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Journal

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Inside this issue:

Witch Head Nebula

The Best of Monochrome

This incredible mosaic was done by Godfrey Booth from the "the heavily light-polluted" sky of Oakville, Ontario. There are way too many objects to list here, but Godfrey says, "From left to right, you can easily see the Flame Nebula, the Horsehead Nebula, and over to the right, the great Orion Nebula. I did a plate-solve of this mosaic, using Astrometry.net ... and it came back with a grand total of 23 nebulae and the major stars." The image was taken over a span of three days using a Sky-Watcher Esprit ƒ/5 with a ZWO 1600 cool camera on a Celestron CGEM mount using a H-alpha filter. The image spans approximately 6.5° × 2° and was processed using PixInsight.

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Société Royale d'Astronomie du Canada

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Shelley Jackson took advantage of the clear October sky to celebrate her love for Halloween, imaging the Witch Head Nebula (IC 2118) from River Place Park near Ayton, Ontario. "This is one of the targets that as soon as I found it existed, I simply had to have. I absolutely love fall, especially the month of October. So many great things about the month including great weather and temperatures, Thanksgiving and the harvest, and Halloween. I think of this target as the greatest representation of my love for Halloween." Shelley used an Askar 200-mm f/4 astrograph lens, on a Sky-Watcher AZ EQ5 pro mount with a ZWO ASI294MC pro OSC CMOS camera cooled to −5 °C gain 120 L-pro filter. Acquisition details: 50 x 180-sec lights plus master dark and flat (total integration time 2 hrs 30 min). The final image was stacked and processed using PixInsight.

Journal

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

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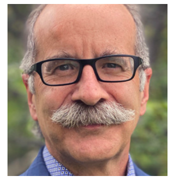
President's Corner



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

What exciting times we live in. I look back to my youth and my inspiration, and like many others in my age group, I drew inspiration from the 1960's space program, the most excellent speculative fiction authors of the day, and the shockingly inspiring Star Trek television series. Our local library, a place I forced my young friends to journey into after Saturday afternoon matinees, offered me insight into geology, paleontology, biology, and of course, astronomy, to name a few.

- Fast forward to today and inspiration abounds and as you get closer to ringing in 2022, I hope that some of these events and activities make it to your list of resolutions and things to do in the upcoming year.
- The *James Webb Space Telescope*. In the last edition of the *Journal*, I hit send before the JWST launch was delayed but as of this writing it seems imminent. If all goes well, we'll begin to see preliminary data and a hint of what this instrument promises.
- Human space travel. Private companies have embraced the possibilities and opportunities that bringing humans into space represents. Richard Branson's *Virgin Galactic* reinvents the space plane with X-1 like launches, Jeff Bezos sends Captain Kirk where no 90-year-old has gone before, and Elon Musk promises the Moon and once again breaks away from the norm with an awe-inspiring journey sending four civilians on a 3-day journey in Earth orbit. If you haven't done so, watch the most-excellent Netflix limited series *Countdown, Inspiration4 Mission to Space*.
- World-renowned lectures. Available to pretty much everyone with an internet connection, the proliferation of information and insight is unprecedented. For curated talks, check out the schedules of the RASC Centres that have been attracting speakers from around the globe.
- Modern Science Fiction. Some based on good science, some not. The ability to paint a picture of what-if continues to inspire. I particularly enjoy well-written speculation based on new scientific discovery; it can be hard to find amidst the shoot-em-up and space operas but if you want to start somewhere, check out Robert Heinlein's future history series where you'll see shocking links to Elon Musk's reality. Robert Sawyer, the only Canadian author to win the Hugo, Nebula, and John W. Campbell awards, is a more modern author worth exploring.
- Space Stations. The ISS continues to host astronauts from around the world, while China begins to construct its first permanent space station. Use the Heavens-above app to

catch flybys over your town or city, and if you're lucky, you might get to see a double flyby with a spacecraft near the station prior to docking or just after release.

- Interplanetary Travel. Missions abound to Mercury, Venus, the Moon, Mars, Jupiter, Saturn, and minor planets. As more and more data is retrieved, we all have new and interesting things to discuss and share as we show our friends and family these familiar objects in our telescopes.
- Edited and Curated Content. Our very own *SkyNews* magazine is a great example of the marriage between edited and curated content with its magazine and website, and our Editorial Board team continues to make this RASC asset better than ever.
- Astronomical events: conjunctions, oppositions, eclipses, meteor showers, lunar x, etc., etc. Be sure to plan and share your plan with others to capture 2022's night sky's best. *SkyNews* magazine, the *Observer's Handbook* and the *2022 Night Sky Almanac* are all great resources for information and insight.
- Education for everyone. RASC!! The RASC is a great source for education and presents an opportunity for today's youth and others to get educated with comprehensive programming and a chance to do science and to be exposed to the scientific method. Observing, Astroimaging, and Robotic Telescope programs, coupled with national and local outreach programs, have something for all levels of engagement. Our publications continue to expand and update with relevant books, workbooks, and other "merch."

On a final note, the Society office is moving and we're all very excited to offer highlights of our new office and Dorner Telescope Museum on College Street in Toronto in the new year.

We really do live in interesting times.

Best wishes for the New Year and Clear Skies in 2022. ✶

News Notes / En manchette

Compiled by Jay Anderson

Supernova redux

It's challenging to make predictions, especially in astronomy, and most of those are limited to the nearby Solar System: the timing of upcoming lunar and solar eclipses, the position of planets and other bodies, and the clockwork return of some comets.

Now, looking far beyond the Solar System, astronomers have added a solid prediction of an event happening deep in intergalactic space: an image of an exploding star, dubbed Supernova Requiem (AT 2016jka), which will appear around the year 2037. Although this rebroadcast will not be visible to the naked eye, some future telescopes should be able to spot it.

It turns out that this future appearance will be the fourth-known view of the same supernova, magnified, brightened, and split into separate images by a massive foreground cluster of galaxies acting like a cosmic zoom lens. Three images of the supernova were first found from archival data taken in 2016 by NASA's *Hubble Space Telescope*. The infrequent Hubble images were not able to resolve the arrival times of each appearance but were able to impose a time limit of less than 200 days for the three events.

The multiple images are produced by the monster galaxy cluster's powerful gravity, which distorts and magnifies the light from the supernova far behind it, an effect called gravitational lensing. The three lensed supernova images, seen as tiny dots captured in a single Hubble snapshot, represent light from the explosive aftermath of what is believed to be a type Ia supernova. The dots vary in brightness and colour, which signify three different phases of the fading blast as it cooled over time.

"This new discovery is the third example of a multiply imaged supernova for which we can actually measure the delay in arrival times," explained lead researcher Steve Rodney of the University of South Carolina in Columbia. "It is the most distant of the three, and the predicted delay is extraordinarily long. We will be able to come back and see the final arrival, which we predict will be in 2037, plus or minus a couple of years."

The light that Hubble captured from the cluster, MACS J0138.0-2155, took about four billion years to reach Earth. The light from Supernova Requiem needed an estimated 10 billion years for its journey, based on the distance of its host galaxy.

The team's prediction of the supernova's return appearance is based on computer models of the cluster, which describe the various paths the supernova light is taking through the maze of clumpy dark matter in the galactic grouping. Each magnified image takes a different route through the cluster and arrives at Earth at a different time, due, in part, to differences in the length of the pathways the supernova light followed.

"Whenever some light passes near a very massive object, like a galaxy or galaxy cluster, the warping of space-time that Einstein's theory of general relativity tells us is present for any mass, delays the travel of light around that mass," Rodney said.

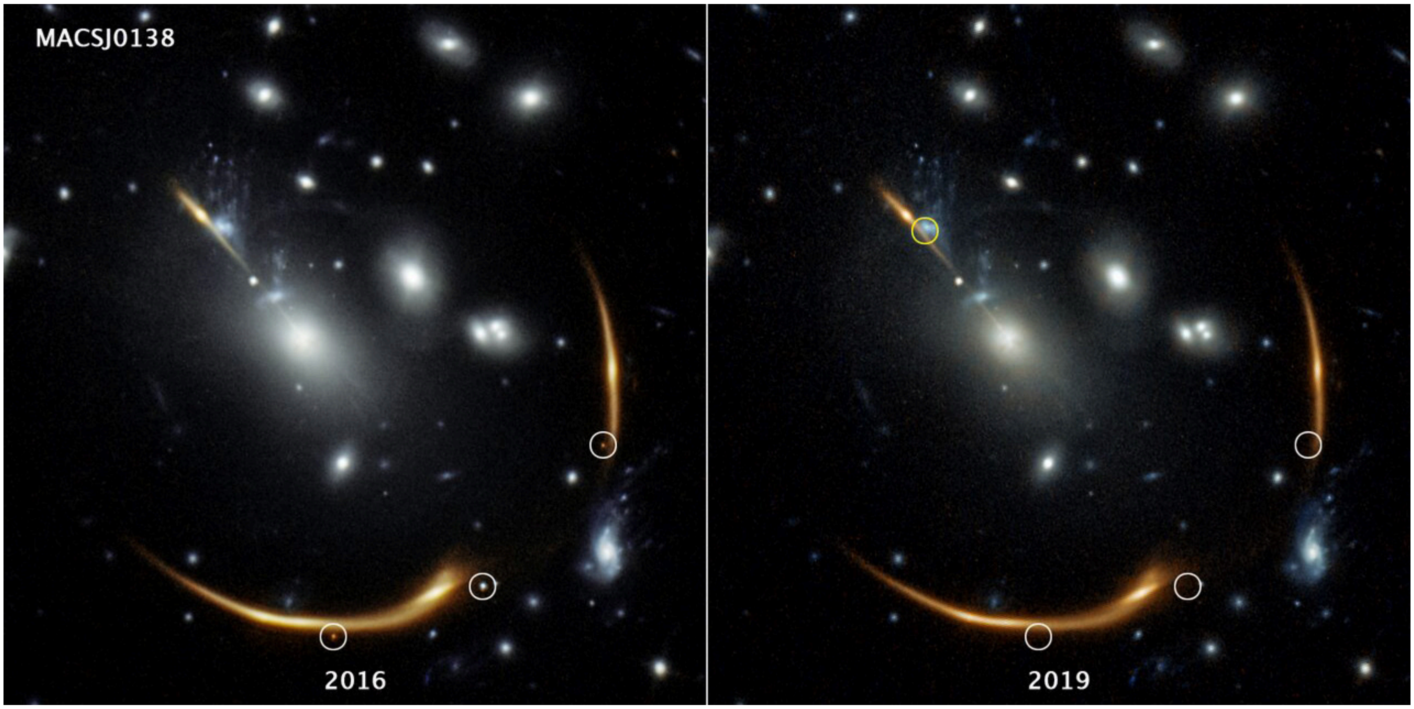


Figure 1 — Three views of the same supernova appear in the 2016 image on the left, taken by the Hubble Space Telescope*, but they're gone in the 2019 image. The distant supernova is superimposed on the giant galaxy cluster MACS J0138, a cluster so massive that its gravity bends and magnifies the light from the supernova, located in a galaxy far behind it. This gravitational lensing splits the supernova's light into multiple mirror images, highlighted by the white circles in the 2016 image. The multiply imaged supernova disappears in the 2019 image of the same cluster, at right. The snapshot, helped astronomers confirm the object's pedigree. Researchers predict that a fourth image of the same supernova will make an appearance in 2037 at the position highlighted by the yellow circle at top left. Credit: Joseph DePasquale (STScI)*

He compares the supernova's various light paths to several trains that leave a station at the same time, all travelling at the same speed and bound for the same location. Each train, however, takes a different route, and the distance for each route is not the same. Because the trains travel over different track lengths across different terrain, they do not arrive at their destination at the same time.

In addition, the lensed supernova image predicted to appear in 2037 lags behind the other images of the same supernova because its light travels directly through the middle of the cluster, where the densest amount of dark matter resides. The immense mass of the cluster bends the light, producing the longer time delay.

"This is the last one to arrive because it's like the train that has to go deep down into a valley and climb back out again. That's the slowest kind of trip for light," Rodney explained.

The lensed supernova images were discovered in 2019 by Gabe Brammer, a study co-author at the Cosmic Dawn Center at the Niels Bohr Institute, University of Copenhagen, in Denmark. Brammer spotted the mirrored supernova images while analyzing distant galaxies magnified by massive foreground galaxy clusters as part of an ongoing Hubble program called REsolved QUIEscent Magnified Galaxies (REQUIEM).

He was comparing new REQUIEM data from 2019 with archival images taken in 2016 from a different Hubble science program. A tiny red object in the 2016 data caught his eye, which he initially thought was a far-flung galaxy. But it had disappeared in the 2019 images.

"But then, on further inspection of the 2016 data, I noticed there were actually three magnified objects, two red and a purple," he explained. "Each of the three objects was paired with a lensed image of a distant massive galaxy. Immediately it suggested to me that it was not a distant galaxy but actually a transient source in this system that had faded from view in the 2019 images like a light bulb that had been flicked off."

Brammer teamed up with Rodney to conduct a further analysis of the system. The lensed supernova images are arranged in an arc around the cluster's core. They appear as small dots near the smeared orange features that are thought to be the magnified snapshots of the supernova's host galaxy.

Study co-author Johan Richard of the University of Lyon in France produced a map of the amount of dark matter in the cluster, inferred from the lensing it produces. The map shows the predicted locations of lensed objects. This supernova is predicted to appear a fifth time in 2042, but it will be so faint that the research team thinks it will not be visible.

Catching the rerun of the explosive event will help astronomers measure the time delays between all four supernova images, which will offer clues to the type of warped-space terrain the exploded star's light had to cover. The research team notes that observation of the fourth image could provide a time-delay precision of ~7 days, less than 1 percent of the 20-year baseline between event arrivals. Armed with those measurements, researchers can fine-tune the models that map out the cluster's mass. Developing precise dark-matter maps of massive galaxy clusters is another way for astronomers to measure the Universe's expansion rate and investigate the nature of dark energy, a hypothetical form of energy that works against gravity and causes the cosmos to expand at a faster rate.

This time-delay method is valuable because it's a more direct way of measuring the Universe's expansion rate, Rodney explained.

"These long time delays are particularly valuable because you can get a good, precise measurement of that time delay if you are just patient and wait years, in this case more than a decade, for the final image to return," he said. "It is a completely independent path to calculate the Universe's expansion rate. The real value in the future will be using a larger sample of these to improve the precision."

Spotting lensed images of supernovae will become increasingly common in the next 20 years with the launch of NASA's *Nancy Grace Roman Space Telescope* and the start of operations at the Vera C. Rubin Observatory. Both telescopes will observe large swaths of the sky, which will allow them to spot dozens more multiply imaged supernovae.

Future telescopes such as NASA's *James Webb Space Telescope* also could detect light from supernova REQUIEM at other epochs of the blast.

Prepared with material provided by the Goddard Space Flight Center

Indigestion: Red Giant swallows black hole

Massive stars in a binary relationship are common in our Universe but the liaisons do not always end peacefully. Often, one of the partners often ages more quickly that the other and the two then engage in an end-of-life astronomical parasitism, frequently with explosive results. Such endings are the stuff of theoretical investigation, but a study recently published in the journal *Science* provides a real-life confirmation of the numerical modelling.

In the classical model of a heavyweight binary system, one star is usually more massive than the other, quickly using up its supply of nuclear fuel and evolving into a supergiant star, fusing elements beyond hydrogen in its core. At some point, this rapidly evolving star will use up its internal supply of fuel and, if heavy enough, explode as a supernova before collapsing into a compact object—a neutron star or black hole.

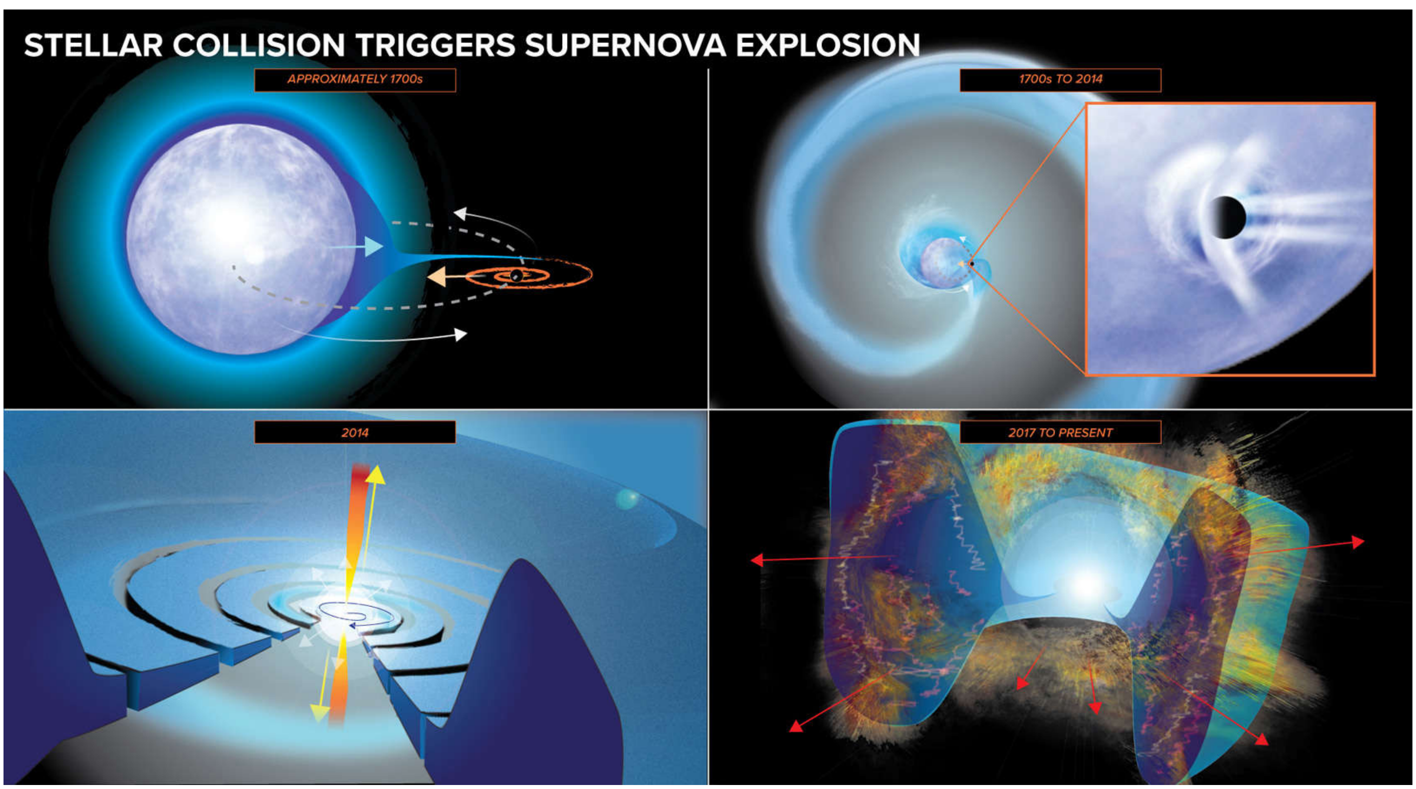


Figure 2 — A merger-induced supernova: (top left) A black hole or neutron star orbits a massive star, pulling off material. (top right) The compact object flings material away from the star, forming a spiral of gas around it. (bottom left) The compact object reaches the star's core, blasting out a fast jet of matter and energy. (bottom right) The star explodes, debris slamming into previously ejected material. Credit: Bill Saxton, NRAO/AUI/NSF.

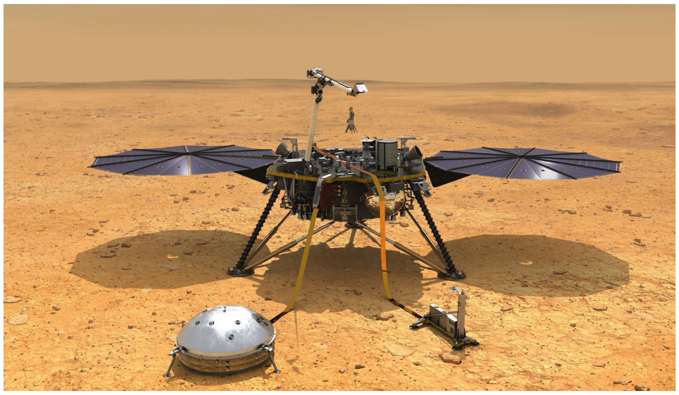


Figure 3 — An artist's impression of the InSight lander on Mars. The seismometer is the hemispherical instrument in the foreground. Image: NASA.

Astronomers know that a massive star and a companion compact object can form a stable orbit in which the two bodies gradually spiral closer and closer over an extremely long period of time. Such a binary system can be stable for millions to billions of years but the partners will eventually collide and emit gravitational waves, as detected by LIGO in 2015 and 2017.

After the first compact object has formed, the lighter (but still heavy) star of the pair undergoes its own evolution, swelling into a supergiant in its own good time and expanding to engulf the compact companion. Over time, the compact object siphons away the atmosphere of its larger companion star, ejecting a portion of it into space to form a surrounding torus of gas. This process drags the two objects ever closer until the black hole plunges into the star, causing the star to collapse and explode as a supernova.

In 2017, a particularly luminous and unusual source of radio waves was discovered in data taken by the Very Large Array (VLA) Sky Survey, a project that scans the night sky in radio wavelengths. Led by Caltech graduate student Dillon Dong, a team of astronomers has now established that the bright radio flare was caused by a black hole or neutron star crashing into its companion star in a never-before-seen process—a process much more rapid than the typical case.

"Massive stars usually explode as supernovae when they run out of nuclear fuel," says Gregg Hallinan, professor of astronomy at Caltech. "But in this case, an invading black hole or neutron star has prematurely triggered its companion star to explode."

Hallinan and his team look for so-called radio transients—short-lived sources of radio waves that flare brightly and burn out quickly like a match lit in a dark room. Radio transients are an excellent way to identify unusual astronomical events, such as massive stars that explode and blast out energetic jets, or the mergers of neutron stars.

Using Keck Observatory's Low Resolution Imaging Spectrometer (LRIS), the team then made follow-up optical observations of the radio source's home galaxy and discovered a massive outflow of material ejected from a central location, suggesting there was an energetic explosion of a massive star.

As Dong sifted through the VLA's massive dataset, he singled out an extremely luminous source of radio waves from the VLA survey called VT 1210+4956. This source is tied for the brightest radio transient ever associated with a supernova.

Dong determined that the bright radio energy was originally a star surrounded by a thick and dense shell of gas. This gas shell had been cast off the star a few hundred years before the present day. VT 1210+4956, the radio transient, occurred when the star finally exploded in a supernova and the material ejected from the explosion interacted with the surrounding, previously emitted gas shell. Yet, the gas shell itself, and the timescale on which it was cast off from the star, were unusual, so Dong suspected that there might be more to the story of this explosion.

Following Dong's discovery, Caltech graduate student Anna Ho (Ph.D. '20) suggested that this radio transient be compared with a different catalogue of brief bright events in the X-ray spectrum. Some of these X-ray events were so short lived that they were only present in the sky for a few seconds of Earth time. By examining this other catalogue, Dong discovered a source of X-rays that originated from the same spot in the sky as VT 1210+4956; the source had been detected by the Monitor of All Sky X-ray Image (MAXI) instrument on the *International Space Station*. Through careful analysis, Dong established that the X-rays and the radio waves were likely coming from the same event.

"The X-ray transient was an unusual event—it signaled that a relativistic jet was launched at the time of the explosion," says Dong. "And the luminous radio glow indicated that the material from that explosion later crashed into a massive torus of dense gas that had been ejected from the star centuries earlier. These two events have never been associated with each other, and on their own they're very rare."

So, what happened? After careful modelling, the team determined the most likely explanation—an event that involved some of the same cosmic players that are known to generate gravitational waves. The X-rays were produced by a jet launched from the core of the star at the moment of its collapse. The radio waves, by contrast, were produced years later as the material from the exploding star, moving at 1000 km/s, reached the torus of gas that had been ejected by the in-spiraling compact object.

However, in the case of VT 1210+4956, the two objects instead collided immediately and catastrophically, producing the blasts of X-rays and radio waves observed. Although collisions such as this have been predicted theoretically, VT 1210+4956 provides the first concrete evidence that it happens.

The VLA Sky Survey produces enormous amounts of data about radio signals from the night sky, but sifting through that data to discover a bright and interesting event such as VT 1210+4956 is like finding a needle in a haystack. Finding this particular needle, Dong says, was, in a way, serendipitous.

"We had ideas of what we might find in the VLA survey, but we were open to the possibility of finding things we didn't expect," explains Dong. "We created the conditions to discover something interesting by conducting loosely constrained, open-minded searches of large data sets and then taking into account all of the contextual clues we could assemble about the objects that we found. During this process you find yourself pulled in different directions by different explanations, and you simply let nature tell you what's out there."

Compiled with material provided by the W.M. Keck Observatory

Mars: shakin' all over

On September 18, NASA's InSight lander celebrated its 1,000th Martian day, or sol, by measuring one of the biggest, longest-lasting marsquakes the mission has ever detected. The temblor is estimated to be about a magnitude 4.2 and shook for nearly an hour and a half. This is the third major quake InSight has detected in a month: on August 25, the mission's seismometer detected two quakes of magnitudes 4.2 and 4.1. For comparison, a magnitude 4.2 quake has five times the energy of the mission's previous record holder, a magnitude 3.7 quake detected in 2019.

The quakes might not have been detected at all had the mission not taken action earlier in the year as Mars's highly elliptical orbit took it farther from the Sun. Lower temperatures required the spacecraft to rely more on its heaters to keep warm; that, plus dust buildup on InSight's solar panels, had reduced the lander's power levels, requiring the mission to conserve energy by temporarily turning off certain instruments.

The team managed to keep the seismometer on by taking a counterintuitive approach: They used InSight's robotic arm to trickle sand near one solar panel in the hopes that, as wind gusts carried it across the panel, the granules would sweep off some of the dust. The plan worked, and over several dust-clearing activities, the team saw power levels remain fairly steady. Now that Mars is approaching the Sun once again, power is starting to inch back up.

"If we hadn't acted quickly earlier this year, we might have missed out on some great science," said InSight's principal investigator, Bruce Banerdt of NASA's Jet Propulsion Laboratory in Southern California, which leads the mission. "Even after more than two years, Mars seems to have given us something new with these two quakes, which have unique characteristics."

Analysis of previous temblors has allowed the InSight team to map out the basic character of the Martian interior in detail. By combining InSight's marsquake data with planet-wide gravitational measurements, the researchers determined that Mars likely has a 24- to 72-km-thick crust with a very deep lithosphere close to 500 km deep. The crust of Mars is likely highly enriched in radioactive elements that help to heat the layer at the expense of the interior. Similar to Earth, a low-velocity layer probably exists beneath the lithosphere. The Martian core is liquid and large, 1,830 km, which means that the mantle has only one rocky layer rather than two like the Earth.

Previous marsquakes have also shown that there are at least two shallow layers below InSight. The first is about 10 km thick and is probably a much-fractured layer pummelled by meteorite impacts over the eons. The second layer extends to roughly 20 km and is more consolidated than the shallower surface layer.

While the September 18 quake is still being studied, scientists already know more about the August 25 quakes: The magnitude-4.2 event occurred about 8,500 km from InSight - the most distant temblor the lander has detected so far.

Scientists are working to pinpoint the source and determine which direction the new seismic waves travelled, but they know the shaking occurred too far away to have originated where InSight has detected almost all of its previous large quakes: Cerberus Fossae, a region roughly 1,600 km away where lava may have flowed within the last few million years. One especially intriguing possible location is Valles Marineris, the epically long canyon system that scars the Martian equator.

To the surprise of researchers, the August 25 quakes were two different types, as well. The magnitude-4.2 quake was dominated by slow, low-frequency vibrations, while fast, high-frequency vibrations characterized the magnitude-4.1 quake. The magnitude-4.1 quake was also much closer to the lander—only about 925 km away. That's good news for seismologists: recording different quakes from a range of distances and with different kinds of seismic waves provides more information about a planet's inner structure.

Looking ahead, the mission's team is considering whether to perform more dust cleanings after Mars's solar conjunction, when Earth and Mars are on opposite sides of the Sun. Because the Sun's radiation can affect radio signals, interfering with communications, the team stopped issuing commands to the lander on September 29, though the seismometer will continue to listen for quakes throughout conjunction. ✶

Compiled with material provided by the Jet Propulsion Laboratory.

Research Articles / Articles de reserches

A Green Laser Observation Across Minas Basin

by Roy Bishop, Halifax

Abstract

After assessing the photometry, and with the consent of a former Editor of the *Observer's Handbook*, a second former Editor, curious about what the first Editor would observe, pointed a green laser directly into the eyes of the first Editor. The photometry, the preparations, and the observations are described, with an emphasis on the *Observer's Handbook* as an invaluable source of information.

Introduction

But for the COVID-19 pandemic, 2020 August 22 was the Saturday of what would have been the weekend of the annual Nova East Star Party, Atlantic Canada's largest and oldest annual star party. It was a lovely, late summer day, with a clear, transparent sky, no wind, pleasant temperature, and low humidity. I was in my cottage at Evangeline Beach on the south shore of the Bay of Fundy's Minas Basin, the location of the largest ocean tides on Earth (a 15-m vertical range that day). Dave Chapman, like myself a member of the Halifax Centre of the RASC, was camping at Nova Scotia's Blomidon Provincial Park, 14 km north across the water from Evangeline Beach.

The Thought

That afternoon while gazing line-of-sight at the Park, I had a thought. After dark, it would be interesting to aim my 5 milliwatt green laser pointer at Dave and get his description of how it looks from a distance of 14 km.

Before contacting Dave, however, I needed to determine if pointing a green laser directly into his eyes was something I should *not* do!

The Assessment

A green laser has a wavelength of 532 nm (it's in the *Observer's Handbook*, p. 32). I measured the diameter of the beam leaving my laser: about 1.5 mm. Diffraction will give the beam an angular spread of:

wavelength divided by beam diameter

= 532 nm/1.5 mm = 1/2800 radian, or 1.2 minutes of arc

An angular spread of 1.2 minutes of arc is interesting because that is approximately the resolution limit of the unaided eye. That is particularly interesting because it means that, to the person holding a laser pointer, the beam it casts into the night sky (visible because of light scattered by the air back toward the laser) does not appear to spread out. In Hollywood terms, the beam resembles a "Star Wars lightsabre"! That narrow beam, coupled with the high sensitivity of the eye to green light (see the diagram on p. 67 of the Handbook), is why a green laser is so useful for astronomy public outreach, for pointing out objects in the night sky.

Although not apparent to the person holding a laser pointer, the beam *does* spread, and that spread will protect Dave's eyes provided he is far enough away. I verified the calculated 1.2 minutes of arc spread with a direct measurement. I set the laser in the north doorway of my cottage and aimed it at the south interior wall, thirteen paces distant (about 12 metres). The diameter of the spot on that wall was about 6 mm. A spread of 6.0 – 1.5 = 4.5 mm in 12 m is an angular spread of:

4.5 mm/12 m = 1/2700 radian, or 1.3 minutes of arc

about the same as my prediction based on diffraction.

Dave was 14 km from me, so the laser beam when it reached him would have a diameter of:

14 km × (1/2700) = 5.2 m

How much light does the laser emit? The wavelength of green laser light (532 nm) is close to the peak of the bright-adapted (photopic) response of the retina (555 nm), for which 1/683 watt powers one lumen of visible light ("luminous efficacy," it's in the Handbook, p. 32). Thus my 5 mW laser produces approximately:

5 mW/[(1/683) W/lm] = 3.4 lm

Neglecting absorption and scattering by the atmosphere (with the transparent air that day, a good approximation), at Dave's location those lumens would be spread over a 5.2-m diameter spot, for an illuminance of:

3.4 lm/[pi x (2.6 m)^2] = 0.16 lx

"lux" (lx), the Système International (SI) unit of illuminance, is defined in the Handbook, bottom of p. 32, middle column.

What will Dave see if he looks directly into the laser beam? More specifically, what is the visual magnitude of my effectively point-source laser if it produces an illuminance of 0.16 lx at Dave's position 14 km across Minas Basin at Blomidon Park? The *Observer's Handbook* has the answer, a dozen lines from the bottom of page 31:

m = –13.99 – 2.5 log 0.16 = –12.0

That month, the brightest point-like object in the night sky was Venus (m = –4.4). Thus, as Dave would see it, my laser would be:

10 exp [0.4 x {–4.4 – (–12.0)}] = 1100 times

Figure 1 — The photo shows a view of Cape Blomidon from Evangeline Beach, 17 km across Minas Basin. The "V" indicates Dave Chapman's location in Blomidon Provincial Park, 14 km from Evangeline Beach, on the crest of the 200-m high escarpment when he observed the laser beam. Minas Basin extends northward past Cape Blomidon approximately 11 km to the distant shoreline of northern Nova Scotia (the blue hills visible to the right of Cape Blomidon). That entire 11-kilometre expanse of water is not visible in the photo because it is hidden behind the curvature of Earth. The camera's line-of-sight was tangent to the sea near Cape Blomidon. (Photo by Roy Bishop.)

brighter than Venus, dazzling but not dangerous (the relation for converting a magnitude difference into an intensity ratio is also in the Handbook, the first item under Magnitude Relations, p. 31).

The Preparations

Dave and I did the experiment at 9:30 p.m. that evening, within the half hour before the end of astronomical twilight. Dave knew exactly where I was located across Minas Basin because, before sunset, I used a small (25-cm wide) mirror to send a beam of sunlight in his direction. I could not see the reflected beam of sunlight to aim it, so I positioned myself such that the outer end of a bare tree branch several metres away was aligned with Blomidon Park. With the mirror held near my eyes, by tilting the sunbeam across the end of the tree branch, most of the half-degree-wide beam (the angular diameter of the Sun) flashed across the Park. With no optical aid, Dave immediately spotted the sparkle of light on the distant shoreline of Evangeline Beach.

Compared to aiming the 30-arc-minute-wide sunbeam at Dave, aiming the 1.3-arc-minute-wide laser beam would be far more difficult. Its spot would be $(30/1.3)^2 = 530$ times smaller in area, and I wanted to target Dave, not other campers in Blomidon Park! The laser beam in the dark would be a different beast than the glint of sunlight from the other side of the Annapolis Valley on that sunny afternoon!

To facilitate aiming the narrow laser beam at Dave, with elastics I attached the small laser pointer to the pivot arms of tripod-mounted 15 × 60 binoculars. When darkness came, I could see light scattered from the outgoing laser beam, and with a shim of folded paper I adjusted the laser so its beam was near the centre of the field of view of the binoculars. Not only did that steady the direction of the laser beam, but also it effectively brought me less than a kilometre from Blomidon Park.

But where was Dave? Via cell phone I asked him to turn on the red LED in his headlamp. Within a couple of seconds, in the binoculars a red speck of light appeared against the dark forest on the edge of Blomidon's 200-m cliff, near the north end of the camping area of the Park. I could see my target!

The Results

Dave reported that when I aimed the beam toward him, my small, 5 mW, green laser powered by only two AAA batteries "was dazzling, much brighter than Venus, and much brighter than any other light in the Annapolis Valley."

When Dave turned around, he said that "the beam playing on the trees behind me was also easy to see, several metres across." The illuminance on those trees (0.16 lx) was comparable to that provided by a gibbous Moon (I leave it as an exercise for the reader to check that. The relevant equations are in the Handbook, 12 and 14 lines up from the bottom of p. 31).

When turning away from the laser beam, Dave said that he "did not experience any after-image," consistent with the beam not being a danger to his eyes when viewed from 14 km. Nevertheless, he remarked that even at that large distance, such a dazzling point of light in the dark would definitely be a distraction to anyone whose attention was needed elsewhere, such as the driver of a car, or the pilot of a plane.

The *Observer's Handbook*

May this quantitative account of a Saturday project by two retired editors have given you a deeper appreciation of the goal set in 1906 by Clarence Chant, the father of Canadian astronomy and the creator of the *Observer's Handbook*. He said of his first edition: "the object has been to produce a companion which the observer would wish always to have in his pocket or on the table before him." I had the 2020 edition on the table before me on that Saturday afternoon. Without the few lines of information cited from pages 31 and 32, I could not have assessed the implications of the thought I had that afternoon. For more than a century, the editors and contributors of the *Observer's Handbook*, volunteering their time and knowledge because of their love of astronomy, have strived to make the Handbook the singularly most useful reference for observers of the sky.

Acknowledgment

I am indebted to David Chapman for his willing participation and the descriptions of what he saw. As he said on that lovely August afternoon when I proposed to shine a green laser directly into his eyes*, "I think I could try this."

***Warning:** The brightness of a laser directed at anyone's eyes varies as the inverse square of its distance from the observer. For example, if instead of being 14 km from my low-power laser, Dave Chapman had been "social distancing" at 2 m, then instead of appearing about 1000 times brighter than Venus, the light striking his retinas would have appeared 1000 times multiplied by the square of (14 km/2 m), about 50 thousand million (50 billion) times brighter than Venus; likely, and quickly, causing irreversible damage to his vision. It is no wonder that governments have been scrambling to regulate the power-output, use, and availability of green laser pointers, and to establish the legal consequences of their improper use by individuals who do not understand the hazard and/or are socially inept. ✶

Photometric Monitoring and Period Changes in SX Phoenicis Star XX Cygni. IV.

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Abstract

Over the last ten years, 135 new times of maximum light were collected at the Allan I. Carswell Observatory (York University, Toronto) and 723 new times of maximum light were collected from the Transiting Exoplanet Survey Satellite (TESS). This work uses these new times of maximum light to discuss the period changes and pulsations of the δ Scuti star XX Cyg. A new $O - C$ diagram for XX Cyg is presented, along with an updated period of 0.134865124(2) days. The period of XX Cyg is found to be increasing continuously with a rate of $(1/P)(dP/dt) = (1.12 \pm 0.06) \times 10^{-8}\text{yr}^{-1}$. Fourier analysis performed on the TESS data shows that XX Cyg pulsates with a fundamental frequency of 7.408(8) cycles day^{-1}. Pulsations are also reported at 17 other harmonic frequencies.

1. Introduction

High amplitude δ Scuti (HADS) stars are short-period pulsating variable stars, usually with a period of several hours duration, that are currently evolving off the main sequence (Hog & Peterson (1997)). They are located within the instability strip of the Hertzsprung-Russell (H-R) diagram. HADS stars typically pulsate in radial modes, with some evidence for non-radial modes with small amplitudes (Pigulski et al. (2004)). Population II HADS stars are called SX Phoenicis stars (SX Phe), and are more evolved than Population I HADS stars (Pigulski et al. (2004)). Population II HADS stars are usually found in globular clusters, with about 150 stars located in the galactic field. There are about 200 SX Phe stars in globular clusters and nearby galaxies (Rodriguez et al. (2000); Clement et al. (2001)).

The star discussed in this paper is XX Cygni (XX Cyg), a metal-poor Population II SX Phe-type variable star. It has a visual magnitude of $V = 11.7$, a variation of $\Delta V = 0.8$ (Kiss & Derakas (2000)), and a radial velocity of −135 km/s

(Kharchenko et al. (2007)). XX Cyg has a long observational history commencing with photographic observations in 1906 (Parkhurst & Jordan (1906)). It was previously labelled as a dwarf Cepheid, but is now more properly designated as a Population II SX Phe variable star (Joner (1982); McNamara & Feltz (1980)). A summary of some other properties of XX Cyg including position, spectral type, effective temperature (T_{eff}), iron to hydrogen ratio ([Fe/H]), local gravity (g) and pulsation constant Q, are provided in Table 1.

This paper presents 858 newly determined times of maximum light of XX Cyg from which a period is measured and Fourier analysis made. The analysis includes an updated period, ephemeris, $O - C$ diagram, and value of $(1/P)(dP/dt)$ for XX Cyg. Fourier analysis is used to investigate the radial and non-radial modes of pulsation. In Section 2, the data collection and reduction procedures are described. In Section 3 we discuss the period analysis, and in Section 4 we discuss the pulsation analysis.

Data (Col. 1)	Values (Col. 2)
[1] Spectral Type	A5-F5
[2] R.A. (2000)	$20^h\ 3^m\ 15.6^s$
[2] Dec. (2000)	+58° 57' 16.5"
[1] [Fe/H]	-0.49 dex
[2] T_{eff}	6982K
[1] $\log(g)$	3.66
[1] Q	0.0333 days

Table 1 — Basic Properties of XX Cyg (1: Joner (1982), 2: GAIA Collaboration et al. (2018))

2. Observations & Data Reduction

2.1 Data from the Allan I. Carswell Observatory

Of the new times of maximum light, 135 were obtained using the 0.6-m f/13 Cassegrain telescope from the Allan I. Carswell Observatory, located at York University in Toronto, Ontario, Canada. Data were obtained over 100 nights between 2010 and 2019. Two different instruments were used for data collection. Observing seasons from 2010 to 2015 utilized the SBIG ST-9 CCD camera as well as an $f/6.6$ optical reducer, yielding an approximate 5′ × 5′ field of view. Observing seasons between 2016 and 2019 used the SBIG STXL 6303 CCD camera with an approximate 10′ × 6′ field of view (no optical reducer). The field of view as seen using the STXL is shown in Figure 1, with three common comparison stars marked for use in differential photometry analysis. In order to maximize temporal resolution, a Johnson I band filter was used until 2013, after which a Johnson R band filter was used. The use of these filters took advantage of the increased sensitivity of the CCD chip to red light, allowing us to reduce the exposure time of the images. The exposure times ranged from 60 s to 120 s.

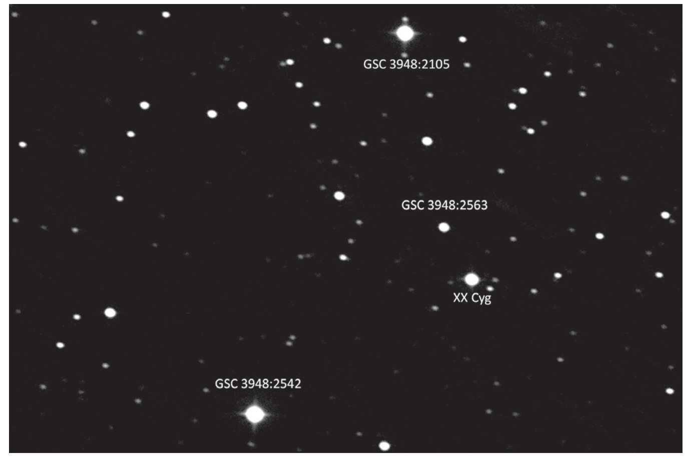

Figure 1 — Field for XX Cyg, taken with the STXL 6303 CCD camera and the 60 cm telescope. XX Cyg and three comparison stars are marked. North is up, and east is left. The field of view is approximately 9.7′ x 6.4′ with an angular scale of 0.378" per pixel.

After successfully imaging the star on a given night, and gathering the necessary bias, dark, and flat-field images, standard IRAF routines were used for the photometric analysis. While using the ST-9 CCD camera, dark, bias, and flat frames were used to calibrate images. The STXL 6303 CCD camera only required the use of bias and flat frames since the dark current was negligible.

After calibrating each light frame on a given observing night, AIMR, a locally developed Python routine, was used to mark the positions of the target stars in the first data image of an evening, and the coordinates were saved to a DS9 region file. AIMR was used to automatically determine star positions for all other images taken that night. The images were processed through other locally developed data-reduction tools including, IMSTDEV, which was used to determine the image background noise, and APCALC, which was used to find the optimal aperture, annulus, and deannulus values, to measure the sky values (curve of growth analysis). The IRAF Phot package was then used to extract the instrumental magnitude data for the selected stars throughout the night of observations. The final step in order to calculate the time of maximum light was to use PHOTDAT (another locally developed Python program). PHOTDAT was used to carry out differential photometry of XX Cyg using nearby comparison stars (differential photometry). The three main comparison stars were GSC 3948:2542 (V = 10.4535), GSC 3948:2563 (V = 13.2645), and GSC 3948:2105 (V = 10.9567, all from GAIA Collaboration et al. (2018)), however other stars present in the field were occasionally used.

2.2. Data from TESS

A total of 723 times of maximum light were obtained by processing batch data from the Transiting Exoplanet Survey Satellite, hereafter referred to as "TESS" (Ricker et al. (2015)). Data were processed and analyzed by a Python based

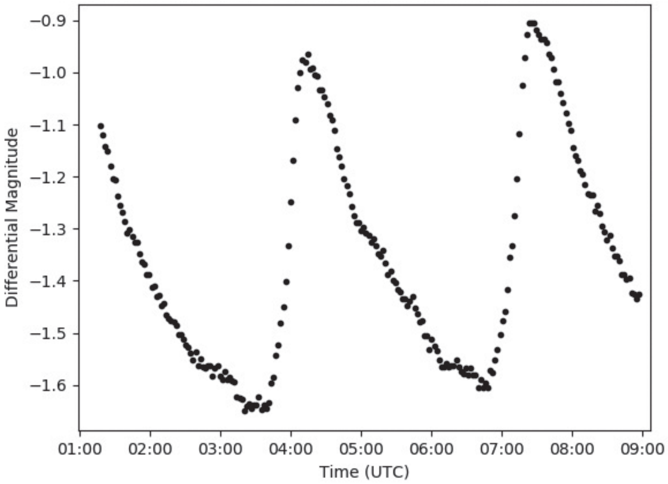

Figure 2 — Differential light curve of XX Cyg, from data taken at the Allan I. Carswell Observatory on the night of 2019 August 23.

'in-house' data-pipeline, "DORADO" (Digital Observatory Resources (for) Automated Data Operations), which makes use of the Python packages Numpy, Matplotlib, Photutils, Astropy, Ccdproc, Scipy, Scikit/Skimage, and Lightkurve. XX Cyg was observed during sectors 14-17, which performed observations from 07/18/19 – 08/15/19 for sector 14, 08/15/19 – 09/11/19 for sector 15, 09/11/19 –10/07/19 for sector 16, and 10/07/19 – 11/02/19 for sector 17. Data were acquired from the Mikulski Archive for Space Telescopes, "MAST," at the Space Telescope Science Institute, in the form of a Target Pixel File, "TPF," cut from 2-minute cadence (the interval between flux measurements) observations as a series of 11 × 11 pixel "stamps" containing the calibrated flux values. The TPF used had already been processed in the TESS pipeline (Ricker et al. (2015)) during which all images were calibrated, corrected for cosmic rays, and had an automatically generated aperture mask applied.

After reading in the TPF to DORADO, the TESS pipeline automatically generated aperture mask was discarded, as it did not properly encompass the star throughout the series of observations and on occasions included background sky pixels and excluded object pixels leading to greater variation in the resulting light curve. The TESS pipeline mask was replaced in favour of a mask made through a process of visually inspecting the pixels belonging to the object over multiple stamps. Once this had been corrected, sum-based aperture photometry was performed over all stamps in the series accounting for background/sky contributions to the annulus aperture area.

3. Period Analysis

3.1. Data from the Allan I. Carswell Observatory

After performing differential photometry on the data obtained from the 0.6-m telescope, a plot of differential magnitude vs. time was generated for each night of observations. A 2nd or 3rd order polynomial was then fit around each peak (between

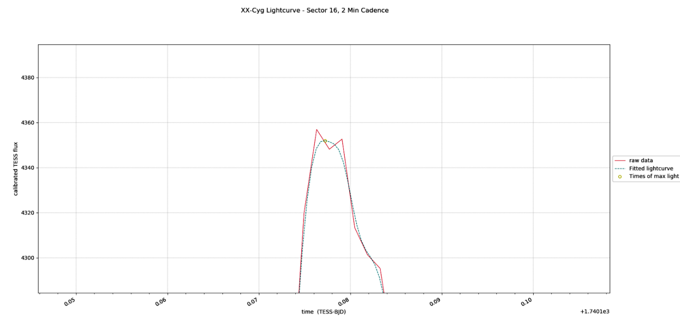

Figure 3 — A segment of the light curve of XX Cyg from TESS data containing a time of maximum light plotted as a yellow open circle, with raw data in solid red, and the smooth fitted curve in dashed blue.

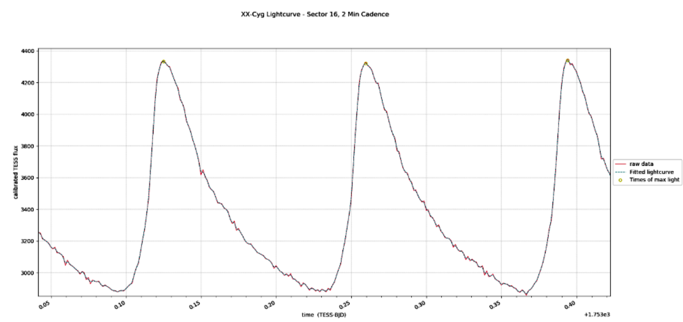

Figure 4 — A segment of the light curve of XX Cyg from TESS data containing multiple cycles. Data were obtained in sector 16 with a 2-minute cadence. Times of maximum light are plotted as a yellow open circle, with raw data in solid red, and the smooth fitted curve in dashed blue.

10 and 20 data points) in the light curve, which allowed for the determination of the time of maximum light in units of Heliocentric Julian Date (HJD). The time of maximum light generated during this process is accurate to within ±0.001 d (often much less), while the timestamp of each data point is accurate to less than ±1 s. The variation in the differential magnitude of each data point was of order 0.01 mag as determined from the standard deviation of the comparison star's observed magnitude throughout the observing session.

Figure 2 shows a typical light curve created during this process.

3.2. Data from TESS

In order to generate a clean light curve from the aperture sums, a 'TessLightCurve' data object was created from the time-series and aperture sum array using the package 'LightKurve.' The annulus aperture was very effective at reducing the influence of light contamination from sunlight, lunar reflection, and reflected light from the Earth, which varied throughout a sector and from sector to sector due to the orbit of TESS. The TESS spacecraft's pointing was altered from +54º to +85º ecliptic latitude for sectors 14-16 of observations due to excessive light contamination from Earth and moonlight. Each TESS sector is composed of two highly elliptical cislunar orbits about Earth with a period of 13.7 days each, leading to the 27.4 day duration for a sector's observation. Light contamination is thus presented as a flux trend throughout the aperture sum array. Noticeable flux trends corresponding to the 13.7-day orbit were 'flattened' and outlying data points that exceeded 7σ were removed from the light curve. The light curve was then stored using an Astropy Table due to the limitations of the 'TessLightCurve' data objects.

The times of maximum light were obtained using the peak-finding Scipy 'signal.aggrelmax' function on a smoothed light curve. The flux values of the light curve contain random fluctuations that result in small scale jagged features as seen in Figure 3. Thus a search limit was set that required a local maximum to be the largest value within a specified number of points equivalent to ~ 12 minutes on either side of a time of maximum light. To avoid each small-scale vertex above the search limit being read as a time of maximum light, DORADO took a Fourier Basis approach to curve fitting. A Real-Valued Fast Fourier Transform was performed on the flux values φ_q of the light curve to obtain the discrete Fourier transform, "DFT,"as a function of frequency. The maximum number of terms retained was determined by inspection of the light curve for smoothness (continuity). The resulting series were transformed back into the time domain.

As a result of the removal of some high-frequency terms, their 'power' was lost and the amplitude of the smoothed curve was lower than the original time series data. The lower amplitude peaks suffer from trending when computing the time of maximum light, leading to visible patterns in the resulting *O* – *C* diagram.

The Fourier fit was further processed using an interpolated univariate spline and the 'knots' of the curve were obtained. The raw time series were then fit with a least squares univariate spline using the Fourier fit knots as reference knots to lower the influence of the jagged features of the raw data. Lastly, the data point count for each sector was increased to 50,000 data points using the spline and was then convoluted using a Blackman window function. The resulting curve was continuous and smooth with increased time resolution as shown in Figure 4. The times of maximum light were identified from this fit.

3.3. The O – C Diagram

With an updated list of times of maximum light; a new ephemeris and *O* – *C* diagram were generated. In order to obtain optimal results, as many times of maximum light were included in the *O* – *C* diagram as possible. A comprehensive literature search on XX Cyg was conducted using the SIMBAD astronomical database. Similar searches have also been conducted by authors of other papers, such as Yang et al. (2012) and Conidis et al. (2011).

Not all of the TESS data was included in this *O* – *C* analysis.

Source (Col. 1)	**Maxima (HJD)** (Col. 2)	**Cycle (E)** (Col. 3)
Alania (1954)	2434630.21300	29356
Romano (1982)	2438939.42100	61308
Romano (1982)	2440124.34600	70094
Romano (1982)	2440152.24700	70301

Table 2 — Excluded times of maximum light.

A challenge presented by the rich TESS data set is the overwhelming number of points concentrated in an approximately 4-month period. TESS data generated 1.5 times more times of maximum light over its observing period than have been generated by all other observatories combined since XX Cyg was first observed in 1906. A concern of having such a large fraction of the data lie in such a small temporal window is that it could introduce bias into both the new ephemeris and the *O* – *C* diagram, skewing the results. To minimize any bias, only 20 randomly selected times of maximum light from the TESS data were included in the period analysis. This is in keeping with the number of times of maximum light collected in a typical observing season. Ten different selections of the 20 TESS data points included in the analysis described below were chosen. The coefficients for equations 2 and 3 were compared for each set of random TESS data included in the analysis. The coefficients variation was comfortably within the stated errors indicating the results of the analysis below were independent of the selected 20 TESS data points.

In total, 513 points were included in the *O* – *C* analysis. Of these reported values, 135 were newly obtained using the 0.6-m telescope, 20 were obtained using TESS, and 358 were contributed by other observatories via the literature search. Table

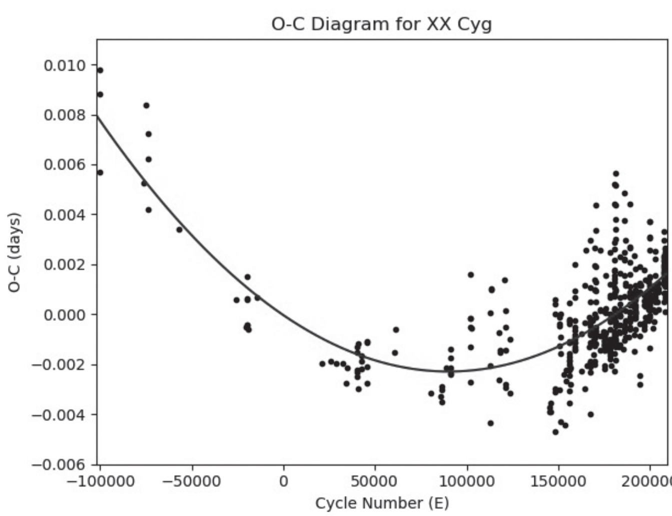

Figure 5: The O – C diagram of XX Cyg with the best quadratic polynomial fit (solid blue line)

S.14 f (Col. 1)	**S.14** P (Col. 2)	**S.15** f (Col. 3)	**S.15** P (Col. 4)	**S.16** f (Col. 5)	**S.16** P (Col. 6)	**S.17** f (Col. 7)	**S.17** P (Col. 8)	**Mean** f (Col. 9)	σ_f (Col. 10)	**Mean** P (Col. 11)	σ_P (Col. 12)
7.410	1.55×10^{14}	7.409	2.14×10^{14}	7.417	1.68×10^{14}	7.396	1.09×10^{14}	7.408	0.008	1.61×10^{14}	3.74×10^{14}
14.820	3.09×10^{13}	14.818	3.97×10^{13}	14.835	3.97×10^{13}	14.831	6.94×10^{13}	14.826	0.007	4.49×10^{13}	1.46×10^{13}
22.230	6.24×10^{12}	22.226	6.72×10^{12}	22.252	1.06×10^{13}	22.227	9.33×10^{12}	22.234	0.011	8.22×10^{12}	1.8×10^{12}
29.677	1.53×10^{12}	29.674	3.08×10^{12}	29.669	2.86×10^{12}	29.662	5.55×10^{12}	29.671	0.005	3.25×10^{12}	1.45×10^{12}
37.087	7.26×10^{11}	37.082	1.34×10^{12}	37.087	8.26×10^{11}	37.058	1.05×10^{12}	37.078	0.012	9.85×10^{11}	2.35×10^{11}
44.497	5.49×10^{11}	44.491	8.55×10^{11}	44.504	4.05×10^{11}	44.494	9.98×10^{11}	44.496	0.005	7.02×10^{11}	2.36×10^{11}
51.907	3.1×10^{11}	51.900	4.09×10^{11}	51.921	1.79×10^{11}	51.889	3.29×10^{11}	51.904	0.012	3.07×10^{11}	8.26×10^{10}
59.316	1.76×10^{11}	59.309	1.85×10^{11}	59.339	7.77×10^{10}	59.325	2.65×10^{11}	59.322	0.011	1.76×10^{11}	6.65×10^{10}
66.726	7.96×10^{10}	66.718	6.54×10^{10}	66.715	4.02×10^{10}	66.721	1.06×10^{11}	66.720	0.004	7.28×10^{10}	2.38×10^{10}
74.136	3.05×10^{10}	74.165	4.58×10^{10}	74.133	3.11×10^{10}	74.156	8.83×10^{10}	74.147	0.013	4.89×10^{10}	2.36×10^{10}
81.583	1.51×10^{10}	81.574	4.5×10^{10}	81.550	2.39×10^{10}	81.552	4.78×10^{10}	81.565	0.014	3.3×10^{10}	1.38×10^{10}
88.993	1.58×10^{10}	88.982	2.6×10^{10}	88.967	1.99×10^{10}	88.987	3.7×10^{10}	88.983	0.010	2.46×10^{10}	8×10^{9}
96.403	1.27×10^{10}	96.391	2.02×10^{10}	96.385	1.25×10^{10}	96.383	1.99×10^{10}	96.390	0.008	1.63×10^{10}	3.72×10^{9}
103.813	6.49×10^{9}	103.800	1.45×10^{10}	103.802	8.05×10^{9}	103.819	1.3×10^{10}	103.808	0.008	1.05×10^{10}	3.33×10^{9}
111.223	4.33×10^{9}	111.209	4.04×10^{9}	111.219	5.32×10^{9}	111.214	5.74×10^{9}	111.216	0.005	4.86×10^{9}	6.96×10^{8}
118.633	4.05×10^{9}	118.656	2.67×10^{9}	118.637	4.01×10^{9}	118.650	4.72×10^{9}	118.644	0.009	3.86×10^{9}	7.45×10^{8}
126.043	1.71×10^{9}	126.065	9.47×10^{8}	126.054	2.1×10^{9}	126.045	3.26×10^{9}	126.052	0.009	2.01×10^{9}	8.35×10^{8}
133.453	3.86×10^{8}	133.474	2.41×10^{9}	133.471	9.02×10^{8}	133.481	1.91×10^{9}	133.470	0.010	1.4×10^{9}	7.98×10^{8}

Table 3 — The 18 frequencies (f) and powers (P) resolved during Fourier Analysis. Columns 1, 3, 5, 7 and the frequencies found from Sectors 14, 15, 16, and 17 respectively. Columns 2, 4, 6, and 8 are the associated powers for these frequencies. Column 9 is the Mean Frequency across all 4 sectors and Column 10 is the Standard Deviation of the Mean Frequencies. Column 11 is the Mean Power of the frequencies across all 4 sectors and Column 12 is the Standard Deviation of the Mean Power.

4 in Appendix A contains a summary of the times of maximum light obtained from the literature search, including the source and the number of data points contributed. Table 5 in Appendix A contains all of the new data obtained from the 0.6-m telescope (135) being reported in this paper and used for the *O* – *C* analysis. The table includes the time of maximum light, the Integer Cycle Number, as calculated using Equation 2, and the *O* – *C* value, also calculated from Equation 2. All the times of maximum light generated from TESS data (723) as well as the complete set of 513 data points used in the *O* – *C* analysis are available from the Canadian Astronomical Data Centre (CADC).

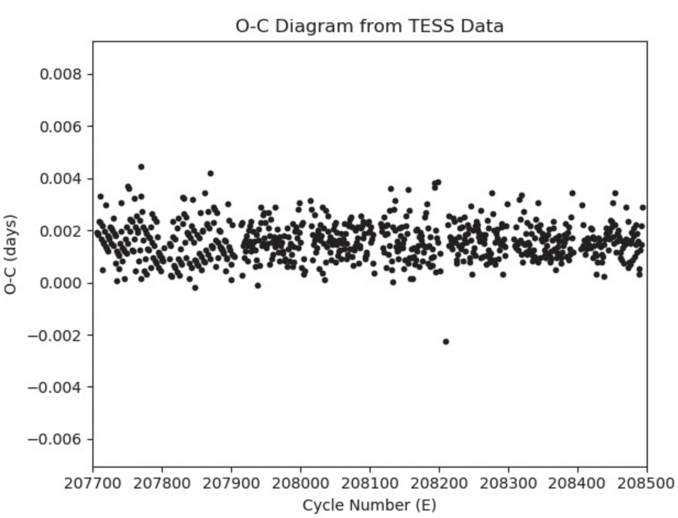

Figure 6 — The O – C diagram of XX Cyg generated using TESS data

All together, only 4 times of maximum light published in the literature were excluded from the calculations, due to having standard deviations of 3σ away from the polynomial fit of the *O* – *C* diagram. As a result of the large number of data points now included in this analysis, the effect of the excluded data on the final result is negligible. All excluded times of maximum light are listed in Table 2.

The linear ephemeris given in Conidis et al. (2011) (Equation 1) was used to calculate the cycle number *(E)* of each time of maximum light.

Assuming a constant pulsation rate, the observed time of maximum light (HJD) was then plotted against the integer

$$\mathrm{HJD_{max}} = 2,430,671.1031 + 0.314865117 \cdot \mathrm{E} \qquad (1)$$

cycle number to obtain a new value of HJD_0 and a new period. This yielded an updated period of 0.134865124 days, which is slightly longer than the period reported in Yang et al. (2012) of 0.134865117 days. This newly obtained ephemeris is given in Equation. 2. The number in parentheses beside each coefficient is the error associated with the last cited digit of each coefficient.

There has been considerable discussion in the literature about

$$\mathrm{HJD_{max}} = 2,430,671.1026(3) + 0.134865124(2) \cdot \mathrm{E} \qquad (2)$$

whether or not XX Cyg underwent an abrupt period change in 1942 while exhibiting a constant period prior to and following this, or whether its period has been continuously increasing with no abrupt change. In the first case, the $O - C$ diagram would be best fit by two first-order polynomials, while in the second case, it would be best fit by a single second-order polynomial. To determine the correct fit, Blake et al. (2003) and Conidis et al. (2011) conducted a statistical test of both fits, and concluded that the $O - C$ diagram is best represented by a single second-order polynomial.

More recently, Yang et al. (2012) constructed models of stellar evolution that track stars from their birth to their evolution off the main sequence. Such models predict the rate of change of the period of post-main-sequence stars such as XX Cyg, and attribute them to evolutionary changes in the stellar parameters T_{eff} (effective temperature), M_{bol} (bolometric magnitude), and M (stellar mass). Additionally, their analysis included a calculation of the rate of change of period, allowing for a comparison between observed and theoretical rates. This comparison showed that the observed and theoretical rates of change were consistent and thus stellar evolution is likely the main cause for the observed rate of change of period. This confirms that XX Cyg is best described by a continuously increasing period, with no discontinuous jump.

Thus, we utilize a second-order polynomial to describe the $O - C$ diagram. This fit to all 513 data points is given in Equation 3, and the $O - C$ diagram, along with the second-order polynomial fit, is shown in the Figure 5.

$$O - C = (2.79 \pm 0.08) \times 10^{-13} \cdot \mathrm{E}^2$$
$$-(5.01 \pm .18) \times 10^{-8} \cdot \mathrm{E} - (5.22 \pm 1.4) \times 10^{-5} \qquad (3)$$

The standard deviation among the residuals of the $O - C$ diagram is 0.0011. For comparison, the standard deviation of the residuals reported by Conidis et al. (2011) is 0.00133, with their analysis of 238 times of maximum light. The error is essentially unchanged despite a more than doubling of the number of data points.

For completeness, the $O - C$ diagram from the 723 TESS data points is shown in Figure 6. The scatter in the data is comparable to that seen in Figure 5 and given the relatively brief span of time displayed, no trend in the $O - C$ data is evident.

Given a continuously increasing period, the quadratic co-efficient, ($C_2 = 2.79 \times 10^{-13}$) from Equation. 3 can be related to the rate of change of period through Equation 4 (Breger & Pamyatnykh (1998)).

$$C_2 = 0.5 \times P \times \frac{dP}{dt} \qquad (4)$$

Using Equation 4, it was determined that the rate of change of period is $(1/P)(dP/dt) = (1.12 \pm 0.03) \times 10^{-8} \mathrm{yr}^{-1}$, which is essentially identical with that determined by Yang et al. (2012) of $(1/P)(dP/dt) = 1.13(2) \times 10^{-8} \mathrm{yr}^{-1}$. This increasing period change is in excellent agreement with the stellar models and updated analysis from Yang et al. (2012).

4. Pulsation Analysis of Tess Data

To analyze the pulsation characteristics in the TESS data, a periodogram is constructed using Equation 5, where *P (x(t))* is the periodogram of the time series *x(t)* in frequency space, and *F F T (x(t))* is the Fast Fourier Transform of the time-series. The amplitude of the periodogram at a given frequency is the power of that frequency in the original time-series function. To identify peak frequencies, Scipy '.signal.aggrelmax' was used with constraints to avoid the influence of noise by broadening the spread of points considered in identifying a local maximum. The top 18 frequencies are tabulated in Table 3.

$$P(x(t)) = |\mathrm{FFT}(x(t))|^2 \qquad (5)$$

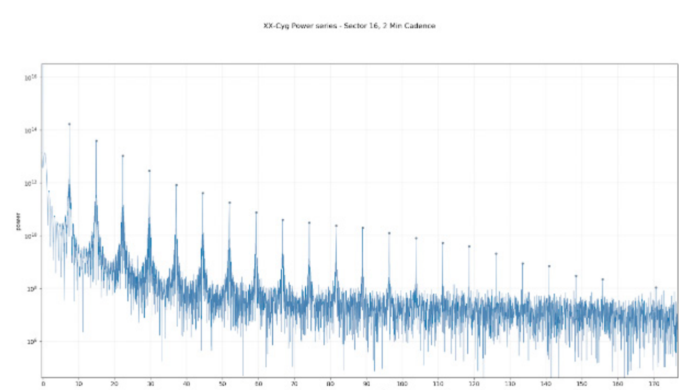

Figure 7 — The Power Spectral Energy Periodogram for XX Cyg sector-16. Identified distinct peaks are plotted with open circle markers.

Fourier analysis was performed on the entire TESS data of 723 times of maximum light. Figure 7 displays the Fourier spectrum produced by the DORADO analysis. Table 3 identifies 18 frequencies and associated powers extracted during this analysis. The results show a fundamental frequency of 7.408(8) cycles day^{-1}, as well as 17 harmonics that exhibit power down to 10^{-5} of the fundamental frequency power. These results are in agreement with those presented in Yang et al. (2012), and indicate that XX Cyg is a radial mode pulsating star, with no evidence for pulsation in non-radial modes.

5. Conclusion

This paper has presented 135 newly determined times of maximum light, using data collected between 2010 and 2019 at the Allan I. Carswell Observatory in Toronto, Ontario, Canada. In addition, 723 times of maximum light are reported from TESS data. Using 513 times of maximum light, we present an updated ephemeris (Equation 2) and $O - C$ diagram (Figure 5) that assumes a continuously (linearly) increasing period with time. An updated period of 0.134865124 (2) days, which has a rate of change of $(1/P)(dP/dt) = (1.12 \pm 0.03) \times 10^{-8}\text{yr}^{-1}$ results.

Fourier analysis performed on data from TESS shows the top 18 frequencies that XX Cyg pulsates in, with a fundamental frequency of 7.408(8) cycles day^{-1}, and 17 harmonics. No secondary frequency is detected.

The long-term monitoring of variable stars such as XX Cyg is well suited to a university observatory. The time available for such observations, as well as the large number of interested undergraduate students interested in experiencing research, allows near continuous collection of data and analysis of the differential photometry. Many bright stars are available for such research projects in bright, light-polluted environments and other institutions are encouraged to engage their students in such observing projects. ✶

6. Acknowledgements

We wish to express our appreciation to the Department of Physics and Astronomy and the Faculty of Science at York University for the funding and support of this re-search. Specifically, we appreciate the many conversations with Michael De Robertis during the preparation of this paper. We want to thank the Allan I. Carswell Observatory staff for their help in collecting and reducing the data for XX Cyg: Rahila Amlany, Richard Bloch, Simon Chang, Matthew Cutone, Dante Dardaine, Amanda De Souza, Keivn Delany, Kim Deosamy, Isaac DeSouza, Swati Dhakal, Natalee Galati, Francesco J. De Chellis, Tails Manashirov, Katelynn Massicotte, Jen Mehrnoush Zomederis, Colin Mundy, Sophia Nasr, Rafia Naz, Michael Palermo, Will Pauls, Aggrey Sambay, Abteen Sanaee, Arian Seyedi, Gaganpreet Sidhu, Andrew Suh, Atifa Syed, Ashley Tedesco, Quinton Weyrich, and Elaheh Yaraghi-Esfahani.

We would also like to thank the TESS team for their dedication and making their data so accessible. This paper includes data collected with the TESS mission, obtained from the MAST data archive at the Space Telescope Science Institute (STScI). Funding for the TESS mission is provided by the NASA Explorer Program. STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5–26555.

7. References

Acerbi, F., Barani, C.. 1996. in Proc. 28th Conf. Variable Star Research, ed. M. Zejda (Brno: Obs. Planetarium Brno), pp. 18–22
Agerer, F., Hubscher, J. 2000, Information Bulletin on Variable Stars, 4912:1
Biro, I. B., et al, 2006, IBVS, 5684:1
Blake, R. M., Delaney, P. A., Khosravani, H., Tome, J., Lightman, M. 2003, Publications of the Astronomical Society of the Pacific, 115:212
Breger, M., Pamyatnykh, A. A. 1998, A&A, 332:958
Clement, C. M., Muzzin, A., Dufton, Q., Ponnampalam, T., Wang, J., et al. 2001, The Astronomical Journal, 122:2587
Conidis, G. J., Sadavoy, S. I., Maxwell, A. J., Delaney, P. A,. Manzer, L. H. 2011, Publications of the Astronomical Society of the Pacific, 123:26
Derekas, A., Kiss, L. L., Bedding, T. R., Ashley, M. C. B.,
Cs´ak, B., et al. 2009, Monthly Notices of the Royal Astronomical Society, 394:995
Detre, L. 1936, Astronomische Nachrichten. 258:329
Fiacconi, D., Tinelli, L. 2009, Open European Journal on Variable Stars, 114:1
Fitch, W. S., Wisniewski, W. Z., Johnson, H. L. 1966, Communications of the Lunar and Planetary Laboratory, 5:71
Gaia Collaboration, 2018, A&A, 616, A1
Hog, E., Petersen, J. O. 1997, Astronomy and Astrophysics, 323:827
Hubscher, J. 2005a, Information Bulletin on Variable Stars, 5657:1
Hubscher, J. 2005b, Information Bulletin on Variable Stars, 5643:1
Hubscher, J., Paschke, A., Walter, F. 2006, Information Bulletin on Variable Stars, 5731:1
Hubscher, J. 2007, Information Bulletin on Variable Stars, 5802:1
Hubscher, J., Steinbach, H-M., Walter, F. 2009, Information Bulletin on Variable Stars, 5889:1
Hubscher, J. et al. 2011a, Information Bulletin on Variable Stars. 5959:1
Hubscher, J. 2011b, Information Bulletin on Variable Stars. 5984:1
Hubscher, J., Lehmann, P. B. 2015a, Information Bulletin on Variable Stars, 6149:1
Hubscher, J. 2015b, Information Bulletin on Variable Stars, 6152:1
Joner, M, D. 1982, Publications of the Astronomical Society of the Pacific, 94:289
Jordan, F. C. 1929, Publ. Allegheny Obs. 7:1 Kharchenko, N, V., Scholz, R-D., Piskunov, A. E., Roeser, S., Schilbach, E. 2007, VizieR Online Data Catalog, CRVAD-2 Kim, C., Joner, M. D. 1994, Astrophysics and Space Science, 218:113
Kiss, L. L., Derekas, A. 2000, Information Bulletin on Variable Stars, 4950:1
Kleissen, E. 1938, Astronomische Nachrichten, 267:137
Klingenberg, G., Dvorak, S. W., Robertson, C. W. 2006, Information Bulletin on Variable Stars, 5701:1
McNamara, D. H., Feltz, K. A. Jr. 1980, Publications of the Astronomical Society of the Pacific, 92:195
Parkhurst, J. A., Jordan, F. C. 1906, The Astrophysical Journal, 23:79
Pigulski, A. 2004, Communications in Asteroseismology, 145:74
Ricker, G. R, Winn, J. N., Vanderspek, R., Latham, D. W.,

Source (Col. 1)	Data Points (Col. 2)	Source (Col. 3)	Data Points (Col. 4)	Source (Col. 5)	Data Points (Col. 6)
Acerbi & Barani (1996)	4	Agerer (2000)	4	Biro (2006)	1
Derekas (2009)	3	Detre (1936)	7	Fiacconi (2009)	12
Fitch (1996)	1	Hubscher (2005a)	6	Hubscher (2005b)	3
Hubscher (2006)	14	Hubscher (2007)	1	Hubscher (2009)	2
Hubscher (2011a)	2	Hubscher (2011b)	6	Hubscher (2015a)	2
Hubscher (2015b)	1	Joner (1982)	6	Jordan (1929)	4
Kim (1994)	7	Kiss (2000)	5	Kleissen (1938)	2
Klingenberg (2006)	8	McNamara (1980)	9	Parkhurst (1906)	3
Wils (2009)	6	Rodriguez (1993)	7	Romano (1982)	1
Sadun (1986)	3	Samolyk (2010)	16	Samolyk (2011)	6
Samolyk (2012)	1	Samolyk (2013)	2	Samolyk (2014)	2
Samolyk (2016)	9	Samolyk (2017)	9	Samolyk (2018)	5
Samolyk (2019)	5	Shapley (1915)	2	Szeidel (1981)	23
Yang, Fu, & Zha (2012)	46	Current Publication	135	Blake (2003)	20
Conidis (2011)	64	Zhou (2002)	18	TESS	723

Appendix 1

Table 4 — (left) Summary of times of maximum light obtained from the literature with the Source (Col. 1, Col. 3, and Col. 5) and the Number of Data Points used in the current analysis (Col. 2, Col. 4, and Col. 6).

Table 5 — (below) Newly published times of maximum light determined from data obtained using the 0.6-m telescope, with the Maxima in HJD (Col. 1, Col. 4, and Col. 7), the Integer Cycle Number, E, using Equation 2 (Col. 2, Col. 5, and COl. 8), and the O – C value (Col. 3, Col. 6, and Col. 9).

Bakos, G. A., et al. 2015, Journal of Astronomical Telescopes, Instruments, and Systems, 1:014003

Rodriguez, E., Lopez-Gonzalez, M. J. 2000, VizieR Online Data Catalog, 335:

Rodriguez, E., Rolland, A., Lopez de Coca, P. 1993, Astronomy and Astrophysics Supplement Series, 100:571

Romano, G., Perissinotto, M.. 1982, Information Bulletin on Variable Stars, 2161:1

Sadun, A. C., Ressler, M. 1986, Publications of the Astronomical Society of the Pacific, 98:504

Samolyk, G. 2010, Journal of the American Association of Variable Star Observers (JAAVSO), 38:12

Samolyk, G. 2011, Journal of the American Association of Variable Star Observers (JAAVSO), 39:23

Samolyk, G. 2012, Journal of the American Association of Variable Star Observers (JAAVSO). 40:923

Samolyk, G. 2013, Journal of the American Association of Variable Star Observers (JAAVSO), 41:85

Samolyk, G. 2014, Journal of the American Association of Variable Star Observers (JAAVSO), 42:124

Samolyk, G. 2016, Journal of the American Association of Variable Star Observers (JAAVSO), 44:66

Samolyk, G. 2017, Journal of the American Association of Variable Star Observers (JAAVSO), 45:1

Samolyk, G. 2018, Journal of the American Association of Variable Star Observers (JAAVSO), 46:70

Samolyk, G. 2019, Journal of the American Association of Variable Star Observers (JAAVSO), 47:1

Shapley, H., Shapley, M. B. 1915, The Astrophysical Journal, 42:148 Szeidl, B., Mahdy, H. A.. 1981, Commmunications of the Konkoly Observatory Hungary, 75:1

Wils, P., Kleidis, S., Hambsch, F-J., Vidal-Sainz, J., Vanleenhove, M., et al. 2009, Information Bulletin on Variable Stars, 5878:1

Yang, X. H., et al. 2012, AJ, 144:92

Zhou, A. Y., et al. 2002, Ap&SS, 281:699

Maxima (HJD) (Col. 1)	Cycle (E) (Col. 2)	$O-C$ (days) (Col. 3)	Maxima (HJD) (Col. 4)	Cycle (E) (Col. 5)	$O-C$ (days) (Col. 6)	Maxima (HJD) (Col. 7)	Cycle (E) (Col. 8)	$O-C$ (days) (Col. 9)
2,454,313.76702	175,306	-0.00092	2,456,190.55213	189,222	0.00113	2,457,605.69222	199,715	0.00148
2,454,726.58831	178,367	-0.00177	2,456,190.68678	189,223	0.00092	2,457,605.82666	199,716	0.00106
2,454,728.61155	178,382	-0.00151	2,456,197.69959	189,275	0.00074	2,457,624.57051	199,855	-0.00135
2,454,731.58011	178,404	0.00002	2,456,198.64452	189,282	0.00161	2,457,624.70672	199,856	0.00000
2,455,058.63065	180,829	0.00263	2,456,205.65529	189,334	-0.00060	2,457,632.66397	199,915	0.00021
2,455,059.70675	180,837	-0.00019	2,456,210.51052	189,370	-0.00052	2,457,632.79915	199,916	0.00052
2,455,075.62244	180,955	0.00142	2,456,210.65031	189,371	0.00441	2,457,646.55606	200,018	0.00119
2,455,083.71294	181,015	0.00001	2,456,508.83253	191,582	-0.00016	2,457,646.69087	200,019	0.00113
2,455,092.61497	181,081	0.00094	2,456,526.63539	191,714	0.00050	2,457,647.63692	200,026	0.00313
2,455,092.74845	181,082	-0.00044	2,456,526.77035	191,715	0.00060	2,457,647.77237	200,027	0.00371
2,455,098.68191	181,126	-0.00105	2,456,527.71300	191,722	-0.00081	2,457,653.56850	200,070	0.00064
2,455,419.79699	183,507	0.00017	2,456,528.65839	191,729	0.00053	2,457,653.70309	200,071	0.00037
2,455,425.73110	183,551	0.00022	2,456,528.79327	191,730	0.00054	2,457,658.69426	200,108	0.00153
2,455,427.61826	183,565	-0.00073	2,456,539.58430	191,810	0.00236	2,457,666.64967	200,167	-0.00011
2,455,427.75344	183,566	-0.00042	2,456,539.71772	191,811	0.00092	2,457,667.59481	200,174	0.00098
2,455,438.67786	183,647	-0.00007	2,456,546.59531	191,862	0.00039	2,457,668.67356	200,182	0.00081
2,455,440.56769	183,661	0.00164	2,456,546.73095	191,863	0.00116	2,457,693.48905	200,366	0.00111
2,455,440.70322	183,662	0.00231	2,456,552.66400	191,907	0.00015	2,458,005.56669	202,680	0.00086
2,455,453.64840	183,758	0.00044	2,456,553.60798	191,914	0.00007	2,458,005.70177	202,681	0.00107
2,455,460.65976	183,810	-0.00119	2,456,554.68867	191,922	0.00184	2,458,009.61287	202,710	0.00109
2,455,462.68463	183,825	0.00070	2,456,555.63072	191,929	-0.00017	2,458,009.74784	202,711	0.00119
2,455,482.50909	183,972	-0.00001	2,456,560.62101	191,966	0.00011	2,458,017.56952	202,769	0.00069
2,455,775.70745	186,146	0.00157	2,456,561.56526	191,973	0.00031	2,458,017.70380	202,770	0.00011
2,455,775.84291	186,147	0.00217	2,456,561.69986	191,974	0.00004	2,458,018.51383	202,776	0.00095
2,455,778.67666	186,168	0.00375	2,456,562.64447	191,981	0.00060	2,458,018.64826	202,777	0.00051
2,455,778.81001	186,169	0.00223	2,456,563.58863	191,988	0.00070	2,458,023.63933	202,814	0.00157
2,455,785.69075	186,220	0.00485	2,456,563.72377	191,989	0.00098	2,458,025.52669	202,828	0.00082
2,455,796.61247	186,301	0.00250	2,456,566.68990	192,011	0.00007	2,458,031.73220	202,874	0.00253
2,455,799.71261	186,324	0.00074	2,456,567.63466	192,018	0.00078	2,458,044.54202	202,969	0.00017
2,455,839.63490	186,620	0.00295	2,456,568.57885	192,025	0.00091	2,458,044.67753	202,970	0.00081
2,455,840.57715	186,627	0.00115	2,456,574.51140	192,069	-0.00060	2,458,045.62302	202,977	0.00225
2,455,841.65616	186,635	0.00124	2,456,574.64771	192,070	0.00084	2,458,719.67891	207,975	0.00225
2,455,859.59212	186,768	0.00014	2,456,575.59085	192,077	-0.00008	2,458,719.81312	207,976	0.00159
2,456,154.67898	188,956	0.00211	2,456,917.61012	194,613	0.00124	2,458,720.62191	207,982	0.00119
2,456,154.81442	188,957	0.00268	2,456,918.55383	194,620	0.00089	2,458,720.75645	207,983	0.00087
2,456,155.62101	188,963	0.00008	2,456,920.57781	194,635	0.00190	2,458,739.63885	208,123	0.00215
2,456,157.64461	188,978	0.00070	2,456,925.56553	194,672	-0.00039	2,458,741.66230	208,138	0.00262
2,456,163.57834	189,022	0.00037	2,456,927.59005	194,687	0.00115	2,458,744.62937	208,160	0.00266
2,456,163.71360	189,023	0.00076	2,456,976.54610	195,050	0.00116	2,458,745.57190	208,167	0.00114
2,456,168.70294	189,060	0.00009	2,457,280.66720	197,305	0.00141	2,458,746.65124	208,175	0.00155
2,456,170.59140	189,074	0.00044	2,457,281.61017	197,312	0.00032	2,458,746.78523	208,176	0.00068
2,456,182.59480	189,163	0.00084	2,457,283.63325	197,327	0.00043	2,458,751.63983	208,212	0.00013
2,456,182.72873	189,164	-0.00009	2,457,604.61553	199,707	0.00371	2,458,755.55329	208,241	0.00251
2,456,183.67558	189,171	0.00270	2,457,604.74974	199,708	0.00306	2,458,755.68652	208,242	0.00087
2,456,184.61666	189,178	-0.00027	2,457,604.88412	199,709	0.00257	2,458,761.62119	208,286	0.00148

AAVSO

Your Monthly Guide to Variable Stars

by Jim Fox, AAVSO

December – Algol, "The Demon Star"

Many, if not most, of the stars we see change brightness over various periods of time for various reasons. Sometimes a star can dim, brighten, and dim again in less than a second! Other stars can take years to complete a cycle of brightness variation.

These stars are called "variable stars." One variable that YOU can see this month is Algol, or Beta Persei. Known to Arab astronomers in antiquity, they gave it the name "al Goul," meaning "the Demon" or "the Evil One," since it seemed to wink at them from time to time. The English astronomer John Goodricke is credited with determining that Algol has a definite period, changing from magnitude 2.1 to magnitude 3.4.

In 1881, Edward Pickering presented convincing evidence that Algol is an eclipsing binary: two stars of differing brightness that orbit one another in such a way that their orbit lies nearly edge on to our line of sight. In this manner, the dimmer star will pass in front of the brighter star causing the pair to appear dimmer. Such stars are called "eclipsing variables."

The two stars are separated by 57 million miles, about the same distance as Venus lies from our Sun. But while Venus takes 225 days to orbit the Sun, the stars of the Algol system orbit one another in about 69 hours, the period of variability. The duration of the eclipse lasts about 8 hours. That means you can watch the entire eclipse within a single night under favourable timing!

More commonly, you will be able to see either the dimming or the brightening within a convenient time. Gamma Andromedae, magnitude 2.1, and Alpha Trianguli, magnitude 3.4, are conveniently near for comparison. You can also compare Algol to Alpha Persei, magnitude 1.8, and Delta Persei, magnitude 3.0, as you watch it dim or brighten.

Predicted times for minimum light can be found at www.aavso.org/legacy-ebs or within "The Sky This Month" section of most issues of *Sky & Telescope* magazine. Since the dimming or brightening takes only 4 hours, you should check the brightness of Algol every 20 to 30 minutes to follow the change. You should pick up the change after only a few observations.

January – Pleione in the Pleiades

[Editor's note: This contribution comes from the AAVSO's selection of variables from January 2021]

Many, if not most, of the stars we see change brightness over various periods of time for various reasons. Sometimes a star can dim, brighten, and dim again in less than a second! Other stars can take years to complete a cycle of brightness variation.

These stars are called "variable stars." One variable star that YOU can see this month is Pleione, a member of the bright Pleiades star cluster in the constellation Taurus.

While our Sun rotates once in a little over 25 days, Pleione rotates once in just under 12 hours. This is so fast that centrifugal force can push material from its outer atmosphere into a disk around the star. Interactions between the star and the disk can cause minor magnitude changes, ranging between magnitude 4.8 and 5.5. With a little practice, you should be able to detect changes of a tenth of a magnitude.

You can find Pleione next to the brighter star Atlas in the handle of the small cup formed by the brightest stars in the Pleiades cluster. Binoculars may make it easier to pick out the individual stars within the cluster. Check Pleione from night to night and compare it to other stars in the cluster, especially Taygeta (magnitude 4.3) and Celaeno (magnitude 5.5) at the other end of the "cup."

For more than 100 years, the American Association of Variable Star Observers (AAVSO) has encouraged the observation and study of variable stars, maintaining databases of all submitted observations. Observing techniques include both visual and photometric (CCD/CMOS, DSLR and photoelectric) and now even spectroscopic. For more information on the AAVSO and how you can contribute to astronomical science through variable stars, visit their website at www.aavso.org ✶

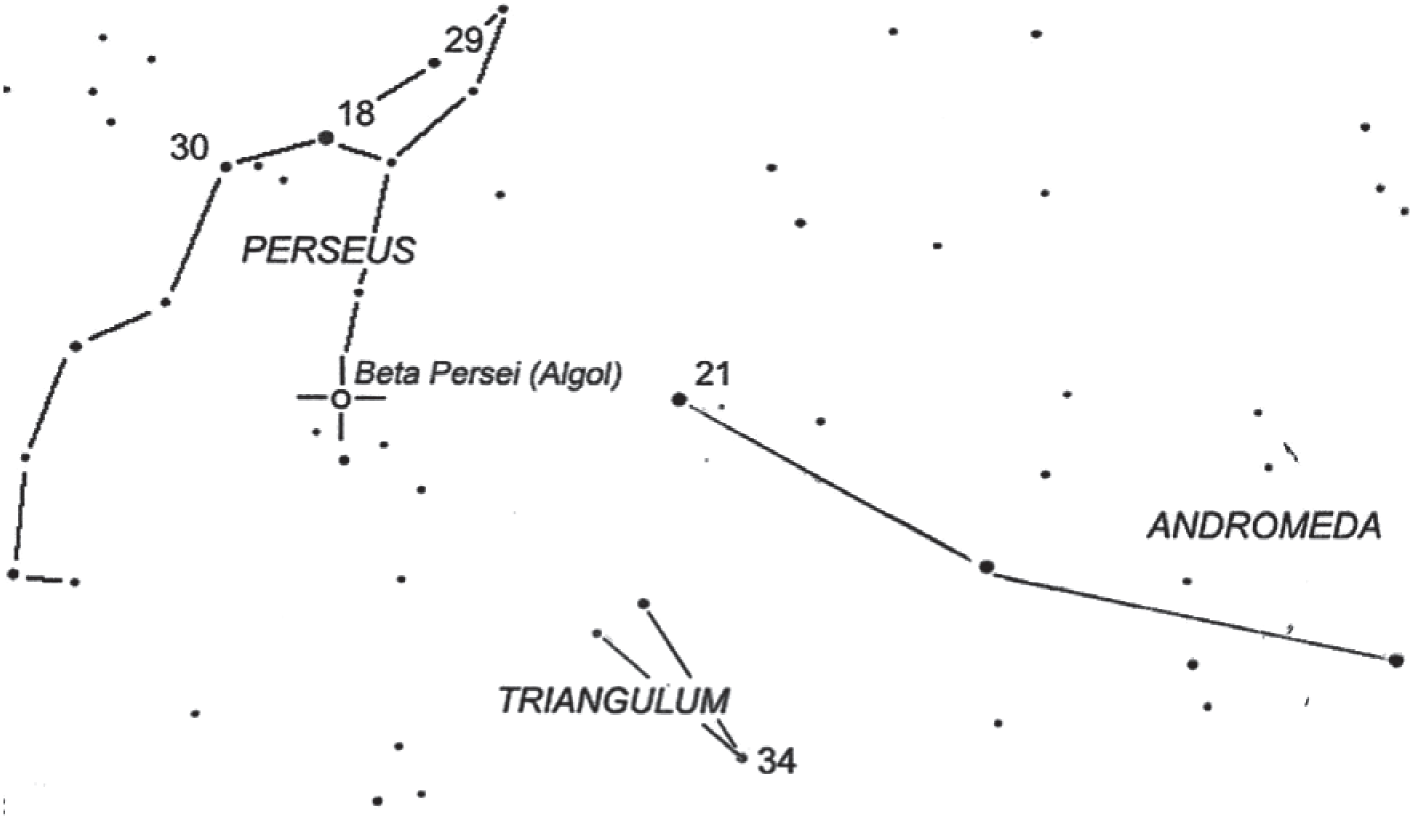

Figure 1 — This finder chart for Algol will help you estimate its brightness. The image is not inverted so it is suitable for binoculars. Algol is the highlighted circle and magnitudes are in tenths with the decimal point omitted so as not to be confused with a star – so, 21 = 2.1. Chart is courtesy of AAVSO.

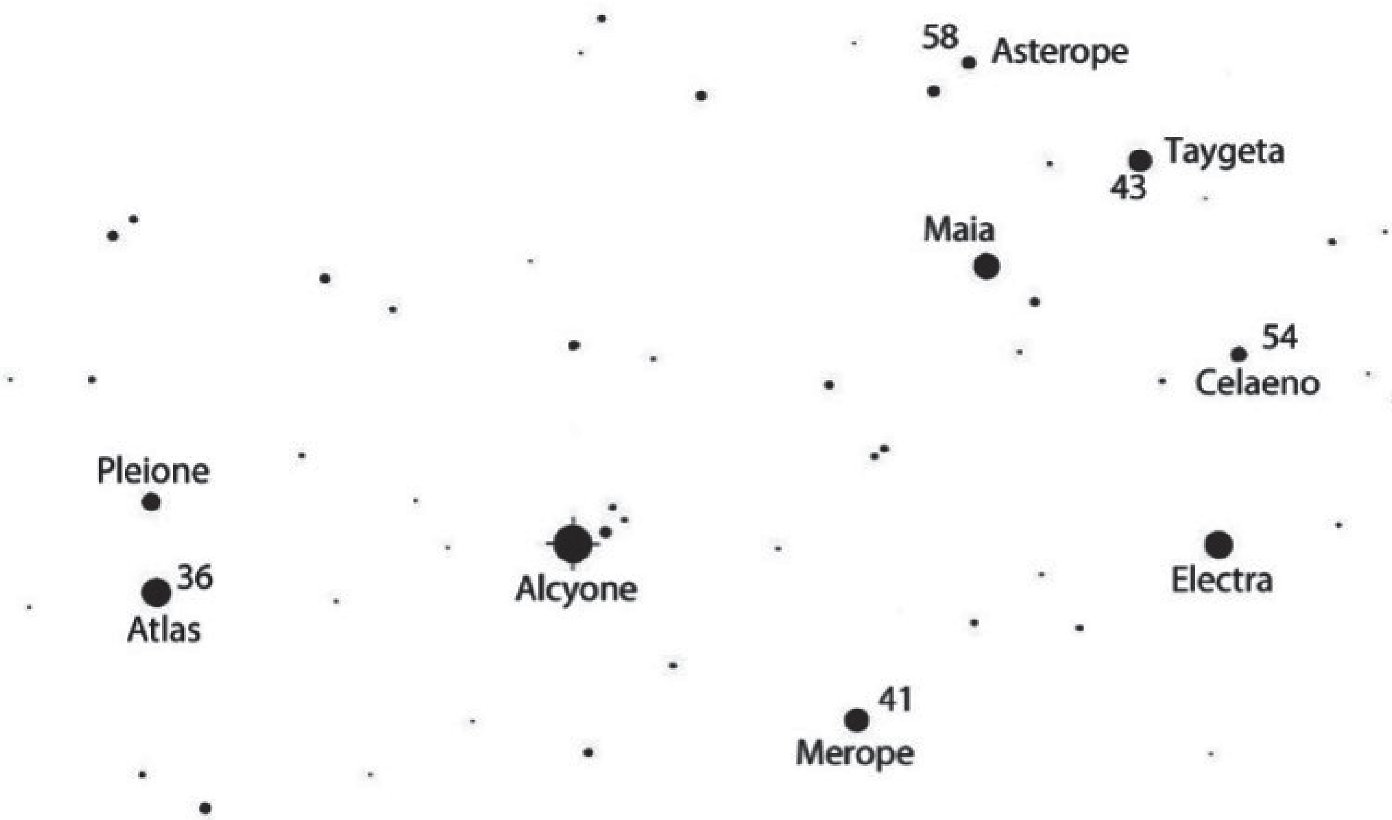

Figure 2 — This finder chart for Pleione will help you estimate its brightness. The image is not inverted so it is suitable for binoculars. Magnitudes are in tenths with the decimal point omitted so as not to be confused with a star – so, 40 = 4.0.

Skyward

Rebirth of an Observatory and Remembering a Dear Friend

by David Levy, Kingston & Montréal Centres

"How would you like to go to prison?" was one of the first things that Frank Lopez asked me. My stunned expression prompted Frank to clarify: "The Federal prison off Wilmot Road has an astronomy club."

That was enough: we enjoyed two wonderful evenings down there, and even showed Orion to the group using one of my favourite telescopes.

I dealt with Frank once again in the last few months, as our Jarnac Observatory's Shaar house, the major observatory building in my backyard, threatened to collapse earlier this year. The Shaar name is from the Hebrew word for "gate" or "opening," and I use the name because the structure resembles a miniature version of our Shaar Hashomayim synagogue in Montréal. The observatory is as much a temple for me as the Shaar was.

Frank brings a lifetime of experience to the observatories he builds and repairs. He came up with a plan that would restore my building with a brand-new sliding roof. Working occasionally with assistants—but mostly alone—the construction took several months, virtually all last winter and spring. (Actually, my sliding roof is the entire top half of the building.) During this time, I learned a lot about Frank's work ethic. He does not rush things. He takes his time and works steadily for three days a week with construction and maintenance. The rest of his time he manages his Stellar Vision astronomy store in Tucson. I learned that he built most of the observatory complex for Dr. Tim Hunter's Grasslands observatory southeast of Tucson near Sonoita, and a large observatory structure for David Rossetter's 25-inch Dobsonian northeast of the city centre.

Throughout most of southern Arizona, Frank's Stellar Vision observatory business is really the best game in town. He knows what he is doing and brings his decades of experience to each project. Frank builds observatories with energy, strength, and even humour (https://stellarvisiontucson.com).

These structures do a lot more than house telescopes over many years. They store the memories of 1,001 nights under the stars. They offer stories of terrible nights when a telescope fell off its mount; of only slightly fewer frustrating nights when cameras failed to work. They protect their telescopes from the winds and the rains that Arizona occasionally goes through.

Figure 1 — The photo shows the new building, with the Shoemaker-Levy dome off to the far left. Credit: Wendee Wallach-Levy

But mostly they protect memories of precious nights under the stars. Finally, I like to imagine that long after I have closed up and gone to bed, the telescopes talk to one another about what they have seen, and what they have yet to see.

One recent evening after a big monsoon storm after the Shaar was finally completed, I went out and discovered that the telescopes inside were safe and dry. On a drier night I went out, opened its big roof, and stared at the stars. I felt as though I was starting my love of the night sky all over again.

Fond Memories of Carolyn Shoemaker

One clear evening during the summer of 2019, I was using Pegasus, one of my childhood friend Carl's telescopes, at our annual Adirondack Astronomy Retreat. When my cell phone began to ring, I picked it up with some surprise. At the other end of the line was Carolyn Shoemaker. I was thrilled to hear from her, as it had been some time since our last contact. Carolyn was doing well, except for a mild loss of hearing. She had called to say that since her daughter and son-in-law had moved to New Mexico, she would be living at the Peaks, a comfortable assisted living facility in Flagstaff. My colleague Brent Archinal gave me her cell phone number. I was able to speak with her again a few months later. I wanted to find a way to increase the frequency of our conversations. "You speak with your brother Richard every Monday," Wendee commented, and suggested, "Why not call Carolyn every Monday as well?

For the next 18 months that's what I did. Carolyn would pick up the phone and announce, "It is David. It must be Monday!" Wendee would often join the discussion as well. But when I called on Monday, August 9, no one answered. After repeated tries, her daughter Linda called to say that Carolyn had had a minor fall and was in the hospital. On Thursday evening, August 12, she went into respiratory arrest. Carolyn died the next morning at 10:40 a.m. Arizona time.

With her husband Gene and the five-year comet and asteroid program we shared, Carolyn was responsible for a very rich period in my life. In fact, virtually every article one reads about the Shoemakers will agree that the discovery and impacts of Comet Shoemaker-Levy 9 were the most significant part of our professional lives.

Carolyn began her observing project a few years after her husband Gene was disqualified as a potential astronaut because of Addison's disease. He decided to go at the problem of impacts, not from studying craters as he walked about on the Moon, but from the opposite direction of the comets and asteroids that collide with the Moon, and with the Earth. Carolyn quickly learned to become proficient at using the stereomicroscope. She would place two films into the microscope; they were identical except that the second plate would be about 45 minutes later than the first. The films were almost always identical, except that when an asteroid was moving slowly, it would appear to float above the starry background. Carolyn discovered 377 asteroids this way, each one charted until its orbit round the Sun could be determined accurately. When one included the asteroids for which orbits have not yet been determined, that number rose significantly, according to Carolyn, to about 800.

In 1983, Carolyn discovered the first of her 32 comets. When their colleague Henry Holt joined the following year, the number of new comets rose rapidly. It was only a year or two after that when she surpassed the number of comets another famous astronomer, Caroline Herschel, discovered, and *Sky & Telescope* published a news note about "Carolyn passing Caroline." I joined the team in 1989. In a sense, passing Herschel's record might have been Carolyn's golden moment, but it wasn't. That came later, on a cloudy and dull day on 1993 March 25. Two nights earlier I had taken two exposures that she was scanning. Suddenly looking up, she announced "I don't know what I have, but it looks like a squashed comet." That was the discovery moment of Comet Shoemaker-Levy 9. Sixteen months later, when the 21 pieces of this fragmented

Figure 2 — This photograph was taken in 2004, and shows Carolyn, Wendee, and the author during a visit to Kitt Peak. The trio are standing next to the sign that has been there since 1958.

coment collided with Jupiter, we got to meet President Clinton and chat amiably with Vice President Gore and share the world's excitement over the first collision of a comet and a planet ever witnessed by humans. It was a satisfying peak to all our careers.

After Gene died in a car accident in Australia, Carolyn continued observing with Wendee and me for several years. One evening she confided that sometimes she wished she had died with Gene. But she did not, and the world was able to enjoy her company for more than 24 more years. The weekly telephone calls began much later. I shall miss the deep friendship I enjoyed with Carolyn Shoemaker, the woman whose energy, intelligence, and terrific sense of humour brightened our lives and made the night sky a happier place. ✶

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.*

Pen & Pixel

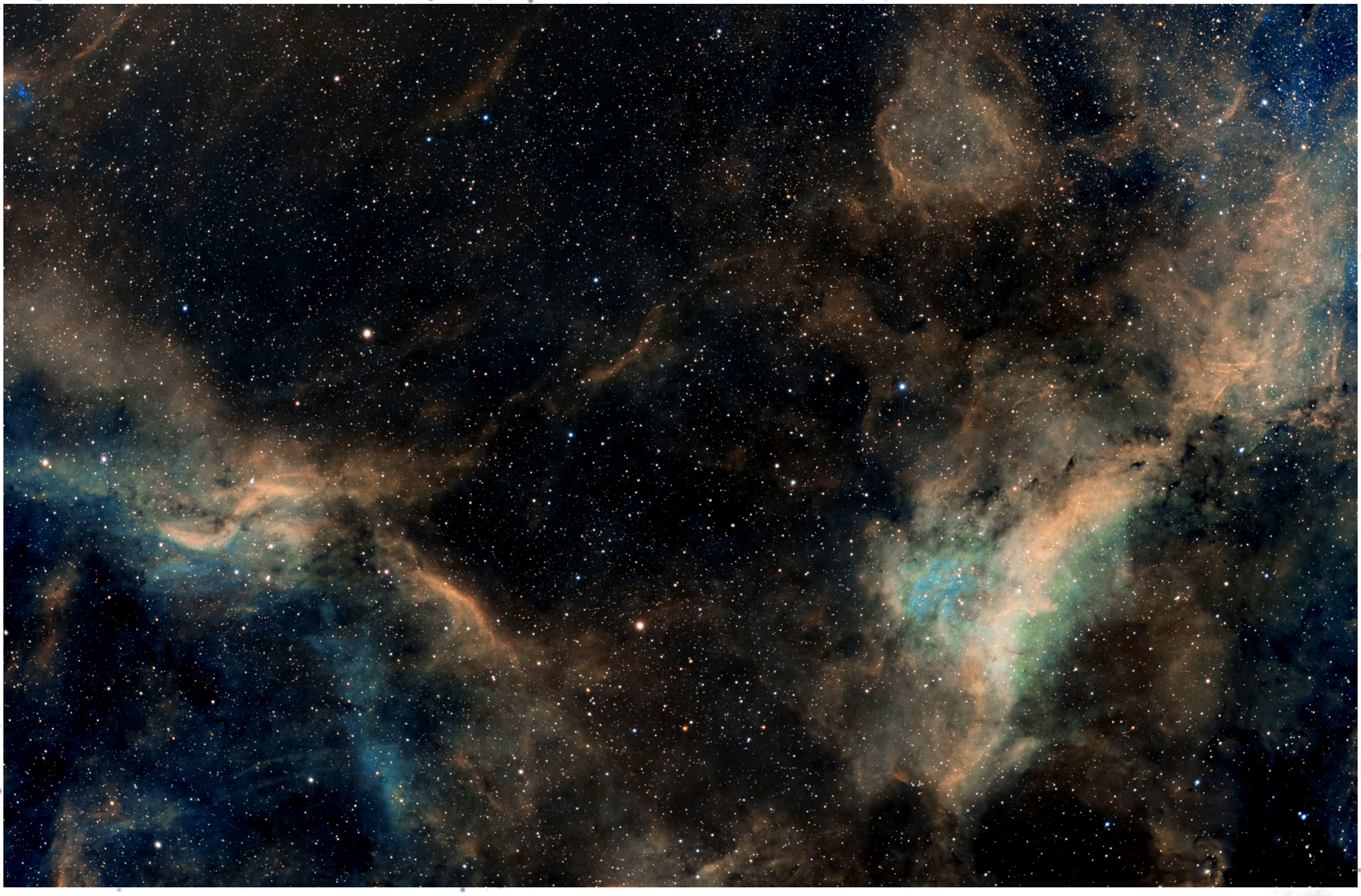

Figure 1 — Dave Dev imaged the Propeller Nebula (DWB 111) in Cygnus from River Place Park near Ayton, Ontario, and the Greater Toronto Area. He used a Sharpstar 94-mm refractor with an ASI 2600 mono and used about four hours on each filter: Hα, O3, and S2. Final image was processed using PixInsight.

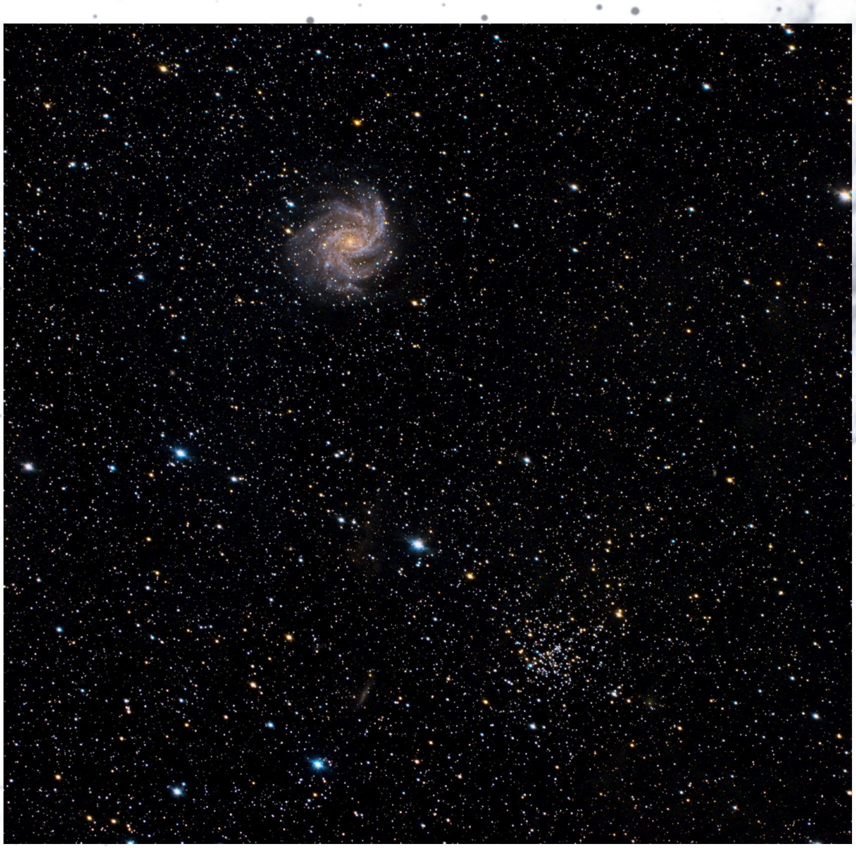

Figure 2 — From her backyard in Ottawa, Andrea Girone captured the Fireworks Galaxy (NGC 6946) and its neighbouring star cluster NGC 6939, located in Cepheus. She used a Celestron 11" SCT fitted with a Hyperstar reducer with a focal length of 540 mm at f/1.9 on a CGEM mount with an ASI533MCPro Cooled CMOS camera. She used 40 x 180 s lights and calibrated and processed the final image in PixInsight.

Figure 3 — Ronald Brecher imaged the Triangulum Galaxy (M33) from his SkyShed in Guelph. Acquisition, focusing, and control of his Paramount MX mount was done with N.I.N.A., TheSkyX and PHD2. He used an Optec DirectSync motor and controller for focusing, while the equipment control was done with PrimaLuce Labs Eagle 4 Pro computer. All pre-processing and processing in PixInsight. For luminance, Ron used a Sky-Watcher Esprit 150 ƒ/7 refractor and QHY600M camera with Optolong UV/IR filter. For chrominance he used a Takahashi FSQ-106 ED IV ƒ/5 and QHY367C Pro one-shot colour camera with Optolong UV/IR filter. Total integration was 8 hr 45 minutes.

Figure 4 — The lovely Horsehead Nebula (or Barnard 33) in Orion was taken by Ed Mizzi from his backyard observatory—the Ed Dome—in Waterdown, Ontario. He estimates his sky to be about a Bortel 7, so imaged this in narrowband. He used a Sky-Watcher Esprit 100 APO telescope and a ZWO AS 183 mono camera, on an EQ6-R Pro mount. He imaged using Sequence Generator Pro and PHD. This image is the result of 87 x 4-minute subs (45 Hα; 27 OIII; and 15 SII). Final image was stacked and processed using PixInsight.

Astronomical Art & Artifact

J.F.W. DesBarres's Astronomical Instruments and the Castle Frederick Observatory: Fundamental Documents

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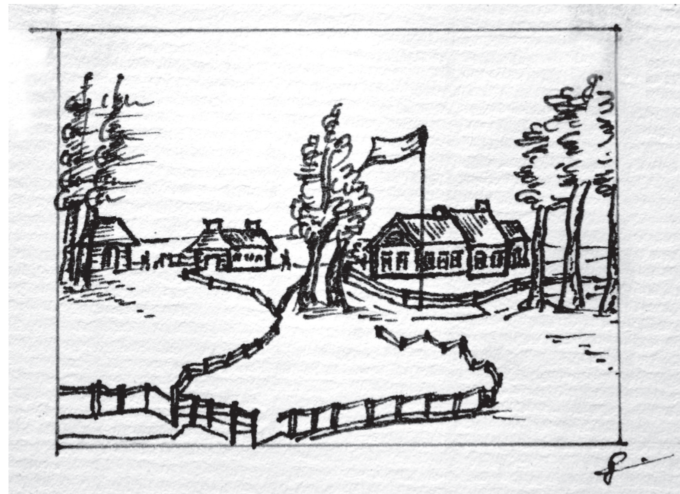
Abstract

J.F.W. DesBarres (1721–1824) was one of the most redoubtable and memorable figures in Canadian astronomy of the colonial period. At Castle Frederick he established an observatory that at the time was among the best equipped on these shores (*ca*. 1763–1774), and his crowning achievement in practical astronomy was *The Atlantic Neptune* (published 1774–1782). The key documents from among his surviving manuscripts describing his astronomical and associated instruments are offered here in a convenient edition, to aid those wishing to work with this material, or those curious about the equipment of a well-provisioned observatory in "Canada" of the mid-Georgian era, and the paper record from which that information is extracted. Two significant discoveries that came to light in the preparation of these documents are briefly discussed.

J.F.W. DesBarres, by way of an introduction

Joseph Frederick Wallet DesBarres (1721–1824) was of Swiss origin, although most of his extraordinarily long and active life was spent in the lands ruled by kings named George. Before arriving in England he received training in mathematics from some of the learned celebrities of that age, Jean (1667–1748) and Daniel Bernoulli (1700–1782) (one hopes not concurrently, for the Bernoullis were famous for not getting along famously; and, in the outrageously cantankerous elder Jean Bernoulli, DesBarres shared a teacher with Euler; Evans 1965, 1–3; Straub 1981, 37, 43; Fellmann & Fleckenstein 1981, 54, 55). After arriving on Albion's shores he enrolled as a cadet at the Royal Military Academy, Woolwich (Evans 1965, 3–6; Marshall 1976). Through training, natural ability, and doubtless application, he became a superb cartographer as he followed a career as a military engineer (i.e. surveyor; Hornsby 2011). He made the most of the opportunities presented to him as a practical astronomer in the aftermath of the Seven Years' War (1756–1763) to practically amass considerable land holdings (by some estimates it came to 70,000 acres in the Atlantic provinces; Evans 1965, 197–235; Bishop 1979, 429). Modern historians have remarked on the slowness of his rise



Figures 1a & 1b — The first figure shows Castle Frederick in the 1760s–1770s, and the second is how the site appears at present. 1a is a copy of a contemporary pen & ink sketch presumably by DesBarres himself. Both images reproduced courtesy of the Specula astronomica minima.

in military rank, but he did end up as a Lieutenant Colonel, and, more significantly, served as Lieutenant Governor of Cape Breton (1784–1787), and Lieutenant Governor of Prince Edward Island (1804–1812). His record in fulfilling high office could not be characterized as unequivocally successful, but he was not an unskilled administrator. His Achilles' heel was an abrasive manner, rather than any deficit in ability (he could be faulted more for the quality of the administration of his own estates, than for the administration of his offices). And, if one's fate during the dangerous period immediately following the relinquishment of office was some gauge of success, DesBarres did better than Warren Hastings.

The astronomical aspects of DesBarres's career are well covered by Roy Bishop (1977 & 2012), including the possible location and physical appearance of his observatory on the Castle Frederick estate (Figures 1a & 1b), his cartographical achievements are most attractively presented in Hornsby (2011), who deals with the making of *The Atlantic Neptune* (published 1774–1782), and his practical astronomy as a colonial practice

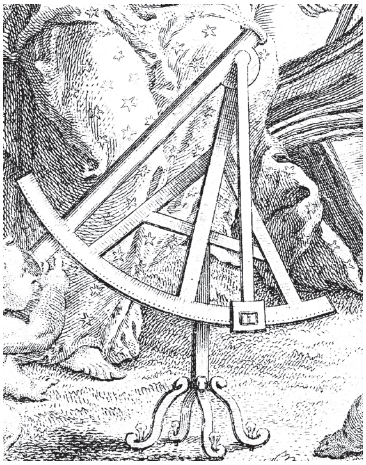


Figure 2 — A detail showing an astronomical quadrant from the frontispiece of Lacaille's Ephemerides des movemens célestes *(1763), a book that DesBarres is known to have owned (D1). Reproduced courtesy of the Specula astronomica minima.*

has recently been broached by Rosenfeld (2021), including evidence that a black Nova Scotian participated in his astronomical expeditions. All three authors have relied on the documents edited here for details of the equipment DesBarres had available to him.

DesBarres's instruments

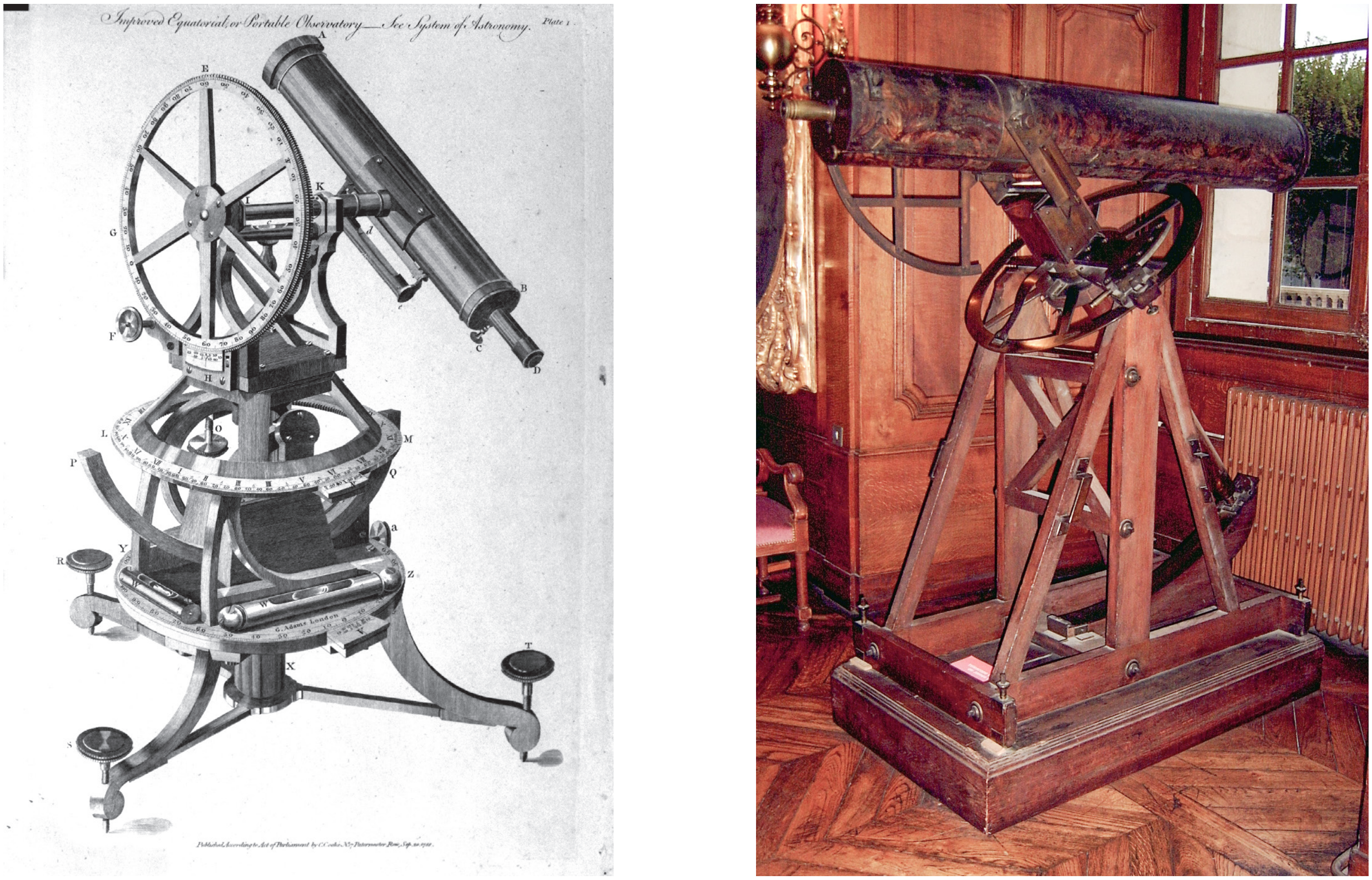
Note: in the lists in this section, the edited documents are referred to as "D1, D2, D3", etc., and the documents are found in the final section of this paper.

According to the documents transcribed below, DesBarres's astronomical equipment comprised:

1. A large astronomical quadrant (D1; D3; D4; D7; Figure 2)—*an observational instrument with an accurately engraved arc for measuring angles, in its transportable versions much used on astronomical expeditions in the 18th century (Turner 2002).*
2. A large reflecting telescope on an equatorial mount (D1; D3[1]; D4; Figure 3a and 3b).
3. An achromatic refracting telescope with a triplet objective, finder and stand (D2; D3[1]; D4; Figures 4a & 4b)—*an innovation of Peter Dollond from ca. 1765, which was said to offer superior resolution (Gee 2014, 155, 255).*
4. A Hadley's quadrant (D3; D4).
5. A sextant (D2; D6; D7).
6. A clock (D3[2]; Figure 5).
7. A pair of 17-inch celestial & terrestrial globes, with calottes (D1; D3; D6; D7).
8. A plain table (D1; D3; Figure 6)—*an instrument that enables angles and distances to be measured and plotted to scale on paper, from direct observations in the field (Wyld 1760, 25–33, 38–45).*
9. Observatory, & drawing offices (D8).

The associated equipment was listed as:

10. Library (see references at end for full bibliographic citations):
    i. J. Cassini, *Elemens d'astronomie…* (1740) (D1).
    ii. G. Juan, & A. de Ulloa, *Voyage historique de l'Amérique méridionale fait par ordre du roi d'Espagne...* (1752) (D1).
    iii. N.-L. de Lacaille, *Ephemerides des movemens célestes, pour dix années, depuis 1765 jusqu'en 1775, et pour le meridien de la ville de Paris…* (1763) (D1).
    iv. N. Maskelyne, *The Nautical Almanac and Astronomical Ephemeris, for the Year 1770...* (1769).
    v. P.L. Maupertuis, *La figure de la terre, determinée par les observations...* (1738) (D1)
    vi. T. Mayer, *Tabulae motuum solis et lunae novae et correctae...*, ed. N. Maskelyne (1770).
    [vii. J. De Lalande, *La Connoissance des temps, pour l'année commune 1770... (1768)—neither this title, nor the following one by Maskelyne, could be procured by DesBarres's agent in London.*
    viii. N. Maskelyne, *The British Mariner's Guide...* (1763) (D2)]
11. Magnifier (D2).
12. Beam compass (D7)—*this is a drafting tool for drawing circles of large radii.*
13. Sliding pillared microscope (D1)—*this was a standard type of microscope of the period, many of which were produced by the same people who made telescopes. It is not known what DesBarres used his for, but it was not uncommon for astronomers of the period, such as Charles Messier and Palitzsch, to own microscopes, which they presumably used (Anon. 1817, 52; Helfricht & Koge 1990, 21–22).*
14. Barometer (D2).
15. Thermometer (D2).
16. Dividers (compasses) (D2)—*(Hambly 1991, 69–88).*
17. Spectacles (D2).
18. Magnets (D2)—*the magnets appear to have been for remagnetizing compass needles.*
19. Pocket levels (D2).
20. Lead pencils (D1; D2; Figure 7)—*(Finlay 1990, 51–58).*
21. Pens
    i. Steel drawing pens (D1; D2)—*this could refer to one of two instruments, either dip pens with steel nibs, or to ruling pens, which were used for producing lines of even thickness. The width of the lines produced by the latter were altered by moving the tines of the nib either closer, or further apart (Finlay 1990, 44–45; Hambly 1991, 60–63).*
    ii. Crow quills (D2: Figure 7)—*the flight feathers of crows were preferred for producing very fine script, or lines in technical drawings (Finlay 1990, 4).*
22. Pen knives (D1: Figure 7)—*these were small knives with specially shaped blades for cutting the nibs of quill pens. They could also be used to carefully erase ink or pencil from drawings, or to sharpen pencils, although writing manuals of the time warned against using them for anything other than maintaining writing tools, to avoid damaging them! (Finlay 1990, 13–20; Hambly 1991, 48, 178–179).*
23. Brushes
    i. Large "pencils" (=brushes) (D1).
    ii. Small "pencils" (=brushes) (D1).



Figures 3a & 3b — The first figure shows an equatorially mounted telescope from W.H. Hall's The New Royal Encyclopedia..., *3 vols. (London: C. Cooke, 1788). Most of the instruments so mounted appear to have been refractors, although some Gregorian reflectors are known to have been similarly mounted. Presumably DesBarres's "large reflecting telescope on an equatorial mount" (D1; D3; D4) was one of these. It is also possible (but possibly less likely) that his instrument was one of the much* larger *Gregorians such as those James Short occasionally produced, similar to the example at the Paris Observatory shown in the second figure. Both images reproduced courtesy of the Specula astronomica minima.*

24. Ink
    i. Cakes of India Ink (D1)—*ink was stored and transported in solid form, usually either as cakes, or powder (Finlay 1990, 26, 28).*
    ii. Cakes of "Fine Black" India Ink (D1).
    iii. Ink Powder (D2)—*(Finlay 1990, 27, 28).*
25. Paper
    i. Imperial paper (D2)—*sheets of 22 x 30.25 inches (Paine 1784, 6).*
    ii. Royal paper (D2)—*sheets of 19.25 x 24 inches (Paine 1784, 8).*
    iii. Dutch cartridge paper (D1)—*sheets of 21 x 26 inches, or 19.25 x 24 inches (Paine 1784, 2; Marks 1998, 33, 66, 88). "Dutch paper," or "Dutch gilt paper" was high-quality paper with floral embossed designs. These papers were a German product imported into the Netherlands, then exported elsewhere.*
    iv. Large post paper (D2)—*sheets of 15.25 x 19.5 inches (Paine 1784, 12). "Post" refers to a post horn watermark, which became associated with a particular size of paper.*
    v. Dutch post paper (D1; D2)—*sheets of 15.25 x 19.5 inches, or 13.5 x 14.5 inches (Paine 1784, 12; Marks 1998, 33, 66, 88). "Dutch paper," or "Dutch gilt paper" was high-quality paper with floral embossed designs. These papers were a German product imported into the Netherlands, then exported elsewhere.*
    vi. Fools cap paper (D2)—*sheets of 13.5 x 16.75 inches (Paine 1784, 6). "Foolscap" refers to a fool's cap watermark , which became associated with a particular size of paper.*
    vii. Blotting paper (D1).
26. Wax (D2)—*depending on its constituents and form, wax had a number of uses, from waxing string and cord, to use as a sealant.*
27. Vermillion wafers (D2)—*red adhesive medallions which were moistened for use as seals, as an alternative to sealing wax (Finlay 1990, 61–62).*

Discussion

The documents transcribed and edited below are those of known importance for their information on the astronomical and associated equipment available to DesBarres. Many documents formerly in the possession of his family were said to have been destroyed in the first half of the 20th century (Bishop 2012, 147), yet thousands of DesBarres's papers remain in his *fonds* at Library and Archives Canada (LAC).

As these have yet to be exhaustively searched for references to his astronomical equipment, it is not unreasonable to expect that more information will eventually surface. That aside, the documents we do know of at present are a rich source on his equipment, as can be seen below.

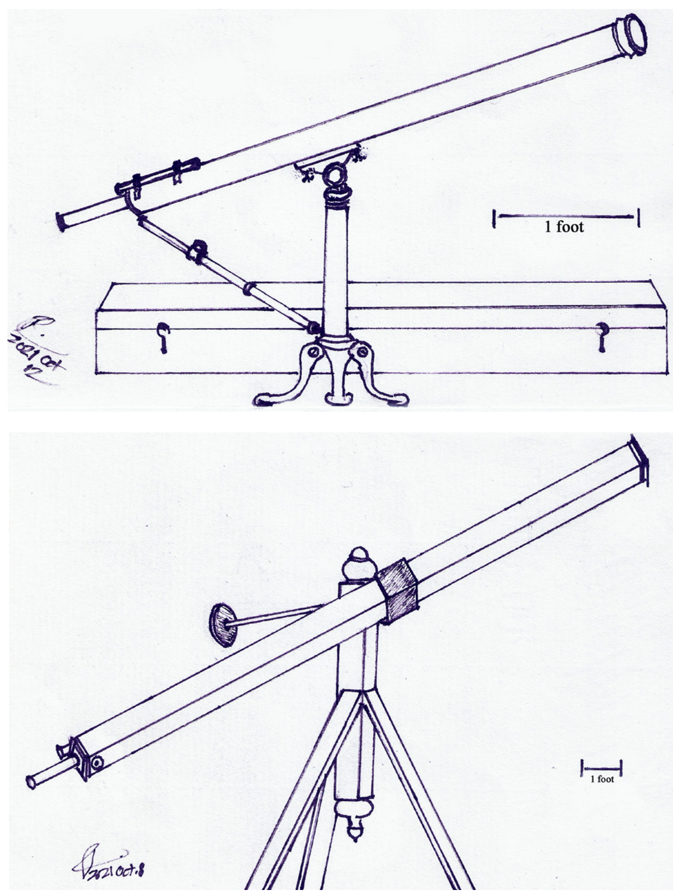
The various contexts in which the astronomical and associated equipment appear are interesting. The documents are quite formal and were all produced as a result of business of one sort or another; these are not personal records, or private diaries. Only two of the documents have anything of the personal about them (D3 and D8). Several of the documents are invoices for shipping (D1, D2), one is a letter from an agent reporting on the state of the equipment after it had arrived in port, and probable progress in getting it to London (D3), another is a receipt for repairs (D4), one is a letter ordering reimbursement for expenses (D5), one is a letter requesting reimbursement (D6), another is a letter requesting valuation of certain equipment (D7), and the longest document is a legal memorandum (D8).

Viewed as lists, the contexts of association provide insights into material culture. There are two notable aspects here. One is the presence and prominence of equipment for recording observations (i.e. the writing and drawing equipment) in among the scientific apparatus. The paper and tools for recording the observations are not separable from those for making observations. It was necessary to import not only telescopes, quadrants, clocks, and ephemerides into Nova Scotia, but the paper, ink, pens, pencils, and so on used with them. This is acknowledged and made explicit by the Navy Board when ordering DesBarres's reimbursement: "That the sum of £598. 19. – charged by the Mem[orialist] for Surveying and Astronomical Instruments, Drawing Implements stationary ware…" (D5). This is an aspect of provisioning astronomy in the colonial 18th century that is not often considered. And, less directly to do with accomplishing science, it is nonetheless possible that the fishing and tailoring equipment in one document could also have been intended to be of use while doing astronomy in the field (D2).

As with most documents, there are limits to what these documents tell us, for they were not at all created as sources for the history of Canadian astronomy. There is much we would like to know, but the documents are not going to tell us. We're not informed who the makers of the apparatus are. The dimensions of the instruments are not given (in the 18th century, the focal length was usually given as a single value to characterize the system, rather than the diameter of the primary optical element one finds today). The features of some of the instruments and their accessories are specified, but by no means all of them (e.g. eyepieces with each of the telescopes). We are told nothing about the design specifications, and rate of the clock, nor of who made it. Most significantly, we are not directly informed of the intended purpose and use of most of the instruments.

The longest document is the legal memorandum (D8), and it's notable for being the only one of these documents using the word "observatory": "…in 1763 to carry on the Survey of the Coasts & Harbours caused an Astronomical Observatory & a Dwelling House to be erected on this granted Land with Suitable Drawing Offices & Accommodations for ~~of~~ his Assistants, who were Young Gentlemen of the Navy, several of them of Birth & Expectations, and with whom he uninterruptedly devoted the intermediate Winter Months in collating the Observations collected on the Coasts during the Milder Seasons and in composing fair Charts thereof for the ~~Survey~~ ^use of the Royal Navy and the Benefit of National Commerce." The observatory is mentioned *before* the house, as if it were of higher importance, and here as well the connection of the instruments for observation with those for recording the observations is made as well, for the "Astronomical Observatory & a Dwelling House" has "Suitable Drawing Offices."

And, in DesBarres's retelling decades after operations ceased, the Castle Frederick observatory was a place for midshipmen to do an astronomical apprenticeship in professional practical astronomy. There can't have been many other locations on the east coast offering that training in the 1760s and 1770s. Here again, one wishes more information were forthcoming about the details of the training, and the names of the assistants (apprentices).



Figures 4a & 4b — The first figure shows a triple element achromat of ca. ƒ/15 on a library stand, and the second figure a triple element achromat ca. ƒ/20. The description of DesBarres's instrument does not specify which version he had. D2's specification of "rack," if it indicates gearing, may be a clue towards identifying his refractor as the ƒ/15 design on a library stand, some of which had gearing. Reproduced courtesy of the Specula astronomica minima.

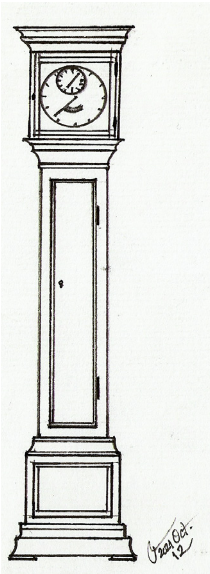


Figure 5 — A pen & ink drawing of a tall-case English astronomical regulator from ca. 1760s. This is the sort of timekeeper that would have been useful for DesBarres's work, but the laconic reference to his clock (D3) provides the modern reader with no details of its features, form, rate, or use. Reproduced courtesy of the Specula astronomica minima.

Finally, two significant discoveries came to light while editing these documents.

For the first time, evidence that DesBarres had a clock has emerged (D3). It likely hadn't been noted previously by any of the historians working on DesBarres (including the present author) because it is not mentioned in the documents concerned with the equipment he was returning to the Navy Board for remuneration (D5, D6, D7). His agent who mentions the clock describes it as " your clock," which either implies that it belonged outright to DesBarres, or that he had decided to keep it, and not hand it in to the Navy Board for remuneration.

The second discovery is the most surprising. While DesBarres was working in Nova Scotia, he employed an instrument maker for seven years: "Charged by the Mem[orialist] for his Maintenance of an Instrument Maker from the 1st May 1766 to the 31 Decr 1773 at the Rate of £40 p[er] An[num] should be allowed him" (D5). There can't have been many scientific instrument makers there at that time. One would give a lot to know the maker's identity, and what specific work the maker performed.

Edition

Notes on the transcriptions: the original orthography has been retained, and notes have been added to aid in comprehension of the documents. Editorial additions are contained in square brackets. In the transcriptions, something of the original layout has been retained, though not slavishly so. Expurgated material appears here in cancelled type, when it can be construed. Annotations have been kept to minimum and are provided to aid in comprehension.

1. 1767 April 7, itemized bill from James Champness for shipping astronomical equipment for Desbarres of Halifax:

"James Champness's Bill Parcells
London April 7th 1767
Goods Shipped for Mr. Desbarres of Halifax
April 7th

- 11 Dozen of very fine Pencils – – £3.12.0
- 9 Steel Drawing Pens – – [£]0.10.6
- Cassinis Elements of Astronomy – – [£]2.2.0
- De La Cailles Ephemerides – – [£]0.18.0
- Maupertuis Degree du Meridian – – [£]1.16.0
- Ulloa Voyage De la Merique – – [£]2.8.9[?]
- 1 Rheam dutch Post – – [£]1.2.*x*[*document damaged*]
- 1 D[itt]o ff[=folios] dutch post – – [£]0.11.*x*[*document damaged*]
- 1 Rheam Dutch Cartridge – – [£]1.10.*x*[*document damaged*]
- 4 Pen Knives – – [£]0.7.6
- 1 Rheam Blotting Paper – – [£]0.10.0
- 2 Dozen Large hair Pencils [=brushes] – – [£]0.2.6
- 3 Doz. D[itt]o. Smaller [pencils=brushes] – – [£]0.3.0
- 6 Cakes of Indian Ink – – [£]0.2.0
- 2 Cakes of fine Black D[itt]o. – – [£]0.1.6
- A Pair of Seventeen Inch Globes – – [£]6.6.6
- Cover to D[itt]o. – – [£]0.14.0
- Packing D[itt]o. – – [£]0.10.6
- a Sliding Pillerd Microscope – – [£]6.6.0
- a Large Reflecting Telescope w[i]th. Some Equatorial Parts – – [£]42.0.0
- a Large Brass Astronomical Quadrant of the Compleatest Sort. – – [£]60.0.0
- Packing Case to Telescope & Quadrant – – [£]0.15.0
- a Plain Table very large with Brass frame Rising Plates to Receive the Paper a Vertical Arch and Telescope on a Large Parralel Ruler & Half with Parallel Plates – – [£]23.10.0
- Packing Case to – – [£]0.6.6
- Wharfage & Searchers – – [£]0.5.0
- Entry & Cartage – – [£]0.5.6
- Water[a]gge – – [£]0.5.0

[subtotal]£156.13.0

- Commission on [£]156:13. – at 5 p[er]C[en]t…– [£]7:16:6
- Prem[ium] Ins[uran]ce: on £170 .. at 2 p[e]rC[en]t: & Policy £3:13:6 [£]162:9:6
- Comm[ission] . . . on d[itt]o. – – ½ p[er]C[en]t. . – . [£].17. [£]1:10:6

£169..

[*docket*:] London April 1st: 1767. [*in another hand*] [£]16.18

Watson & Olive £185.18"

On the verso (back) side of the document is the following docket: "Survey./Watson & Olive/exd./1767," and rotated 180º with respect to these lines, is: "Contingent /from 31st Dec 1766 to 30th Sept 1767," and rotated 90º with respect to these lines, are two crossed-out lines of text.

The document shows three horizontal, and two vertical folds.

DesBarres Papers, Series 5 (M.G. 23, F1–5, Vol. 6) Accounts, 1767–1794, 1252–1253, mfm reel c1456, 1187–1188

Notes: The James Champness of this document may be the instrument maker James Champneys (fl. 1760–1771), who was the defendant in the test case brought by the litigious Peter Dollond to assert his patent for the achromatic lens (Gee 2014, 183–189; Zuidervaart 2016).

Rheam=ream, a quantity of paper consisting of 20 quires, or 480 sheets.

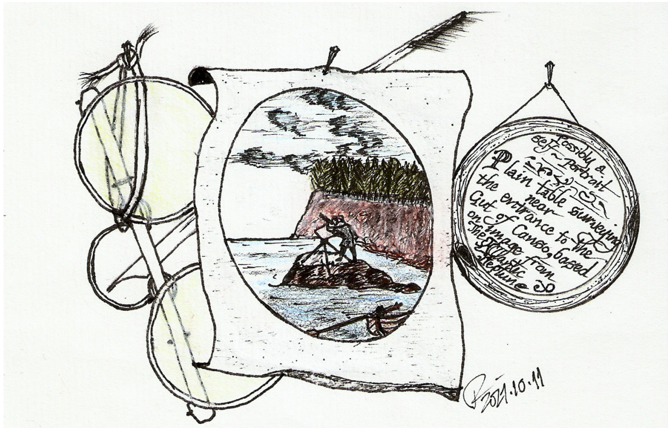


Figure 6 — A copy of a detail from DesBarres's Atlantic Neptune*, showing a figure employing a plain table for coastal surveying. This could be a self portrait of DesBarres at work. Reproduced courtesy of the Specula astronomica minima.*

Wharfage=charge or dues exacted for the use of a wharf.

Cartage=the price paid for conveyance by cart.

Wateragge=waterage, the price paid for conveyance by boat

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2. 1769 April 4, itemized shipping invoice (including sundry charges) from Watson, Olive, & Rashleigh, for astronomical and other goods for Lieutenant Joseph Frederick Wallet DesBarres:

"FFWD[=Forward]….Invoice of sundrys. shiped by Watson Olive & Rashleigh on Board the Amitys Admonition, William Sandifield master for Halifax by order and on Account & Risque of ‸[l]ieutenant Joseph Frederick Wallet DesBarres and you[?] Consigned to John Butler Esq. to deliver him Viz[t] [=Videlicet]

Nº 1 a Case Containing

- a Neat Barometer with a Nonius ….[£]2.12.6
- a Thermometer Farenheits Scale in Mahogony Box ….[£]1.11.6
  Packing Case Tow [=rope] & Screws….[£0].3.6

—[£]4.7.6

[Nº] 2 a d[itt]º Containing

- A Mahogony Sextant with Ivory Arch & Adjusting Screw to the Nonius with Tellescope & 3 dark Glasses in Wainscott Box …. [£]6.6
- Magnifier in horn Box ….[£0].2
- 3 Pair D[ou]ble dividers. 1 P[air] to divide the half. 1 P[air] the Third and 1 P[air] the fourth in fish Skin Cases with Hooks. and with 2 pencils in each Case ….[£] 3.3
- 4 Steel Drawing Pens ….[£0].16
- 2 Pairs of Steel D[ou]ble Joynt Spectacles with dark Glasses in Fish-skin Cases …. 1576. [£]1.11
- 2 large Magnet Bars for Touching of Needles . [£]1.16
- Pocket Level …. [£0].12
- 24 dozen best black Lead Pencils …. 6[£]7.4
  Case ….[£0].3

——[£]21.13—

[Nº] 2 Case Containing

- 1 Ream Superfine Imperial Paper. Nº 1 ….[£]4
- 1 d[itt]º …. d[itt]º….Royal….[Nº] 2….[£]2.5
- 2. d[itt]º…. d[itt]º..Large Post….[Nº] 3…15/6 [£]1.11
- 3.. d[itt]º…. d[itt]º..Fools Cap….[Nº] 4…13/6 .. [£]2.0.6
- 1 d[itt]º. Gilt Quarto Dutch Post….[£0].12.6
- 2[lb] Superfine Dutch Wax …. 7/[£0].14
- 1 Large Box Vermillion Wafers …. |[£0].1
- 6 Paper Ink powder ….[£0].2
- 1 Hundred Crow Quills …. [£0].1
  Case & Rope …. [£0].7

[£]11.14

[Nº] 3 a Case Containing viz[l[ic]et][=videlicet]

- a 3½ f[[oo]t]. Achromatic Telescope with Triple Object Glass. with Rack, Stand, & finder…}…[£]26.5
  PackingCase …. [£0].5

[£]26.10—

[Nº] 4 a Case...Containing viz[l[ic]et][=videlicet]

- ~~1 dozen Mem fine 3[os] white Thread Hose… –[£]2.10~~
- ~~1 dozen … d[itt]º Sup[er] fine d[itt]º D[ou]ble Heels …. [£]3~~
- a Nautical Almanac ….– –[£0].2.6
- Mayers Astron[omica][l] Tables to d[itt]º ….[£0].2.6
  - NB….}British Mariners Guide, out of Print
  - La Connoissance du temps. not to be had

- 12 dozen Cod Hooks …. Nº2 Iron …. —[£0].8
- 12 dozen Machrel [Hooks] …. [Nº]8 Iron….–.–[£0].1.6
- 6 dozen best Trout and Salmon [Hooks] …. – – — [£0].2.3
- ~~6 y[ar]ds Broad D[ou]ble Rich Gold Scollops Lace…16/ [£]4.16~~
- ~~1½ dozen Rich Gold Basket Buttons …. [£0].3.9~~
- ~~Gold thread .. ——— [£0].2.6~~
  - Carried forward … £11.9

[£]64.4.6

FFWD[=Forward] Invoice Continued – – Br[ough][t] Forward—

£64.4.6

Nº 4 a Box Continued——Br[ough][t] Over — [£]11.9

- 500 best Milliners Needles..— – – – —5/m[?][£0].2.6
- 2[lb[s]] best Pins . . . . — . . – – — 2/6[£0].5
- 2 oyz [=ounces?] best Lightcoloured Belladine Silk . .2/. [£0].4
- 1 Gro[ss] 4[d] [=quartered?] Stay Fr*xxx*it . . — – —–16/ [£0].16
- in this Box is a Thermometer which you sent to M[r]

Champnes to repair and for which we have paid his Bill . – – —}[£]1.9.6
Box . . . . [£0].1.6

[£]14.7.6
[£]78.12.

Charges viz.[=videlicet]

- Entry Searchers fees, Cartage Porterage, Wharf & Waterage [£0].17
- Freight Primage & Bills Lading . . . . [£]1.3.6

[£]2.[0].6
[£]80.12.6

- Our Commission on £80.12.6 @ 5 P[er]Cent . . – – — —[£]4.[0].8
- Prim[a][ge] of Insurance on £90 . . . @ 2 P[er]Cent & Policy . – — . [£]2.1.6
- Commission . . . . — . d[itt]o . . 1 P[er]C[ent] . . —— [£0].9

[£]6.11.2
£87.3.8

Errors Accepted
London 4th April 1769
Watson Olive & Rashleigh

NB. We have just found that the thermometer mentioned above to be received from Mr Champness, is not Yours, but Doctor Whites. You will oblige us by delivering it to him and receiving the [£]1.9.6 Charged you for its repair as we can't well alter the Charge — . . —"

The document shows three horizontal folds.

DesBarres Papers, Series 5 (M.G. 23, F1–5, vol. 6) Accounts, 1767–1794, mfm reel c1456, 1189–1190

Notes:

Watson, Olive, & Rashleigh was a firm specializing in shipping all sorts of goods, not just those of science (Fisher 1971, 76).

Nonius: this term was used most often in DesBarres's period to designate a vernier scale: "VERNIER, is a scale, or a division, well adapted for the graduation of mathematical instruments, so called from its inventor Peter Vernier...Vernier's scale then, is a small moveable arch, or scale, sliding along the limb of a quadrant, or any other graduated scale, and divided into equal parts, that are one less in number, than the divisions of the portion of the limb corresponding to it...The method of counting is by observing...which division of the vernier it is that exactly, or nearest, coincides with a division in the [main] scale...By altering the number of divisions, either in the degrees [of the main scale] or in the vernier, or in both, an angle can be observed to many different degrees of accuracy... But though the vernier was originally divided into one less *than the correspondent length on the [main] scale, yet a practice has gradually come into use, of dividing it into one part* more *than those of the [main] scale; so that it is now more usual to practice this latter way, than the former" (Hutton, 1815, 564–565).*

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3. 1774 April 24, letter from Captain John Spry to J.F.W. DesBarres regarding the state of his astronomical equipment shipped aboard the Diligent:

"D[ear] Sir**[,]** I would have wrote you sooner, but when I came to Portsmouth I found every thing in the greatest confusion on board the Dilligent, hardly any thing done in regard of getting the Vessel ready for Docking. Yesterday with great inconvenience I got her into the Dock, but nothing done to her yet, but the Carpenters inspects into her Monday Morning, her Main Deck will be shifted I believe she will be in the Dock all the Neaph tides, as she wants a great repair I hope you injoy health, and all your under takings goes on to your Wishes—— to morrow will go in the Gosport Waggon, which will be in London Wednesday Afternoon—Your Clock—Two Quadrons [=quadrants]—Plain Table—Telescope—Two pair of Wooding legs and on[e] pair of Iron—The Box of the Globe is broke to pieces, so am afraid I cannot send it tomorrow, but will if Possible, otherwise will send it Mond[ay] senet—I have Directed them to J.F.W. Des Barres Esq[ui]r[e] at Mr. Gyberts Perfumer in Poland street London—to be left at the whare House till called for at the White Horse Cellar Piccadilly. I shall be Very glad when Mr. Martin comes down, as there is a vast deal to do for him in the surveying the stores——no news here, but that Adm[ira]l Gayton sails in a few days for Jamaica. Happiness and success Atend You are the Wishes of D[ear Sir Your Most Obed[ien]t and humble Serv[an]t Tho[mas] Spry–J.F.W. DesBarres Esq[ui]r[e]."

In a column to the left of the valediction formula and signature: "Diligent April 24 1774—".

On the verso of the outer leaf is the following docket: "J.F.W. DesBarres Esq[ui]r[e] at Mr. Giberts perfumer in Poland Street London", and rotated 90º with respect to these lines, is "Capt Jh. Spry" in a different medium (probably pencil).

The document shows two vertical, and possibly three horizontal folds.

The wax seal is still present, as is part of the queue (for the seal). Several ink stamps are also visible.

DesBarres Papers, Series 5 (M.G. 23, F1–5, Vols. 3), Charles Morris and Correspondence Received, 1771–1784, 610–613, mfm reel c1456, 0529–0532

Notes: Clark Gayton (1712–1785), at this time Rear Admiral and Commander of the Jamaica Station.

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4. 1774 July 27, receipt from Robert Thompson for astronomical equipment to be repaired by Jesse Ramsden's workshop for Mr. Desbarres:

"July 27. 1774—Rec[eived] From Mr. Desbarres . An Astronomical Quadrant, a large Reflecting Telescope[,] a Refracting Telescope, a Hadley's Quadrant[,] to be deliver'd to Mr. Desbarres or his Order when repair'd for J. Ramsden[,] Robt. Thompson[.]"

Endorsed "Mr Ramsden's Receipt for My Astr. Instruments[.]"

The document shows three horizontal, and two vertical folds.

DesBarres Papers, Series 5 (M.G. 23, F1–5, Vols. 1–2), Naval Surveys and Atlantic Neptune, 1762–1814, 116–117, mfm reel c1456, 0013–0014

Notes: By the time DesBarres called on Ramsden's services the latter, though young, already enjoyed a high reputation, and had perfected his second dividing engine. A foreign visitor that same year (1774) remarked that: "Ramsden is highly esteemed here, he is still a young man and has many ideas. He has considerably improved the portable observatory, and had a book published on it, which is however very rare and now available only when buying the instrument" (McConnell 2007, 28). Robert Thompson is not listed among Ramsden's personnel by either Kitchiner 1825, or McConnell 2007.

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5. 1783 December 18, letter from the Lords of the Admiralty to the Navy Board ordering reimbursement for DesBarres's expenses incurred during his surveying of Nova Scotia, including compensation for the return of the "Surveying & Astronomical Instruments, and Drawing Implements" used:

"18 Dec' 83 Gent[lemen,] Whereas the Lords of the Committee of HM [=His Majesty's] most Hon[ora]ble the Privy Council were pleased upon taking into consideration the Reports of this Board upon Reference of a mem[orial] from JFW DesBarres Esq; praying Payment may be made of his contingent disbursements during the time he was employed in taking surveys & soundings of the coast & marshes of Nova Scotia with some compensation for his Losses & Reward for his services to Report th[at] HM in Council that they Concurred in Opinion with this Board as to the Allowances to be made to the Mem[orialist] for his Contingent Disbursement under the following Heads, thusly. That the sum of £598. 19. – charged by the Mem[orialist] for Surveying and Astronomical Instruments, Drawing Implements stationary ware, being part of a Sum of £795.3., claimed by the Mem[orialist] on that head of which the Sum of £152.10._ has been recd by him remains due to the Mem[orialist] and ought to be paid him upon his —delivering up the Instruments which remain in his Custody & Such Persons as the Lords Com[missioners] of the Admty Shall Appoint to receive them. That the further Sum of £1916.5.–charged by the Mem[orialist] for the Maintenance of Assistants[,] Pilots & Gu[a]rds should be allowed him —That the further Sum of £306.15.8–Charged by the Mem[orialist] for his Maintenance of an Instrument Maker from the 1st May 1766 to the 31 Decr 1773 at the Rate of £40 p[er] An[num] should be allowed him. That the further Sum of £500.– – should be allowed the Mem[orialist] for House Rent fuel etc[eter]a, during the time he was employed upon this Service being after the rate of £50. p[e]r An[num] and that his Disbursements for Deficiencies ~~of Ð~~ supplyed in the Provisions for the Crews damaged and lost in Vessells & Boats sunk and overset or stolen by the Indians averaged for ten Years at the Rate of £600 p[e]r An[num] and Amounting to £600 should also be paid him[.] And whereas H.M. has been pleased by his Order in Council of the 28 of last Month to declare his Royal Approbation of the Zeal Activity and Ability of the Mem[orialist] in prosecuting and Completing the Said Useful work and to direct that the several sums proposed by the said Report be allowed to the Mem[orialist] for his Contingent Disbursements be forthwith paid him upon his delivering up the Surveying & Astronomical Instruments, and Drawing Implements which remain in his Custody to such Person as we shall appoint to receive them and producing Voucher for the Payment of the Money charged for Deficiencies Supplyed in the Provisions for the Crew of the Vessells or on Failure thereof, verifying the Payment upon both, we send you herewith an Affidavit from M DesBarres that he actually paid and Expended the sum of £600 at least for Provisions so damaged lost or stolen, And in Pursuance of H.M. said order in Council, do hereby desire and direct for to cause M DesBarres to be forthwith paid the several sums therein specified, amounting in the Whole to the sum of £3915.17.8 for his Contingency Disbursements ~~the sum~~ in making the said Surveys. We send you also herewith a list of the Astronomical, Surveying and Drawing Instruments provided by Mr DesB. for the purpose of making the said survey and are now remaining in his hands and do hereby farther desire and Direct You to receive the said Instruments and to cause proper Care to be taken of them, until they shall again be wanted for the service. We are Your h[um]ble Servants Keppel[,] Hugh Pigot[,] John Townshend[.]"

On the verso of the outer leaf is the following docket: "Letter from the Lords of Adm[iral]ty to the Navy Board, Dated 18 Dec 1783 to pay Conting[en]cy Disbursements to the year 1783—[.]"

The document shows one horizontal, and one vertical fold.

DesBarres Papers, Series 5 (M.G. 23, F1–5, Vols. 1–2), Naval Surveys and Atlantic Neptune, 1762–1814, 348–354, mfm reel c1456, 0250–0256

Notes: Augustus, Viscount Keppel (1725–1786) was First Lord of the Admiralty (Mackay 2010). John Pigott was Chief Clerk (Storekeeper's Accounts). The Townsend mentioned in this document doesn't appear to be either Isaac Townsend, Commissioner resident at Portsmouth, or Spencer Townsend, Receiver of Fees, the first being in office too early, and the latter too late, to be involved with DesBarres (Collinge 1978).

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6. 1783 December 29, letter of DesBarres to the Committee of the Navy reporting on his return of most of the astronomical equipment, accounting for the outstanding items, and requesting reimbursement:

"Soho Square. 24th Dec[embe]r 1783[.] Gent[lemen,] I have, agreeable to your Desire, delivered to the Store-Keeper at Deptford, as per enclosed Receipt, the Whole of the Astronomical and Surveying Instruments, named in the shedula, accompanying my Representations to the Admiralty Board excepting a Sextant, Price £6.6 in the hands of Capt J[oh]n Knight and one of the 17 inch Globes, Price £3.3.– left at Halifax; I shall request Cap^{r} Knight to return the Sextant to the Storekeeper at Deptford as soon as possible; and will likewise write to Nova Scotia that the other 17 Inch Globe be also returned[.] In the meantime I beg leave to hope that you will be pleased to order my Bills, and should you think it reasonable to request and Security of me for the said Sextant and Globe, it shall be given, or an adequate sum deposited—I have the Honor to be—Gent[lemen,] Your most humble and most obedient Servant[,] JFW DesBarres[.]"

In a column to the left of the valediction formula and signature ("Your most humble…DesBarres"), are the notes: "Price of Astr. Quadrant– –£60. – –/D[itt]^{o} —Reflect: Thelescope £42. – –/The Hon[ora]^{ble} Comm[ittee] of His Majesty's/Navey,—[.]"

On the verso is the docket: "29 Dec' 1783/to the Com[mit]^{ty} of the Navy[,]" which is repeated on another panel, but rotated 90º with respect to the first iteration.

The document shows two horizontal folds, and one vertical fold.

DesBarres Papers, Series 5 (M.G. 23, F1–5, Vols. 1–2), Naval Surveys and Atlantic Neptune, 1762–1814, 357, mfm reel c1456, 0259–0260

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7. 1783 December 26, From Commissioners of the Navy to DesBarres requesting the value of certain astronomical equipment not yet received by them:

"Navy Office 26 Dec^{r}. 1783. Sir[,] We desire you will send Us the Value of the undermentioned Articles in the hands of other people—Viz^{t}[=videlicet]

- A Sextant adjusting Screws to the Nonius with Telescope dark Glasses Magnifiers etc
- A large Astronomical Quadrant et^{c}
- A D[itt]^{o} Reflecting Telescope with equatorial Parts etc
- A p[ai]^{r} 17[-inch] Globes etc
- A D[itt]^{o} Beam Compasses—

and are[,] Sir[,] Yours humble Servants *xxxxxxxx* [*signature undecipherable*] [,] Williams[,] Geo. Martin[.]

J.F.W. Des Barres Esq^{r}."

On the verso is the docket: "On His Maj[esty']^{s} Service J.F.W. Des Barres Esq^{r} Town Navy Office [*the orientation of the writing is turned 180º from here to the end*] 26 Dec: 1783. Com[missioner]^{s} of the Navy."

DesBarres Papers, Series 5 (M.G. 23, F1–5, Vols. 1–2), Naval Surveys and Atlantic Neptune, 1762–1814, 355–356, mfm reel c1456, 0257–0258

Notes: Possibly Henry Hunter Williams, Clerk (Ticket Office) (Collinge 1978). No George Martin is listed in Collinge 1978.

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8. 1817 October, memorial of J.F.W. DesBarres to the Supreme Court of Nova Scotia, in the King vs. DesBarres. This document specifically mentions the reasons for the establishment of his "astronomical observatory" in Falmouth, and a little of its activities:

"The Memorial of Colonel JFWD—formerly Surveyor General of the Coasts & Harbours in North America, since Lieut Governor of Cape Breton and late of Prince Edward Island, now retired. Humbly Sheweth,

That your Memorialist, since the Year 1755 ardently & usefully exerted his humble Abilities in the alternate Capacities of an Officer of the Line & of an Engineer in the principal Events of the war which accomplished the Conquest of all the Territories of France in North America, in the Course of which he was honoured with the encouraging Approbation of his most Gracious Sovereign, His present Majesty's ‸$^{\text{late}}$ Royal Grand Father, as well as with the Commendations of his illustrious Commanders.

That, upon the Surrender of Canada in Autumn 1760, Your Memorialist was ordered to repair to Halifax to assist the then Major General Bastide of the Royal Engineers in taking Surveys & training sections of the Environs of that Place, and to project Designs of a Strong Fortress for the Protection of its Royal Dockyard, Town & Harbour.

That dutifully to Forward the Fulfilment of the Intentions of Government in Promoting and accellerating the Colonization of the then Infant Province of Nova Scotia; Your Memorialist made several Excursions through the Wood into its distant Districts and with his Observations thereon, Submitted ‸$^{\text{in a short Essay}}$ his Ideas on the Expediency, Utility & Advantage of opening practicable Roads of Communication, which by the Governor & Council was transmitted to the Board of Trade.

That Your Memorialist established a few Families on lands granted him in the Township of Falmouth. Amply supplied with Provisions, Building-Materials, Implements of Husbandry, Utensils, Stocks of Cattle & all Requisites, ~~they~~ who speedily rore into a comfortable $^{\text{\& opulent}}$ Stake & Made considerable Progress in~~to~~ the Cultivation & Improvement of the Land. That, Your Memorialist ‸$^{\text{having}}$ engaged in 1763 to carry on the Survey of the Coasts & Harbours caused an Astronomical Observatory & a Dwelling House to be erected on this granted Land with Suitable Drawing Offices & Accommodations for ~~of~~ his Assistants, who were Young Gentlemen of the Navy, several of them of Birth & Expectations, and with whom he uninterruptedly devoted the intermediate Winter Months in collating the Observations collected on the Coasts during the Milder Seasons and in composing fair Charts thereof for the ~~Survey~~ ‸$^{\text{use}}$ of the Royal Navy and the Benefit of National Commerce.

That, expecting the Arrivals of ~~those~~[?] ‸$^{\text{a Number of}}$ Protestant Families from the Continent of Europe, Your Memorialist prayed that a Tract of Land be granted him for their Reception; Whereupon His Majesty was graciously pleased, with the Advice of His most Honourable Privy Council, to issue His Royal Order, dated 11th July 1764, directing His

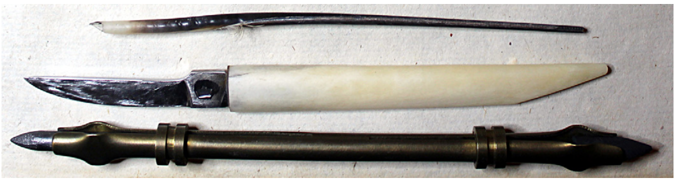


Figure 7 — Reproductions of an 18th-century pen made from a crow quill, a penknife, and a porte-crayon for drawing with a lead. Reproduced courtesy of the Specula astronomica minima.

Governor and ~~the~~ Commander in Chief for the Time being to cause Twenty Thousand Acres of Land in His Province of Nova Scotia to be Surveyed and laid out, in a manner conformable to His Royal Instructions, to Your Memorialist where he might chuse, not already granted or Surveyed to Others, and not possessed or claimed by the Indians, and upon Return of such Survey to pass a Grant for the same to Your Memorialist under the Seal of said Province upon the Terms, Conditions & Reservations expressed in said Royal Order.

That, pursuant to His Majesty's said Order in Council, His Excellency Montagu Wilmot, Captain General & Governor in Chief of His Majesty's Province of Nova Scotia, passed a Patent under the Seal of Said Province, dated 24[th][?] August 1765, granting & confirming unto Your Memorialist his Heirs & Assigns a Tract of Land, Beginning at the Easternmost Point of a Creek in the River or Harbour John; Then running South 450 Chains on ungranted Lands; There North 12° West 500 Chains on ungranted Lands to a Point* [*commonly called Point Gouga.] on a Stream near the Head of Tatmgoushe Bay; Thence back as the Shore runs to the beforementioned Boundary; containing in the whole by Estimation 20 000 Acres,[?] with Allowance for Roads, etc. etc. according to the Plan hereto.

That the Memorialist caused Vessels to be hired in which the Protestant Families above alluded to, with their Baggage, Supplies of Provisions, Seed Grain, Implements of Husbandry and all Requisites, were carried to, and satisfactorily located and established on, the granted Premisses. Occasional Accessions of other Settlers were progressively established on other suitable & eligible Parts of said Premisses, on Covenants mutually agreed upon.

That about the Year 1805 and thereafter, Your Memorialist, residing at the Seat of his Government in Prince Edward Island, Sent one of his Sons to inspect his land Properly in Nova Scotia, investigate the Proceedings ‸, relative thereto which during his long Absence on Public Services had taken place, and report their actual State thereof.‸ In the prosecution of his Mission, the first Object which attached his attention was the Discovery [*the original text under the interlinear correction is largely undecipherable beneath its expunctuation in the digital facsimile*] One of Your Memorialist's Tenants, namely Robert Adams, located on a favourite Piece of Land previously improved at the Memorialist's Costs, called Point Gouga Farm, situate within the concomitance of the Third & Fourth Bounds of Your Memorialist's said Grant of Twenty Thousand Acres, had, after being indulged during many Years to enjoy said Gouga Farm as a Tenant at Will for an inadequate annual Acknowledgment, regularly paid by said Adams up to 1805, ‸had Clandestinely applied for and ‸surreptitiously obtained a Grant thereof to himself. It was said that by means of a deceptious Certificate of some Land Surveyor, representing Point Gouga Farm to be vacant Land, the then Lieutenant Governor with the Advice of His Majesty Colonial Council had been led to pass in the Name of the Crown this Supervacaneous Grant to the Said Subdolous Adams, who thereupon sold what he called his Right & Title to One Duncan Dower equally aware and conscious as himself of Your Memorialist's rightfull Claim. It is palpably evident from a mere Inspection of the Survey and Bounds prescribed in the Royal Patent dispatched to your Memorialist pursuant to His Majesty's Order in Council, that Point Gouga Farm, placed as it is within the Concomitance of the Third & Fourth of said Bounds must ever continue to be such an important, ~~essential & indispensable~~ Portion ~~of the~~ Constituting the Area of the Premisses thereby granted to Your Memorialist, that any Mutilation or perversion of the prescribed Bounds & Land Marks Thereof Whatever could not fail to become totally Subversive of the Efficacy of His Majesty['s] Gracious Intentions, and disgracefully turn His Majesty's Royal Patent to absurdity & Senselessness. ~~From a Desire to withhold the Publicity of the Intrusive[?] Impostures which unsuspiciously had seduced Government into an official Act of Immorality in the Name of the best of Sovereigns the Memorialist due Remonstrances proved unavailing and he was peremptorily directed to Seek Redress in a Court of Law. Your Memorialist~~

Your Memorialist disinclined by ‸any public Exposition of Facts to aggravate the painful Regrets ‸said ~~of the~~ Governor & Council ~~in that~~ [?] ‸should feel upon cool contemplation of an Official Transaction ‸done in the Name of the Crown ‸apparently unadorned with Justice & Dignity, ~~Your Memorialist humbly & respectfully~~ [*this next cancelled line is largely undecipherable beneath its expunctuation in the digital facsimile*] humbly remonstrated on the dangerous Precedent of such Enormities. Strangely disappointed in his reasonable Agg[rievance][?]; ‸He sought for and found Redress in a Court of Law.

Accordingly, On the Sitting of the Supreme Court of Judicature at Truro, in September 1816, an Action of Ejectment was brought & tried before the Honora[ble] Judges Haliburton & Stuart; ‸who Upon Examination of the exhibited Royal Order of His Majesty in Council, & Patent, dated 24[th] August 1765, with the explanatory Survey delineated thereon and having attentively collated said Survey with the prescribed Bound ‸ expressed in said Patent, obviously evincing Point Gouga Farm to be absolutely included within said Bounds, & etc., Pronounced Judgement. in favour of Your Memorial[ist] ["in favour… Memorial[ist]" *is entered in pencil*] [.]

Whereas the Piece of Land ‸lately granted ~~to RobertAdams~~ in the manner above Stated to Robert Adams, has incontrovertibly been proved to be included within the Tract previously granted to Your Memorialist in 1765, the Said Grant to Rob[er]t Adams has Therefore been declared void.

~~In the Disconfiture of~~ Their defeats in Their iniquitous ~~Drift~~ alterately[?], the Adversaries of ~~the~~ Your Memorialist resorted to the ~~absurd & disgraceful~~ ungracious & Absurd Expedient of rashly Charging Your Memorialist with Intrusion on a Tract or Parcel of Land of which His Majesty is Seized, while, from the Description given by them Thereof, it clearly appears to be the very Piece of Land improvidently granted to said Robert Adams which is included within the Bounds prescribed in His Majesty's Patent, dated 24th August 1765; ~~Whereupon~~ As Information ~~has~~ ~~has~~[?] however was been filed ^by His Majestys Attorney General for this Province praying the Process of His Majesty's Supreme Court against Your Memorialist, in Consequence thereof and ~~that~~ he ^has been ["n" *added in pencil*] summoned to appear in Said Court, at Halifax on the Second Tuesday of October 1817, to Answer of and concerning the Premisses".

The verso of the outer leaf bears this docket in the central panel: "Sup. Court Trinity term 1817 The King vs Des Barres *xxxxxxxx* [*undecipherable*] Copy[.]"

The document shows three horizontal, and three vertical folds.

DesBarres Papers, Series 5 (M.G. 23, F1–5, Vols. 22–23) Land correspondence, 1813–1824, mfm reel c1460, 521–529 ✶

Endnotes

1 It is not certain from the document (3) whether this refers to the equatorial Gregorian reflector, or the triple achromatic refractor.

2 Only one globe is mentioned in the document (3).

Acknowledgements

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

References

Manuscripts, Books, Articles and Websites

Anon. (1817). *Catalogue des livres de feu M. Charles Messier, Doyen des astronomes...* Paris: Tilliard Frères

Bishop, R. (1977). An Eighteenth-Century Nova Scotia Observatory. *JRASC 71, 6*, 425–442

Bishop, R. (2012). Castle Frederick Observatory. *JRASC 106, 4*, 142–149

Cassini, J. (1740). *Elemens d'astronomie*. Paris: Imprimerie Royale

Collinge, J.M. (1978). *Office-Holders in Modern Britain: Volume 7, Navy Board Officials 1660–1832*. London: University of London, 1978

de Lacaille, N.-L. (1763). *Ephemerides des movemens célestes, pour dix années, depuis 1765 jusqu'en 1775, et pour le meridien de la ville de Paris...*, tome sixième. Paris: Jean-Thomas Herissant

Des Barres, J.F.W. (1767–1783). Ottawa, Library and Archives Canada, DesBarres Papers, Series 5 (M.G. 23, F1–5, Vol. 1–3, 6)

Des Barres, J.F.W. (1774–1782). *The Atlantic Neptune Published for the Use of the Royal Navy of Great Britain by Joseph F.W. Des Barres Esq. Under the Direction of the Right Hon.ble the Lords Commissioners of the Admiralty*. London: [J.F.W. DesBarres]

Evans, G.N.D. (1965). North American Soldier, Hydrographer, Governor: the Public Careers of J.F.W. DesBarres, 1721–1824, Ph.D. thesis, Yale University

Evans, G.N.D. (1969). *Uncommon Obdurate : The Several Public Careers of J.F.W. DesBarres*. Salem MA–Toronto: Peabody Museum of Salem, and the University of Toronto Press

Fellmann, E.A. and Fleckenstein, J.O. (1981). "Bernoulli, Johann (Jean) I." In (Ed.) C.C. Gillispie *et al.*, *Dictionary of Scientific Biography*, 2 (51–55). New York: Charles Scribner's Sons, 1981

Finlay, M. (1990). *Western Writing Implements in the Age of the Quill Pen*. Wetheral: Plains Books

Fisher, H.E.S. (1971). *The Portugal Trade: a Study of Anglo-Portuguese Commerce 1700–1770*. London: Methuen

Gee, B. (2014). (Eds.) A. McConnell & A.D. Morrison-Low, *Francis Watkins and the Dollond Telescope Patent Controversy*, Science, Technology and Culture, 1700–1945. Abingdon–New York: Routledge

Hambly, M. (1991). (Tr.) D. Bauthier, *Les instruments de dessin 1580–1980*. Paris: Ars mundi

Helfricht, J. & Koge, S. (1990). *Chr. Gärtner und J.G. Palitzsch—Bauernastronomen aus Tolkewitz unf Prohlis bei Dresden*. Veröffentlichungen der Sternwarte Pulsnitz Nr. 25. Pulsnitz: Sternwarte Pulsnitz

Hornsby, S.J. (2011). *Surveyors of Empire: Samuel Holland, J.F.W. Des Barres, and the Making of The Atlantic Neptune*, Carleton Library Series 221. Montreal–Kingston: McGill–Queen University Press

Hutton, C. (1815). *A Philosophical and Mathematical Dictionary...*, vol. 2. London: F.C. and J. Rivington et al.

Juan, G. & de Ulloa, A. (1752). *Voyage historique de l'Amérique méridionale fait par ordre du roi d'Espagne, par don George Juan...et par don Antoine de Ulloa...ouvrage...qui contient une histoire des Yncas du Pérou et les obsérvations astronomiques et physiques faries pour déterminer la figure et la grandeur de la terre...*, 2 vols. Paris: Charles-Antoine Jombert

Kitchiner, W. (1825). *Of Telescopes; Being the Result of Thirty Years' Experiments with Fifty-One Telescopes, of from One to Nine Inches in Diameter...* The Economy of the Eyes, Part II. London: Geo. B. Whittaker

De Lalande, J. (1768). *La Connoissance des temps, pour l'année commune 1770...* Paris: L'imprimerie Royale

Mackay, R. (2010). "Keppel, Augustus, Viscount Keppel (1725–1786)". *Oxford Dictionary of National Biography* https://doi-org.myaccess.library.utoronto.ca/10.1093/ref:odnb/15439 *(accessed 2021 October 10)*

Marks, P.J.M. (1998). *The British Library Guide to Bookbinding History and Techniques*. London–Toronto: British Library & The University of Toronto Press

Marshall, D.W. (1976). "The British Military Engineers 1741–1783: a Study of Organization, Social Origin, and Cartography." Ph.D. The University of Michigan

Maskelyne, N. (1763). *The British Mariner's Guide. Containing, Complete and Easy Instructions for the Discovery of the Longitude at Sea and Land, within a Degree, by Observations...* London: For the author

Maskelyne, N. (1769). *The Nautical Almanac and Astronomical Ephemeris, for the Year 1770*. London: W. Richardson and S. Clark

Maupertuis, P.L. (1738). *La figure de la terre, determinée par les observations...* Paris: Imprimerie Royale

Mayer, T. (1770). (Ed.) N. Maskelyne, *Tabulae motuum solis et lunae novae et correctae...* London: William and John Richardson for John Nourse, John Mount and Thomas Page

McConnell, A. (2007). *Jesse Ramsden (1735–1800), London's Leading Scientific Instrument Maker*. Science, Technology and Culture, 1700–1945. Aldershot: Ashgate

Morgan, R.J. (1987). DesBarres, Joseph Frederick Wallet. *Dictionary of Canadian Biography*. www.biographi.ca/en/bio/desbarres_joseph_frederick_wallet_6E.html (*accessed 2021 September 27*)

Paine, J. (1784). *The Paper-maker's and Stationer's Assistant: Being a Correct List of all the Different Papers, Their Tables, Rates, and Sizes, with the New and Additional Duties...* London: H.D. Symonds

Rosenfeld, R.A. (2021). "Exploring the History of Colonialism and Astronomy in Canada II: The Cases of the Slave-Owning Astronomer and the Black Astronomer Knighted by Queen Victoria." *JRASC 115, 4* (August), 172–178

Straub, H. "Bernoulli, Daniel." In (Ed.) C.C. Gillispie *et al.*, *Dictionary of Scientific Biography*, 2 (36–46). New York: Charles Scribner's Sons, 1981

Turner, A.J. (2002). "The Observatory and the Quadrant in Eighteenth-Century Europe." *Journal for the History of Astronomy 33, 4 (November)*, 373–385

Wyld, S. (1760). *The Practical Surveyor, or the Art of Land-Measuring Made Easy...*, 4th ed. London: W. Johnston

Zuidervaart, H.J. (2016). "The Evasion of Dollond's Notorious Patent on the Achromatic Telescope by the Move to the Dutch Republic of the Instrument Makers Eastland and Champneys." *Bulletin of the Scientific Instrument Society, 128*, 24–35

CFHT Chronicles

Let the Secondary Light In

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

In fall of 2020, CFHT staff recoated the primary mirror, a critical task to undertake mid-pandemic. The re-aluminization was postponed multiple times as we struggled to find a time with the lowest risk of bringing so many people into the same place at the same time. It was scheduled, cancelled, rescheduled many times before the October coating. We found ourselves in a slightly different, yet still all-too-familiar scenario this fall when we decided to recoat our secondary mirror.

CFHT is an equatorial mount telescope. We can house instruments at either prime focus at the top of the telescope or at the Cassegrain (Cass) position at the bottom of the telescope. When we're using our Cass instruments, SPIRou, ESPaDOnS, and Sitelle, we place a secondary mirror at the top of the telescope. The light enters our dome, reflects off the primary mirror to the secondary mirror, which reflects it downwards to a hole in the primary mirror. The secondary mirror is coated with the same thin layer of aluminum as our primary mirror and its coating is no less critical than the primary mirror.

Figure 1 — CFHT staff use carbon dioxide snow to clean off the surface of the secondary mirror.

The secondary mirror sits covered on the dome floor when not in use. With MegaCam generally on the telescope for 10–14 days per month, the secondary mirror sees roughly half the exposure to the elements as our primary mirror. Thus, we don't have to coat the mirror as often as we coat the primary mirror. But we were well past due and decided to recoat in early September of this year.

Recoating the secondary mirror takes fewer staff than recoating our primary mirror; it is only 1.4 m in diameter as opposed to our 3.6-m primary mirror. The rest of the process remains the same—the mirror is removed from its housing, cleaned several times, the old aluminum coating is removed, and the mirror is moved into the aluminizing chamber.

Prior to the mirror entering the chamber, staff prepare the chamber by placing aluminum filaments into holders on the top of the chamber. Once the mirror sits in the chamber, air is removed making the chamber a vacuum. That is when the "flash" occurs—electricity is run through the filaments, vaporizing them. As the material cools, the aluminum falls to the mirror, ensuring an even coating.

Two metrics are used to determine if the coating was a success or not. First, did the aluminum adhere to the surface? CFHT engineers devised a fast, simple test. They place a piece of pressure-sensitive tape on the mirror. If the coating stays on the glass when the tape is removed, the coating adhered properly. They next use an interferometer to measure the thickness of the coating. Our current coating is 130 nm thick, just right.

Let's take a look at the science we can achieve with our secondary mirror and ESPaDOnS.

Figure 2 — Inside the CFHT coating chamber post flash.

White Dwarfs Become Magnetic as They Get Older

(Author's note: like many of the news releases I share in this column, the text below is not solely my own.)

An international team of astronomers from Armagh Observatory in Northern Ireland and Western University in Ontario Canada recently announced new insights into the origin and evolution of the magnetic field of white dwarfs. The team used ESPaDOnS at CFHT, the ISIS spectrograph/spectropolarimeter at the William Herschel Telescope (WHT), and FORS2 at the European Southern Observatory (ESO) to carry out a spectropolarimetric white-dwarf survey out to 20 parsecs from the Sun.

More than 90 percent of the stars of our galaxy end their lives as white dwarfs. Although many have a magnetic field, it's still unknown when it appears on the surface, whether it evolves during the cooling phase of the white dwarf and, above all, what the mechanisms are that generate it.

At least one out of four white dwarfs will end its life as a magnetic star, thus magnetic fields are an essential component of understanding their complexities. New insights into the magnetism of these stars from the team's survey provide the best evidence obtained so far of how magnetism in white dwarfs correlates with age. This could help to explain the origin and evolution of magnetic fields in white dwarfs.

"White dwarfs are the remnants of stars that have run out of fuel and collapse. By nature, they become cooler and fainter with time," says Dr. Stefano Bagnulo, Armagh Observatory and lead author of the paper. "Observations tend to favour the study of the brightest, most massive, hottest white dwarfs, which are the youngest. In our survey, we chose to include older, fainter white dwarfs with the hopes we could learn more about the continued evolution of these remnants."

The team observed all the white dwarfs from the *Gaia* catalogue that lack previous high-precision magnetic measurements in the region within 20 parsecs (65 light-years) of the Sun; obtaining new data for 87 of the 152 stars in the region. The team took spectra of the white dwarfs using three spectropolarimeters, critical instruments to understanding magnetic fields. Spectroscopy breaks the light from one star into its component rainbow or spectra, allowing astronomers to learn

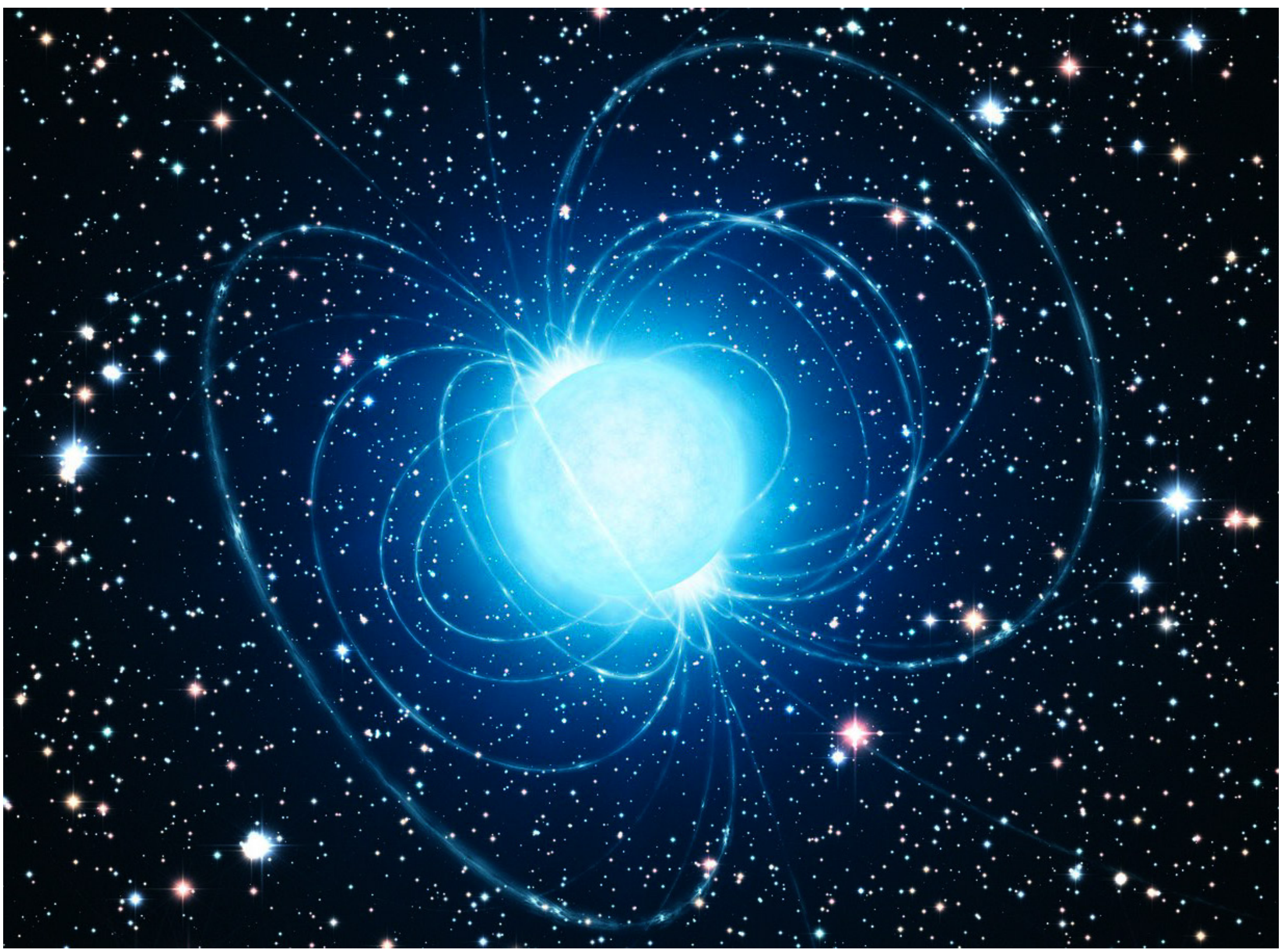


Figure 3 — Artistic rendition of the magnetic field of a white dwarf. Credit: ESO/L. Calçada.

more about the object's composition, temperature, etc. An instrument with spectropolarimetric capabilities, like those used by the team, enhances the study of an object by increasing the sensitivity and detection of magnetic fields by more than two orders of magnitude better than spectroscopy alone.

"Most white-dwarf observations are made using spectroscopic techniques sensitive to only the strongest magnetic fields, thus failing to identify a large fraction of magnetic white dwarfs," said Dr. John Landstreet of Western University and a co-author on the paper. "Two thirds of the stars in our survey were observed for the first time in spectropolarimetric mode, enabling our team to record previously undetected magnetic fields."

The team used CFHT's ESPaDOnS to make a quarter of the observations for the survey. ESPaDOnS is a high-resolution spectrograph that can be used in a high-resolution spectropolarimetric mode for observations like those made by the team. Landstreet was the primary investigator in Canada for the NSERC grant that funded the development of ESPaDOnS's camera and has worked with the instrument since its commissioning in 2004.

The team found magnetic fields are rare at the beginning of the life of a white dwarf. The star no longer produces energy in its interior and starts its cooling phase. These observations demonstrate that magnetic fields do not appear to be a characteristic of a white dwarf since its "birth." Most often, the magnetic field is either created or brought to the stellar surface during the white dwarf's cooling phase.

The team also found the magnetic fields of white dwarfs do not show obvious evidence of decaying over time. The results indicate the magnetic fields are generated during the cooling phase or at least continue to emerge at the stellar surface as the white dwarf ages.

This picture is different from what is observed in larger, hotter magnetic main-sequence stars, like Ap and Bp type stars. In these large stars, astronomers find magnetic fields are present as soon as the star reaches the zero-age main sequence, when they start to fuse hydrogen in their core, and that the magnetic-field strength quickly decreases with time (details also uncovered with data from ESPaDOnS). Magnetism in white dwarfs therefore seems to be a totally different phenomenon than magnetism of larger, hotter, Ap and Bp type stars.

Magnetic fields in white dwarfs appear more frequently after the star's carbon-oxygen core begins to crystallize. One explanation for the cause of these magnetic fields is a dynamo mechanism, which explains the weakest fields detected by the team. A dynamo mechanism occurs when a rotating object, like a white dwarf or the Earth, contains a molten, electrically conducting fluid. In a white dwarf, the crystallizing carbon-oxygen core may generate the magnetic field in the same way the Earth's molten iron core generates its magnetic field.

While the dynamo mechanism holds potential to understand white-dwarf magnetic fields, further theoretical and observational investigation is necessary. Dynamos require fast rotation in an object, a trait not generally observed in white dwarfs. Dynamo mechanisms can explain magnetic fields up to 100,000 Gauss (for reference, Earth's field is 1 Gauss), and astronomers have observed magnetic fields up to several hundred million Gauss in some white dwarfs. The team plans further work to untangle the mystery of white-dwarf magnetic fields.

"John Landstreet's used CFHT for decades and brings an expertise to observations that make the best use of CFHT," said Dr. Nadine Manset, ESPaDOnS instrument scientist at CFHT. "After years of observations pushing the limits of ESPaDOnS, these results expand our understanding of white dwarfs and create new questions to be explored." ✶

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

John Percy's Universe

Dragonfly!

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

Novel. Unique. Photogenic. Inexpensive (relatively speaking). Simple (relatively speaking). Powerful. Productive. And (half) Canadian. That's Dragonfly—the Dragonfly Telephoto Array.

It all began over beer. My colleague Roberto Abraham and his Yale collaborator Pieter van Dokkum were imbibing at a Nepalese restaurant in Toronto—and commiserating. Commiserating about how astronomical instrumentation projects had such bloated timelines and budgets. How "slow and expensive" meant nobody was taking risks. How that was so bad for grad students, who couldn't wait forever to complete their theses. Definitely not fun. And commiserating about how galaxy-evolution theorists love to make predictions about stuff at low surface brightness because existing telescopes were not capable of seeing it. You can hide away anything there, because it's an astronomical window that had not yet been opened. The ideas flew, and a solution emerged—Dragonfly!

The prevailing CDM (Cold Dark Matter) theory of Universe evolution predicts that there should be a wealth of complex structures below the surface-brightness limits of existing wide-field telescopes—due to large galaxies swallowing up small ones—and other aspects of galaxy formation and evolution. Dragonfly was developed to explore small and diffuse galaxies and tidal streams and other structures in this ultra-low-surface-brightness Universe.

Dragonfly lives at the New Mexico Skies observatory, where its operation is completely automated. It may look rather conventional (Figure 1), though unusual—like a nest of paparazzi—but it actually incorporates a wide variety of cutting-edge technologies. It consists of a number of high-end, commercially available Canon 143-mm *f*/2.8 telephoto lenses, each one coupled to a science-grade commercial CCD camera. Dragonfly was commissioned in 2013 with three lenses, made its formal debut (Abraham and van Dokkum 2014) with eight, and presently has 48, in two clusters. It is funded for an expansion to 168 lenses, which would make it the largest refracting telescope in the world, in terms of collecting area. Further expansion is entirely possible, funding permitting. Dragonfly's field of view is a whopping six square degrees—absolutely immense by large reflecting telescope standards. The lenses are mounted on a common framework and co-aligned to image the same piece of sky. The system has no obstructions in the light path, optimized baffling, internal optical surfaces coated with a new generation of anti-reflection coatings. This enables it, with 10-hour integrations, to image extended structures with surface brightnesses an order of magnitude fainter than most other telescopes. With longer exposures, it could go even deeper.

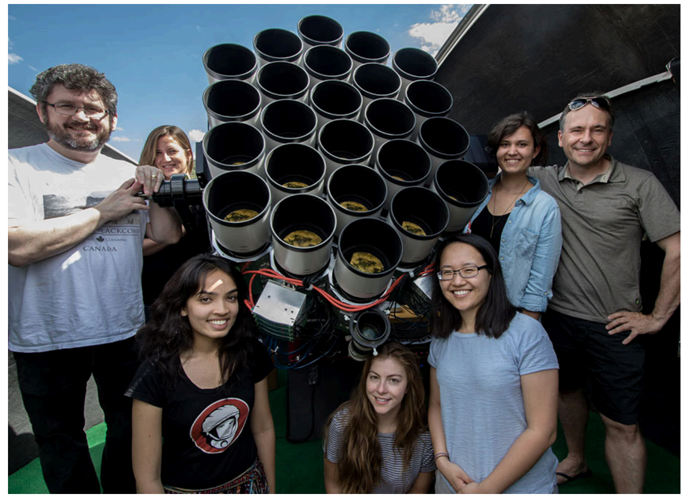


Figure 1 — Dragonfly, and its obviously very happy team, at its home in New Mexico. From left, Roberto Abraham, Shany Danieli, Lamiya Mowla, Deborah Lokhorst, Jielai Zhang, Allison Merritt, and Pieter van Dokkum.

These are the more visible innovations. There are more, behind the scenes. To quote the Dragonfly website (1), they also include "the use of AI planning tools to optimize nightly observations and survey design, unit-based basic data processing with compute sticks, the application of the Internet of Things operational protocols to communicate with the 48 lenses, and fully automated gate-driven, cloud-based data analysis." Obviously state-of-the-art, packed into a very small volume.

Dragonfly has already produced about 50 research papers (2), so I shall mention only some highlights.

In the first major Dragonfly survey, van Dokkum, Abraham *et al.* (2015) reported the discovery of 47 low-surface-brightness galaxies in the Coma Cluster. Their sizes are comparable with that of our Milky Way Galaxy, but their stellar masses are hundreds of times less. They are completely dominated by dark matter—whatever that is. It's one of the big mysteries of the Universe today, and Dragonfly may help to solve it. The authors suggest that, early on, these "ultra-diffuse galaxies" may have lost their gas supply, and hence their ability to form new stars, possibly resulting in very high dark-matter fractions as compared with that of the Milky Way, in which the dark matter is "only" about 10 times the stellar mass. The formation and evolution of galaxies is obviously much more diverse than previously thought.

On the other hand, van Dokkum, Abraham *et al.* (2018) found that NGC 1052-DF2, an ultra-diffuse galaxy, has almost no dark matter! The total mass of the galaxy, as measured by motions of globular clusters within it, is about the same as the mass of visible stars alone. The galaxy has at least 400 times less dark matter than would be expected from previous surveys. So, galaxies are a very diverse lot, from almost all dark matter to almost all stars! There is still much to be learned about galaxies, even our own.

Other Dragonfly publications have explored such topics as galactic haloes around edge-on galaxies, as well as ways of pushing the Dragonfly technology further, such as into narrow-band imaging. This would enable Dragonfly to detect faint clouds of gas around galaxies—part of the flow of gases into and out of galaxies, as they interact and evolve. These new directions are all made possible by Dragonfly's unique ability to image low-surface-brightness sources. To quote Bob Abraham, "Dragonfly could well be the first example of a completely new class of optical telescope."

The project's commitment to fostering the development of early career researchers has led to extraordinary outcomes. Figure 1 shows the Dragonfly team. It includes five graduate students. Notice how happy they look. Their experience was greatly enhanced by being part of a small, closely knit, hands-on team, rather than a huge collaboration. Jielai Zhang (University of Toronto) won an inaugural Schmidt Science Fellowship—arguably the most prestigious of all interdisciplinary science postdoctoral fellowships. Shany Danieli (Yale) won a Cosmology prize and a major Doctoral Dissertation award, and now holds a joint Hubble–Carnegie fellowship at the Institute for Advanced Study. Deborah Lokhorst (University of Toronto) passed up offers of seven prestigious postdoctoral fellowships to take a special position at Canada's Herzberg Institute of Astrophysics, designed to accelerate the development of leaders in astronomical instrumentation.

Despite the pandemic, the summer of 2021 has been extremely productive for students working on the project, as Bob Abraham reports. Deborah Lokhorst has submitted her Ph.D. thesis and is about to submit a paper on a totally unexpected—and bizarre—gigantic H-alpha shell of gas around M82. Colleen Gilhuly has submitted a paper on the Dragonfly edge-on galaxy survey. Qing Liu has submitted a paper showing how Dragonfly`s point-spread function is ten-times better than most other large telescopes for low-surface-brightness work. He is now writing up a seriously cool (in Abraham`s words) paper on modelling galactic cirrus with Dragonfly data. Seery Chen has built a rig in the lab to test out the first of the ultra-narrow-bandpass filters for the big Dragonfly upgrade. Now they are off to New Mexico! Michael Keim has modelled the outer light profiles of supposedly dark-matter-free galaxies, confirmed that they indeed do not have a lot of dark matter, and submitted a paper on this. Imad Pasha has submitted a paper reporting the discovery of a tidal dwarf galaxy in formation around M82—a galaxy well known to many RASC observers. When you look at this, or any other galaxy—including our own—remember that there is much that we do not see, or know, about them.

Dragonfly has also intrigued the media (3), including CBC's flagship science program Quirks and Quarks. The eminent physicist Freeman Dyson, in a news interview in 2016, declared it the scientific highlight of the year.

"So it happens that a small, cheap observatory can make a big, new discovery about the structure of the universe. … The moral is that a modest fraction of the astronomy budget, perhaps as much as a third, should be reserved for small, cheap projects. From time to time, a winner such as Dragonfly will emerge," he said.

I would like to think that one reason for the success of Dragonfly is Abraham's personal affinity for telescopes (4). He has an observatory in his own backyard, and telescopes ranging up to a 22″ Dobsonian. He is the long-time Honorary President of the RASC Toronto Centre, as well as an award-winning teacher, Chair of the David A. Dunlap Department of Astronomy and Astrophysics here at the University of Toronto, and a past president of the Canadian Astronomical Society. As well, he is a Fellow of the Royal Society of Canada. But if the word "amateur" connotes someone who loves their subject, Roberto is a true amateur, as well as one of Canada's most honoured professionals. ✶

Acknowledgement

I would like to thank Roberto Abraham for providing useful documents, updates, and other comments for this column, as well as for his infectious enthusiasm for all things astronomical.

Endnotes

1 www.dragonflytelescope.org

2 www.dragonflytelescope.org/publications

3 www.dragonflytelescope.org/news

4 www.robertoabraham.com

References

Abraham, R.G. and van Dokkum, P.G. (2014), Ultra-low surface brightness imaging with the Dragonfly Telephoto Array," *Publ, Astron. Soc. Pacific, 126*, 55.

Van Dokkum, P.G. *et al*. (2015), Forty-seven Milky-Way-sized extremely diffuse galaxies in the Coma cluster," *Astrophys. J. Letters, 798*, L45.

Van Dokkum, P.G. *et al*. (2018), "A galaxy lacking dark matter," *Nature, 555*, 629.

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

Dish on the Cosmos

The Chemistry of Young Planetary Systems

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

Exoplanetary science is the fastest moving field in astrophysics. In the past 25 years, we have gone from discovering the first planets outside our Solar System to a transformative view of thousands of planetary systems. These observations are only scratching the surface, finding the extreme and easy-to-detect systems. Planets like Earth remain a challenge to find, and we will find orders of magnitude more planets as our observations improve. A parallel revolution has been happening in studying how these planets form, driven primarily by the Atacama Large Millimetre/submillimetre Array (ALMA). The field has been amazed by the early images coming from the observatory. However, with the novelty of the initial discoveries behind us, teams using ALMA are getting down to doing the hard work: surveys. By studying several different protoplanetary disks using ALMA, we can see what features represent underlying patterns that give us insight into how planets form and what features are the happenstance of an individual stellar system. Recently, the Molecules with ALMA at Planet-forming Scales (MAPS) survey released their first results, revealing an exciting new look at the chemistry of planet formation.

MAPS used ALMA to map five separate protoplanetary disks in different stages of planet formation. These five systems were chosen because they were nearby, so the ALMA telescope could see the details of the disk structure. The systems had all been studied with ALMA before, so they were known to have bright emission. The disks were close to face-on, so that the team could study the radius changes in the sample. Finally, the systems have a central-star mass between 1.1 and 2 times that of the Sun, so these targets are similar to the type of systems that could form our Solar System.

ALMA's amazing resolution has been key in making these new studies, with an angular resolution of 0.1 arcseconds in the highest resolution MAPS images. Despite this amazing resolution and the nearby systems, the study was still limited to seeing objects 10 astronomical units across or larger, where 1 AU is the distance from Earth to the Sun. For reference, the 10 AU scale would reach from the Sun out to the orbit of Saturn. The MAPS survey sees all this area as just the central pixel of the map and then charts out from there to distances of >700 AU. These are maps of what would be the outer parts of our Solar System. Even so, the previous ALMA observations showed ongoing planet formation in these outer regions making them a good target to study.

The February 2022 *Journal* deadline for submissions is 2021 December 1.

See the published schedule at

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

One of the unique capabilities of ALMA used in the MAPS study is the ability to simultaneously provide several different views of the same object. MAPS studied two different types of light (emission) from their targets: spectral lines from molecules and the continuous emission from dust grains. Spectral lines arise from a quantum transition in the energy of molecules and atoms. In this case, the transitions are usually between different speeds of rotation. Because of the quantum nature of molecules, these transitions are discrete and always give off a fixed amount of energy, corresponding to a photon at a set frequency that can be observed by ALMA. Each molecule has a different set of spectral lines, so we can map out different chemical species just by looking at different frequencies of light waves. ALMA can study several different frequencies simultaneously.

The other type of light—continuum—comes from dust grains in the protoplanetary disks. In addition to molecules, these disks are filled with condensed matter of a huge range of different sizes ranging from several atoms up to the pebble- and boulder-sized objects that feed planet formation. Dust grains are large enough that they emit a continuous spectrum of radiation throughout the range of frequencies that ALMA can observe. This continuum emission is distinct from the discrete energies of spectral lines. Continuum emission gives us clues to the nature of dust grains through the relative amounts of radiation at different frequencies. For example, more radiation at short frequencies suggests that small dust grains are more abundant relative to larger grains. The relative frequency of different dust grains gives us clues as to how material builds from small particles into larger grains and then to pebbles and on to planets.

Figure 1 shows some of the images created by MAPS showing different systems (columns) in different molecules (rows). The most striking thing about these images is how different each of them looks. The targets show the huge diversity of distributions for a single type of molecule. In some cases, the emission is concentrated into the centre, some show clear rings, and some show emission throughout. By considering all these images together, the MAPS project worked toward developing new insights around planet formation.

Our current model of planet formation is built around the idea that planets accrete from material in the nearby parts of the protoplanetary disks. The planets start out as large grains of dust like those found throughout the gas of the galaxy. In the cold, dense regions where stars form, volatile elements

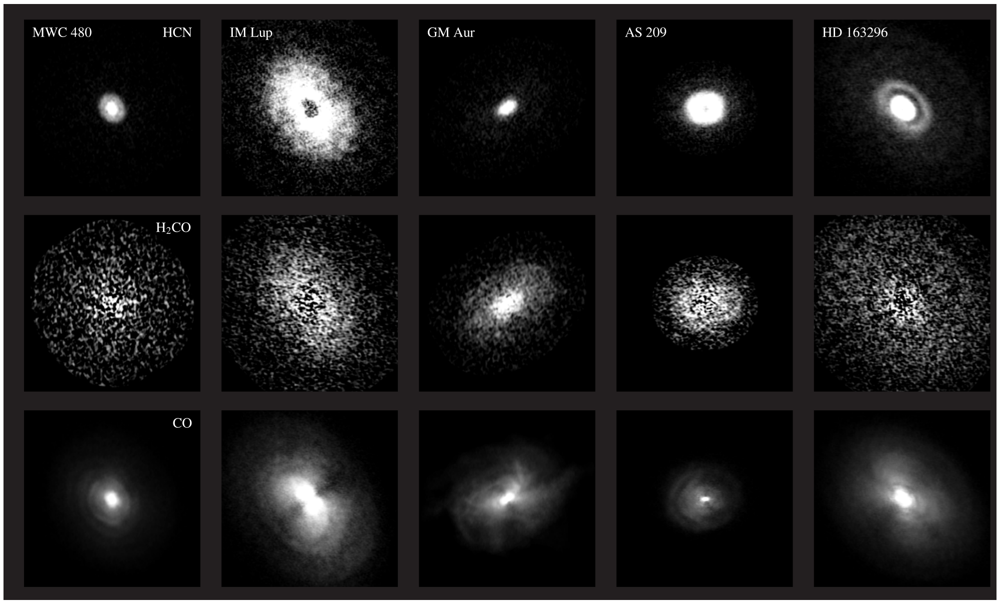


Figure 1 — Molecules in five different protoplanetary disks as imaged in the MAPS program conducted with ALMA. Each column shows one of five different systems that was imaged and the rows show (top to bottom) emission from hydrogen cyanide (HCN), formaldehyde (H2CO), and carbon monoxide (CO). The disks show a wealth of different structures highlighting the chemical complexity of forming planetary systems. These molecules will likely be incorporated into comets and giant planets in the outer parts of these forming planetary systems. Credit: ALMA(ESO/NAOJ/NRAO) and Erik Rosolowsky using data from the MAPS survey (K. Öberg et al., 2021).

freeze onto the surface of these dust grains, increasing their mass. The dust grains stick to each other when they are pushed together, growing to form loose, snowy pebbles of matter, which then build up into boulders and on to planets. This buildup of material is sped up by two effects: having a lot of volatile matter that can freeze onto the dust grains and, later in the process, a gravitational runaway where the more-massive objects become "stickier" through their gravitational pull so that accreting material is more likely to stick to the surface of the building planets. In a protoplanetary disk, the amount of volatile material that freezes onto grains is set by the "snow lines" of different molecules. If the temperature is above a molecule's freezing point, it will be found as a vapour in the protoplanetary disk. Otherwise, it will freeze onto the surface of the dust grains. The best known "snow line" in planetary systems is the water/ice line, which is the key difference between the inner and outer planets in this Solar System. By having more material on the planetary seeds, the outer planets (Jupiter, Saturn, Uranus, and Neptune) were able to build up faster, growing much larger than the inner planets. These systems also have sufficient gravitational attraction to pull in gas from the surrounding disk.

In addition to the snow line for water, the other major snow line is the carbon monoxide (CO) snow line. This occurs much farther out in the protoplanetary disk. These snow lines are important not only because they increase the mass in grains, but also because they take these chemicals out of the gas phase. This changes the reactants and thus the chemistry that is taking place in the disks. CO is thought to dominate the chemistry of protoplanetary disks when it is abundant as a gas. The freezing out of most of the CO changes the chemistry and allows a vastly different set of reactions to proceed. Given that MAPS is focused on the chemistry in the outer parts of these forming stellar systems, which are mostly outside the CO snow line, they naturally see a vibrant chemistry, surprisingly dominated by nitrogen-bearing species. The simplest of these observed chemicals is hydrogen cyanide (HCN, see Figure 1), but there is a wealth of more complicated species. Larger nitrogen-rich molecules are also expected to be found in the disk but are not directly observed by ALMA. These are particularly interesting from the perspective of the origin of life since these regions of the disks are where comets may form. Comets are likely essential for bringing these prebiotic and volatile elements into the inner parts of planetary systems after the first stages of their formation. Indeed, the MAPS results find peculiar abundances of different species that imply that chemistry of forming disks is not constant and that there is a flow of material from the outer system to the inner planetary system.

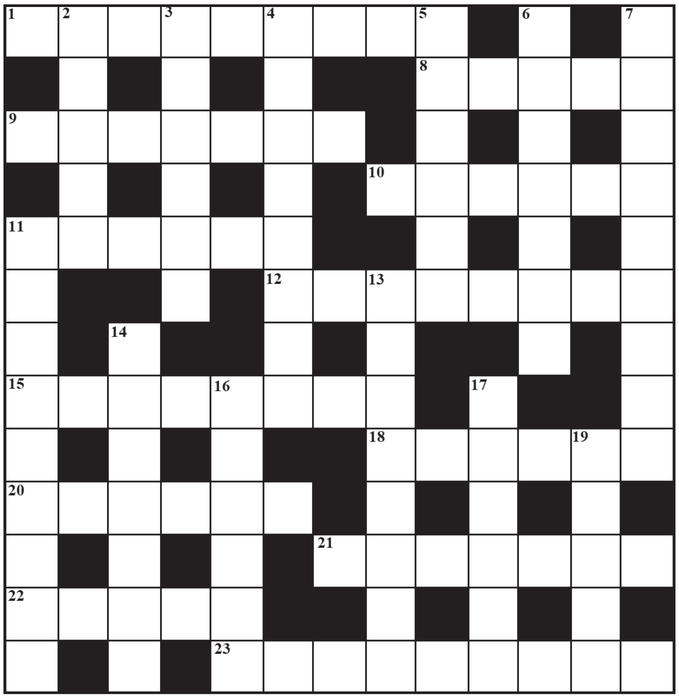
The MAPS data are incredibly complex and the hope for a unifying understanding has not immediately emerged, but seeking complex solutions will drive us to a broader understanding. The MAPS data have only begun to be explored and understood. Looking to the future, more information will come from expanding the observations, not only in studying more disks but also in observing other molecules in these five targets to piece together other parts of the chemical networks that shape these systems.

Read more: https://alma-maps.info/ ✶

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. Sainted woman inflamed the star numbers (9)
8. Resembling a hunter he rode Delphinus to safety (5)
9. Fabled hero peruses about his exploits (7)
10. Shortened star seems to spit out bits of 1P/Halley (3,3)
11. Resembling a harp, leaves turn early around start time (6)
12. Element to lead lead: Ha! Mull it over. (8)
15. Hairy leg scattering turns the Moon orange (8)
18. Bull rider races around Jupiter (6)
20. 60's star in Hercules underwent severe changes (6)
21. Their old Sky & Tel ads did not ruin circulation (7)
22. Stop the Mars mission due to AI change of orbit (5)
23. The study of a variable star and disrupted moon at Yerkes (9)

DOWN

2. Suspicious of broken harp around eastern sky (5)
3. May first precedes lost cause of a southern fly (6)
4. Possible neighbourhood exoplanet south of Mira (3,4,1)
5. Metrical foot from Ida's companion (6)
6. On a Jovian moon I'm caught in a hailstorm with first aid (7)
7. A modern ad composed to attract a princess (9)
11. Some Centres have one to balance splattered rain (9)
13. A rancher seen dancing at the river's end (8)
14. Theoretical particle, one emitted from Saturnian moon (7)
16. A blanket offers no warmth around Copernicus (6)
17. Hydrogen nucleus is for a heavyweight (6)
19. Citizen science collaboration for morning observers (3-2)

Answers to previous puzzle

Across: **1** MIRANDA (Mir(and)a); **5** THEBE (hid); **8** MOTOR (r(t)ev); **9** CEPHEID (anag with HD); **10** SANDAGE (hid); **11** INDEX (2 def); **12** DIVERGING LENS (anag); **15** GRIGG (g+Rigg) **17** NEREIDS (2 def); **20** EQUULEI (an(L)ag+i); **21** CHARA (hid); **22** SITES (S+rev); **24** COESITE (anag)

Down: **1** MIMAS (rev+mas); **2** ROTANEV (an(N)ag); **3** NORMA (anag); **4** ACCRETION DISC (anag); **5** TAPPING (2 def); **6** EMEND (e(men)d); **7** EUDOXUS (rev+OX+us); **12** DEGREES (2 def); **13** REGULUS (2 def); **14** ERIDANI (anag); **16** INUIT (I+nuit); **18** ROCHE (2 def); **19** SPACE (anag)

Index to Vol. 115, 2021

Compiled by James Edgar

Titles

Authors

Columns

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Great Images

by Dave Chapman

A page from Dave Chapman's logbook from 2020 October 1, with his sketched interpretation of Mars.

Journal

The Pleiades, a winter favourite, was captured by Stefanie Harron using a Canon EOS 5D Mark IV with a 400-mm lens on a Celestron AVX mount.