follow the same pattern we see in our own Solar System: the stars in the outskirts should be moving more slowly than the stars in the centre, just as Saturn in the outer Solar System has a lower orbital velocity than Earth does. Astronomers call this pattern of rotation "Keplerian," since it was a key conclusion that could be drawn from Johannes Kepler's careful interpretation of orbital motions. If Saturn were moving as fast as Earth does (and we had already understood gravity), we would conclude that there was substantial mass—comparable to the amount of material in the Sun—between the orbits of Earth and Saturn.

While Rubin worked with optical data, radio observations of neutral hydrogen proved to be a better tool. Here, the 21-cm transition of hydrogen was an even better tracer of the outskirts of galaxies for two reasons. First, relative to the stars, there is more atomic gas in the outskirts of galaxies. Second, the detector technologies for atomic gas made it possible to measure the Doppler effect with high precision. This latter gain came from the use of a "mixer" system, which measures precise differences between the frequency of the incoming wave and a known reference signal. Where optical spectrometers have uncertainties of 10s of km/s, a radio telescope can measure velocities with a precision of metres per second.

Figure 1 shows two maps of the nearby Triangulum Galaxy (M33). The left panel shows the velocity of the atomic gas, measured as how fast the gas is moving toward us (in the north) or away from us (in the south) relative to the galaxy centre. The right panel shows the light of stars traced using ultraviolet emission. This shows that the atomic gas is a good tracer of the galaxy's rotation even when there are few stars in the outskirts. The galaxy is a nearly round disk, but it appears as an oval on the sky since it is tipped relative to our line of sight and one of the axes appears foreshortened. Using our knowledge of this geometry, we can make a "rotation curve" for the galaxy by examining all the points that are a fixed distance from the centre (say, 5 kiloparsecs) and calculate "what speed would the gas at this distance be rotating to give the pattern of velocities that we see in Figure 1." These measurements for M33 appear in Figure 2. This figure also compares the velocities we see to those we would expect given the observed visible matter in the galaxy (gas and stars). In the outskirts of the galaxy, the rotation speed is too high to explain without dark matter. If there were a large amount of material we couldn't see in the outskirts, this would provide the gravity we expect to give the galaxy its observed rotation.

M33 is just one example of the need for dark matter to explain its motion. This observation is replicated in nearly every galaxy we observe. Clusters of galaxies also need dark matter to explain their motions. Even our model for the Universe as a whole needs to include some form of dark matter to explain that galaxies were able to form so soon after the Big Bang. Without the extra gravity provided by the dark matter, the matter that formed the first galaxies would not contract fast enough to form the first objects we observe. Thus, the evidence for dark matter is pervasive, but what it is remains elusive.

Astronomers are convinced that it is not simply more ordinary matter. Early theories suggested that this could be lots of things like brown dwarfs or compact, ultracold clouds of gas that would be nearly impossible to observe. However such objects should occasionally pass between Earth and the field of stars in the centre of the Milky Way, producing a brightening of the background star through gravitational lensing. By observing over several years, lots of such events should be observed, but the number found was far smaller than needed to explain dark matter. A related issue is that the presence of vastly more ordinary matter would have altered the chemical balance of the Universe that was set in the Big Bang. These lines of evidence and others all pointed to the dark matter being something more exotic.

Another possibility to consider is that our knowledge about gravity is just wrong. All the evidence of dark matter is a collection of observations about orbits under the effects of gravity. If there were something that the general theory of relativity (GTR) got wrong, then it could explain our "dark matter" observations. Several theorists are working on new versions of gravitation that could explain observations, but several of these modifications struggle to explain the evidence of vast clouds of dark matter that we infer to be well separated from any visible source of gravitation.

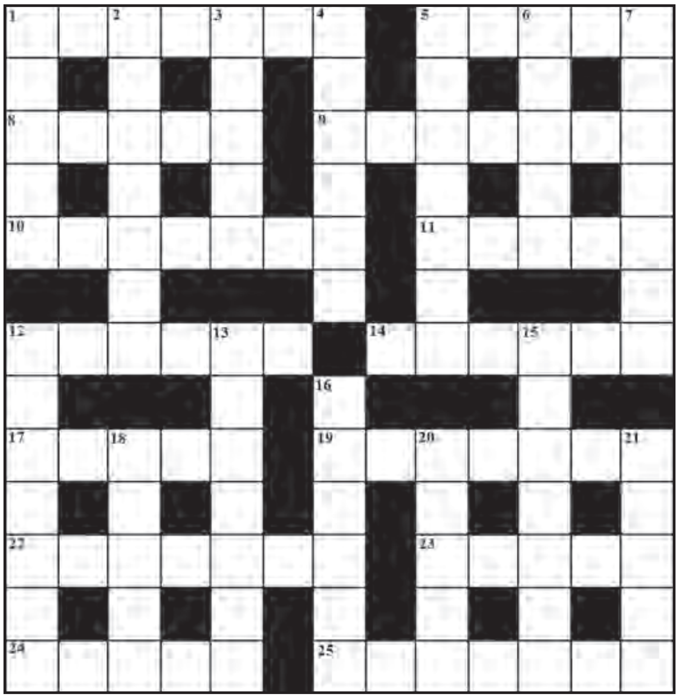
The betting money in physics is that dark matter really is matter, just an exotic type of particle that we haven't detected yet. This extends the Standard Model of Particle Physics, which outlines all the subatomic particles that we currently see. But particle physicists were already sweating over a few open questions that their best theories can't explain. Particle physics needs an amendment and dark matter provides some guidance as to what those changes should be. Several experiments are built around the hypothesis that dark matter isn't completely dark but has some very rare interactions with regular particles. Theory makes predictions for what those observational signatures should be. Experimentalists pore over the results from particle detectors, looking for the signature of the particle that can point the way to the next steps in physics.

Overall, dark matter is an abiding mystery but one worth solving. If it is indeed matter, there would be five times as much dark matter as ordinary matter. It is the clear testimony that our physics is incomplete and in answering these questions, we would make a generational leap in understanding physics, our Universe, and its origins. ✶

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

Astrocryptic

by Curt Nason



ACROSS

1. A bagel crumbled around one star in a lion's shoulder (7)
5. Rusty Montreal star with antimony around half of Taurus (5)
8. Mislead right beside the planetarium (5)
9. Double star aficionados do this puzzle again (7)
10. Circles on a telescope or place on a table (7)
11. Heartbreaking place for one to live (5)
12. The shortest time to sit on the Board, I hear (6)
14. His art resembles terra on Venus (6)
17. Spitzer namely turning out east (5)
19. A lark is dancing near Draco's head (7)
22. Jupiter oddly sported its famous feature (3,4)
23. Roamin' empire lost its head at the Greenwich meridian (5)
24. Highlights of a deserter returning on board (5)
25. Astronomer was heard to steal cattle (7)

DOWN

1. Was he mad as could be when Galle spotted Neptune? (5)
2. Festive drink served around Neptune (7)
3. Future directional marker at the peak of the palace (5)
4. Gold is capital in Latvia, providing overhead in winter (6)
5. They are seen in cloisters and bullish clusters (7)
6. Cinderella returned halfway as a stellar chemist (5)
7. His nebulae images are within macabre cherubic designs (7)
12. Directional indicator is following a cold bear (7)
13. Soup can stirring brightly in the bottom of a ship (7)
15. Impact remnant discovered in mixed kit surrounded by tellurium (6)
16. Varied actors star in a twin role (6)
18. Meade break-up was a boon for Jason company (5)
20. Lunar cliff was the site of a super snafu (5)
21. Elementary layer of a supergiant tapped by a gas company (5)

Answers to previous puzzle

Across: **1** FLAMSTEED (flam(Ste)ed); **8** Arion (Orion, O=A); **9** PERSEUS (anag); **10** ETA AQR (2 def); **11** LYRATE (ana(t)g); **12** THALLIUM (anag); **15** RAYLEIGH (anag); **18** EUROPA (2 def); **20** REEVES (anag); **21** UNITRON (anag); **22** ABORT (anag, i=a); **23** ASTRONOMY (anag+y)

Down: **2** LEERY (an(e)ag); **3** MUSCAE (m+anag); **4** TAU CETI I (2 def); **5** DACTYL (2 def); **6** HIMALIA (a(im) nag+a); **7** ANDROMEDA (anag); **11** LIBRARIAN (Libra+anag); **13** ACHERNAR (anag); **14** HYPERON (Hyperion-i); **16** EJECTA (2 def); **17** PROTON (pro+ton); t**19** PRO AM (2 def)

Great Images

by Eric Klaszus

It seems that all eyes were on Comet Leonard at the end of 2021. Eric Klaszus was another early riser able to catch our little visitor. He sketched the comet using white paper and graphite pencils on the morning of December 3 from East of Olds, Alberta. He used a 17.5″ ƒ/5 Dobsonian and a Tele Vue Panoptic 35-mm lens. The final is an inverted mosaic of Comet Leonard passing by M3 in Boötes.

Journal

This series of images of the November 19 eclipse was taken by Andrea Girones from Ottawa, Ontario. Andrea used a Nikon D7000 (APS-C size sensor) with a Sigma 400-mm lens at ƒ/7.1 at ISO 400. Andrea used various exposures from 1/2000 seconds until she was at 2 seconds for the maximum eclipse. Tracked on a Star Adventurer star tracker; combined in Photoshop.