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Journal

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PROMOTING
ASTRONOMY
IN CANADA

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Newbie No More

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Rho Ophiuchi Cloud Complex

The Best of Monochrome.

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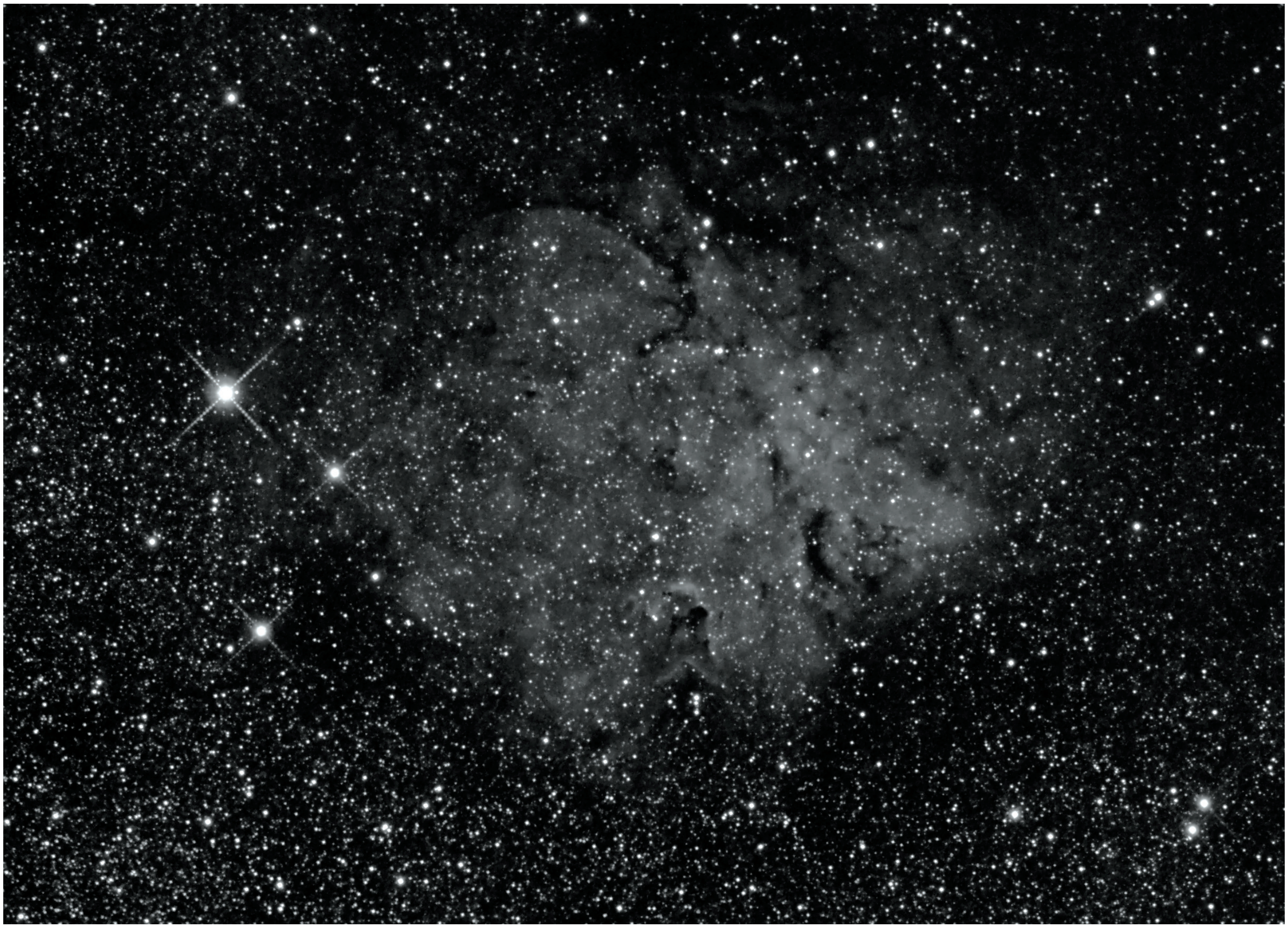

Ron Brecher took this image of Sh2-72, an emission nebula in Aquila from SkyShed in Guelph, Ontario, combining the red, green, and blue colour channels with data collected through a deep red H-alpha filter. Brecher used an SBIG STL-11000M camera, Baader Hα, R, G, and B filters, and a10α f/6.8 ASA astrograph on a Paramount MX for a total of 15 hours.

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Société Royale d'Astronomie du Canada

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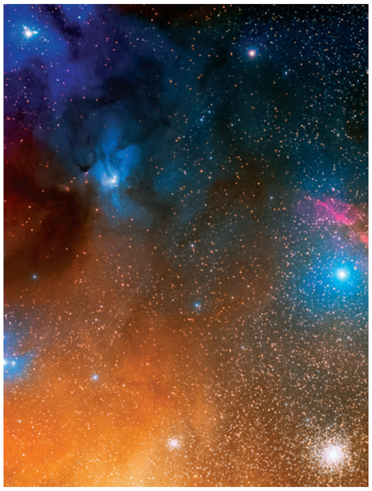

Accomplished astrophotographer Lynn Hilborn imaged the heart of the Rho Ophiuchi cloud complex from his Whistlestop Observatory in Grafton, Ontario. Hilborn used a TS71 telescope at ƒ/5, Moravian G2-8300 camera, and Baader filters on a Tak NJP Temma2 mount.

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.

His Excellency the Right Honourable **David Johnston**, C.C., C.M.M., C.O.M., C.D., Governor General of Canada, is the Viceregal Patron of the RASC.

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President's Corner

by Craig Levine, London Centre
(craigslevine@gmail.com)

As the deadline for this column rapidly approached and then suddenly leapt out at me like my smallest cat making a valiant attempt to get our eldest border collie to play with him, I began thinking about the RASC, how I perceive it, and how it is perceived by the many constituencies within our venerable society and beyond. The more I thought about it, the more it became clear how multifaceted the answer to the question "What is the RASC?" and, depending on the facet that's being examined, it can be a very good thing, or it can present challenges and accompanying opportunities.

What we are can be broken down into three core functions: a membership organization, a charitable entity, and a publishing concern. I want to focus on the membership organization component for this column.

Much of our activities happen at the local level in our Centres, and this is where the majority of our members are focused. For them, the RASC is their club for all things astronomy, for attending public talks, engaging in outreach if they are so inclined, observing, and for the fellowship of a shared passion. And rightly so. For many of our members, myself included, our local Centres were the catalyst that ignited our life-long love of astronomy and the RASC.

A smaller subset of our membership is involved with the RASC's national activities on Council, committees, the Board, as writers and editors, and as speakers willing to travel to one of our many Centres to share their knowledge and experiences. They, and many of our members in general, feel no small measure of pride in being part of a truly national organization that is held in high regard for its venerable and long history, and for the consistent quality of its publications. That our *Observer's Handbook* can be found in a great many professional observatories is testament to the dedication and passion of our long line of editors and contributors. Our local, national, and international reputation's foundation, our *gravitas* if you will, is built on our members who donate so freely of their time either at their Centres and are the face of public astronomy in Canada, or who have a passion for our being part of something pan-Canadian in support of our members in all regions. And the Society as a whole.

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A challenge the RASC faces in regard to growth and our demographics may lie in perception. We have the word "Royal" in our name (and I'm proud of it), and our raison d'être has the weight of science behind it. I'm musing here, but I think that combination may intimidate some. I think back to the time when I discovered the RASC, and my image of the RASC based on those two factors was vastly different from the wonderful reality that has played a large role in my adult life. Our demographics skew disproportionately to male, Caucasian, and middle-aged and older. That tells me that at the national and local levels, we have to work harder and smarter at reaching out to Canadian women, youth, and adults from the diverse communities across our county and within the regions our Centres draw their members from. This is an opportunity for all levels of the organization to grow, spread the joy of astronomy further, and to bring fresh ideas and initiatives into our tent.

Reaching out to new members and incorporating fresh perspectives will require new ideas and methods of outreach from all levels of the RASC. As we craft our strategic plan to take us into the future, I'm looking forward to hearing and discussing the innovative ideas our members will bring forward. ✶

News Notes / En Manchettes

Compiled by Jay Anderson, FRASC

Rosetta settles into retirement

The *Rosetta* spacecraft, in orbit around Comet 67P/Churyumov-Gerasimenko for a little over 2 years, made a gentle crash-landing on September 30, ending its mission after a 12-year expedition. Despite some setbacks, particularly the early shutdown of its Philae lander, the spacecraft rewrote much of our understanding of cometary behaviour, chemistry, and physics.

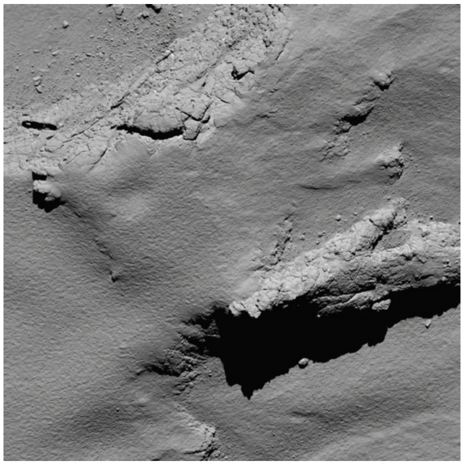


Figure 1 — Rosetta's OSIRIS narrow-angle camera captured this image of Comet 67P/Churyumov-Gerasimenko at 08:21 UT during the spacecraft's final descent on September 30. The spacecraft was at an altitude of 5.7 km at the time. The image scale is about 11 cm/pixel and the image measures about 225 m across. Image: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

Rosetta was launched on a 10-year journey in April 2004, reaching the comet in April 2014 after making close approaches to two asteroids: 2867 Steins and 21 Lutetia. Three months after arrival, *Rosetta* deployed the probe Philae, which made an uncoordinated landing on the comet and was able to send measurements and images for only 48 hours before its battery ran down. *Rosetta* itself operated nearly flawlessly, observing Churyumov-Gerasimenko from beyond the orbit of Mars to past perihelion and onward. A trooper to the end, *Rosetta*'s last image was taken from only 20 m above the comet's surface. Though the touchdown was less than a walking pace, the spacecraft was programmed to shut down its radio on contact and will now travel silently with the comet and Philae until 67P evaporates.

Some of the discoveries made by *Rosetta* and Philae:

- water on the comet had three times the deuterium content of that on Earth. This implies that Earth's water does not seem to have come from comets, if Churyumov-Gerasimenko is a typical specimen. This observation, compounded with measurements of molecular nitrogen, molecular oxygen, and argon suggest that the comet was formed in the icy outlying parts of our Solar System rather than in the warmer inner regions.
- Computer modelling shows that escaping water vapour comes from a nearly uniform distribution of dirty ice spread across the comet. Regions with collimated jets were associated with cliff edges and pits, though much work remains to be done in tracing the source regions of many active outbursts. Particles ejected ranged up to metre size.
- *Rosetta*'s outflowing coma interacted with and blocked the solar wind to create a cavity around the nucleus, but this was much larger than expected at maximum emission rates. While it was expected to reach several tens of kilometres ahead of the comet, observations showed that it reached more than 180 km sunward.
- Radio waves passed between *Rosetta* and Philae while on opposite sides of 67P showed that the head of the comet was very porous—about 75–80 percent. The comet is a very loosely compacted mixture of dust and ice. The high porosity suggests that the comet's formation was a gentle process, with primordial bits and pieces colliding with speeds of 1 m/s or less. High-resolution images of the

interior of pits on the comet surface show structures about 3 m in size; computer modelling suggests that the original cometesimals would be about that size.

- The two-lobed "duck" shape of the comet, joined by a thinner neck, shows that 67P is actually formed of two bodies that "bumped" together some four billion years ago.
- Detailed studies of the dust and gas emitted during the approach to perihelion showed the presence of organic compounds such as glycine and ethanol. Philae detected the presence of glycolaldehyde. Dust particles also provided surprises, containing unique carbon-bearing molecules in a form so complex that they have yet to be given a name. The carbon was mixed with elements such as sodium, magnesium, aluminum, silicon, iron, and calcium in a complex macromolecular compound that resembled material in carbonaceous chondrite meteorites except for a much larger presence of hydrogen.
- The coma consisted primarily of water vapour, carbon dioxide, and carbon monoxide, but Philae detected a few smellier compounds: hydrogen sulphide, ammonia, and hydrogen cyanide. For the curious, that means rotten eggs, bitter almonds, and cat urine.

Rosetta captured the public's imagination with moments of high drama, intrigue, and scientific discovery. It was a major triumph for European space science. This year has been a very good one for Solar System exploration.

Compiled with material provided by the European Space Agency

OSIRIS-REx starts a long journey

On September 4, an Atlas 5 rocket lifted off from Cape Canaveral carrying NASA's Origins, Spectral Interpretation, Resource Identification, Security and Regolith Explorer (*OSIRIS-REx*) spacecraft on a mission to asteroid 101955 Bennu and back. It's a long journey: after one orbit, *OSIRIS-REx* will use the Earth's gravity to boost its path outward to Bennu, which it will reach in 2018. The asteroid will be studied for two years, after which the spacecraft will lower itself gently toward Bennu to pick up a small sample of the comet's regolith. If all goes well, the spacecraft will depart homeward with its precious 60-gram treasure in early 2021, eventually ending its long journey with a parachute landing in Utah on 2023 September 24.

Bennu is an Earth-crossing, 490-metre diameter, carbonaceous asteroid of the Apollo type with a relatively high (0.037 percent) probability of striking Earth in about two centuries. Light-curve studies and radar observations carried out by ground-based telescopes show a mostly round body with a well-defined ridge along the equatorial region that suggests a fine-grained and easily removed regolith. It rotates every 4.3 hours, a speed slow enough that the spacecraft should be able to scrape the surface without difficulty.

Bennu's dark-black surface carries promise of a carbon-rich composition that makes it an attractive target to astronomers eager to study the composition of the early solar nebula. Did asteroids such as Bennu deliver organic compounds to Earth to fuel the initial development of life? NASA liked it because its low-inclination, Earth-like orbit is relatively easy to reach, passing by our planet every six years. Astronomers also wanted to study the Yarkovsky effect, where uneven thermal emissions from the asteroid's surface impose a small force on the body as it rotates, causing its orbit to slowly evolve. These accelerations are important for the millennial changes in the asteroid's orbit and its potential interaction with the Earth.

Canada astronomers are going along for the ride. One of the major instruments on the spacecraft, a laser altimeter, has been provided by the Canadian Space Agency. The *OSIRIS-REx* Laser Altimeter (OLA) will fire short laser pulses and time their return to measure the distance to the surface, creating an accurate three-dimensional model of the asteroid. Mission scientists will use this map of the asteroid's shape, topography, and other surface features to plan the approach for the sample capture. This approach will involve a delicate maneuver in which an 11-foot arm will reach out and perform a five-second "touch" to stir up surface material, collecting at least 2 ounces (60 grams) of small rocks and dust in a sample-return container.

Development of OLA was carried out by teams lead by Dr. Michael Daly of York University and Dr. Catherine Johnson of the University of British Columbia, along with international

Figure 2 — A United Launch Alliance Atlas V rocket lifts off from Space Launch Complex 41 at Cape Canaveral Air Force Station carrying NASA's Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer, or OSIRIS-REx *spacecraft. Photo credit: NASA/Sandy Joseph and Tim Terry.*

collaborators from Johns Hopkins University Applied Physics Laboratory and Lockheed Martin Space Systems. Other scientists from around Canada were selected to lend their expertise to perform investigations that will help unravel the physical, chemical, and geological mysteries that Bennu has in store. These research teams are led by Dr. Edward Cloutis (University of Winnipeg), Dr. Rebecca Ghent (University of Toronto), Dr. Alan Hildebrand (University of Calgary), and Dr. Kim Tait (Royal Ontario Museum).

Material for this note was provided in part by the Canadian Space Agency and NASA.

V Hydrae firing superhot bullets

Astronomers using the *Hubble Space Telescope* have detected 11,000 °C blobs of gas, each twice as massive as the planet Mars, being ejected from the vicinity of V Hydrae (V Hya), a nearby red-giant star. The gas bullets, which seem to be ejected every 8.5 years, are travelling at speeds of 200–250 km/s. They are a puzzle, as red-giant stars similar to V Hya do not usually have enough energy to eject material at such velocities.

The explanation offered suggests the plasma balls were launched by an unseen companion star in an elliptical orbit that carries it close to the red giant's puffed-up atmosphere every 8.5 years. As the companion enters the bloated star's outer atmosphere, it gobbles up material. This material then settles into a disk around the companion, and serves as the launching pad for blobs of plasma, which travel at roughly 800,000 km/h. "We knew this object had a high-speed outflow from previous data, but this is the first time we are seeing this process in action," said Raghvendra Sahai of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, lead author of the study. "We suggest that these gaseous blobs produced during this late phase of a star's life help make the structures seen in planetary nebulae."

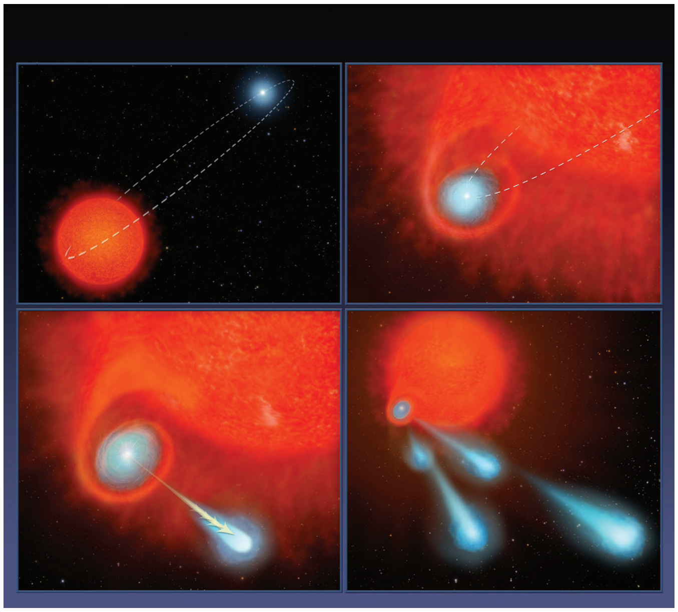


Figure 3 — This four-panel graphic illustrates how the binary-star system V Hya is launching balls of plasma into space. Panel 1 shows the two stars orbiting each other. One of the stars is nearing the end of its life and has swelled in size, becoming a red giant. In panel 2, the smaller star's orbit carries the star into the red giant's expanded atmosphere. As the star moves through the atmosphere, it gobbles up material from the red giant that settles into a disk around the star. The buildup of material reaches a tipping point and is eventually ejected as blobs of hot plasma along the star's spin axis, as shown in panel 3. Image: NASA/ESA/STScI.

Sahai's team used the *Hubble Space Telescope* Imaging Spectrograph (STIS) to conduct observations of V Hya and its surrounding region over an 11-year period, first from 2002 to 2004, and then from 2011 to 2013. "The observations show the blobs moving over time," Sahai said. "The STIS data show blobs that have just been ejected, blobs that have moved a little farther away, and blobs that are even farther away." STIS detected the giant structures as far away as 60 billion kilometres away from V Hya, more than eight times farther away than the Kuiper Belt of icy debris at the edge of our Solar System is from the Sun.

The blobs expand and cool as they move farther away and are then not detectable in visible light. But observations taken at longer, sub-millimetre wavelengths in 2004, by the Submillimeter Array in Hawaii, revealed fuzzy, knotty structures that may be blobs launched 400 years ago, the researchers said.

A surprise from the STIS observation was that the disk does not fire the monster clumps in exactly the same direction every 8.5 years. The direction flip-flops slightly, from side-to-side to back-and-forth, due to a possible wobble in the accretion disk. "This discovery was quite surprising, but it is very pleasing as well because it helped explain some other mysterious things that had been observed about this star by others," Sahai said. Astronomers have noted that V Hya is obscured every 17 years, as if something is blocking its light. Sahai and his colleagues suggest that due to the back-and-forth wobble of the jet direction, the blobs alternate between passing behind and in front of V Hya. When a blob passes in front of V Hya, it shields the red giant from view.

Sahai and his colleagues Mark Morris of the University of California, Los Angeles, and Samantha Scibelli of the State University of New York at Stony Brook, hope to use *Hubble* to conduct further observations of the V Hya system, including the most recent blob ejected in 2011. The astronomers also plan to use the Atacama Large Millimetre/submillimetre Array (ALMA) in Chile to study blobs launched over the past few hundred years that are now too cool to be detected with *Hubble*.

The team's results appeared in the 2016 August 20 issue of *The Astrophysical Journal*.

Material for this note was provided in part by NASA

Peering behind the curtains on M78

Messier 78 is a reflection nebula in Orion, above Alnitak, the left-hand star in the Hunter's belt. Discovery of the nebula is attributed to the French astronomer Pierre Méchain in 1780, but today it is known as the 78th entry in his colleague Charles Messier's catalogue. In Messier's words, M78 was a "Cluster of stars, with much nebulosity in Orion and on the same parallel as the star Delta in the belt, which has served to determine its position; the cluster follows [is east of] the star on the hour wire at 3d 41′, and the cluster is above [north of] the star by 27′7″. M. Méchain had seen this cluster at the beginning of 1780, and reported: 'On the left side of Orion; 2 to 3 minutes in diameter, one can see two fairly bright nuclei, surrounded by nebulosity.'"

Figure 4 — In this new image of the nebula Messier 78, young stars cast a bluish pall over their surroundings, while red fledgling stars peer out from their cocoons of cosmic dust. To our eyes, most of these stars would be hidden behind the dust, but ESO's Visible and Infrared Survey Telescope for Astronomy (VISTA) sees near-infrared light, which passes right through dust. The telescope is like a giant dustbuster that lets astronomers probe deep into the heart of the stellar environment. Image: ESO.

In amateur photographs, M78 is a moderately bright, bluish nebula partnered with nearby and similar nebulas, NGC 2071 and NGC 2067. The bluish tint comes from interstellar dust grains that reflect and scatter light from the hot blue stars embedded in the nebula. New images from the European Southern Observatory's (ESO) Wide-Field Imager at La Silla Observatory in Chile shows the nebula as a glowing azure expanse surrounded by dark ribbons of dust (Figure 4) that block the light coming from behind them. These dense, dusty, cold regions are prime locations for the formation of new stars. When Messier 78 and its neighbours are observed in the submillimetre wavelengths with the Atacama Pathfinder Experiment (APEX) telescope, they reveal the glow of dust grains in pockets just barely warmer than their extremely cold surroundings. Eventually new stars will form out of these pockets as gravity causes them to shrink and heat up.

In the near-infrared part of the spectrum, the ESO's VISTA telescope (Visible and Infrared Survey Telescope for Astronomy) reveals the luminous stellar sources within Messier 78. In the centre of Figure 4, two blue supergiant stars shine brightly, illuminating the nebula. Toward the right of the image, another supergiant star illuminates NGC 2071. Besides these hot, blue stars, VISTA can also see many stars that are just forming within the cosmic dust strewn about this region, their reddish and yellow colours shown clearly in Figure 4. These newborn stars are found in the dust bands around NGC 2071 and along the trail of dust running toward the left of the image. Some of these are T Tauri stars, which often generate prominent outflows called Herbig-Haro objects. Although relatively bright, T Tauri stars are not yet hot enough for nuclear fusion reactions to have commenced in their cores. In several tens of millions of years, they will attain full "starhood," and will take their place alongside their stellar companions lighting up the M78 region.

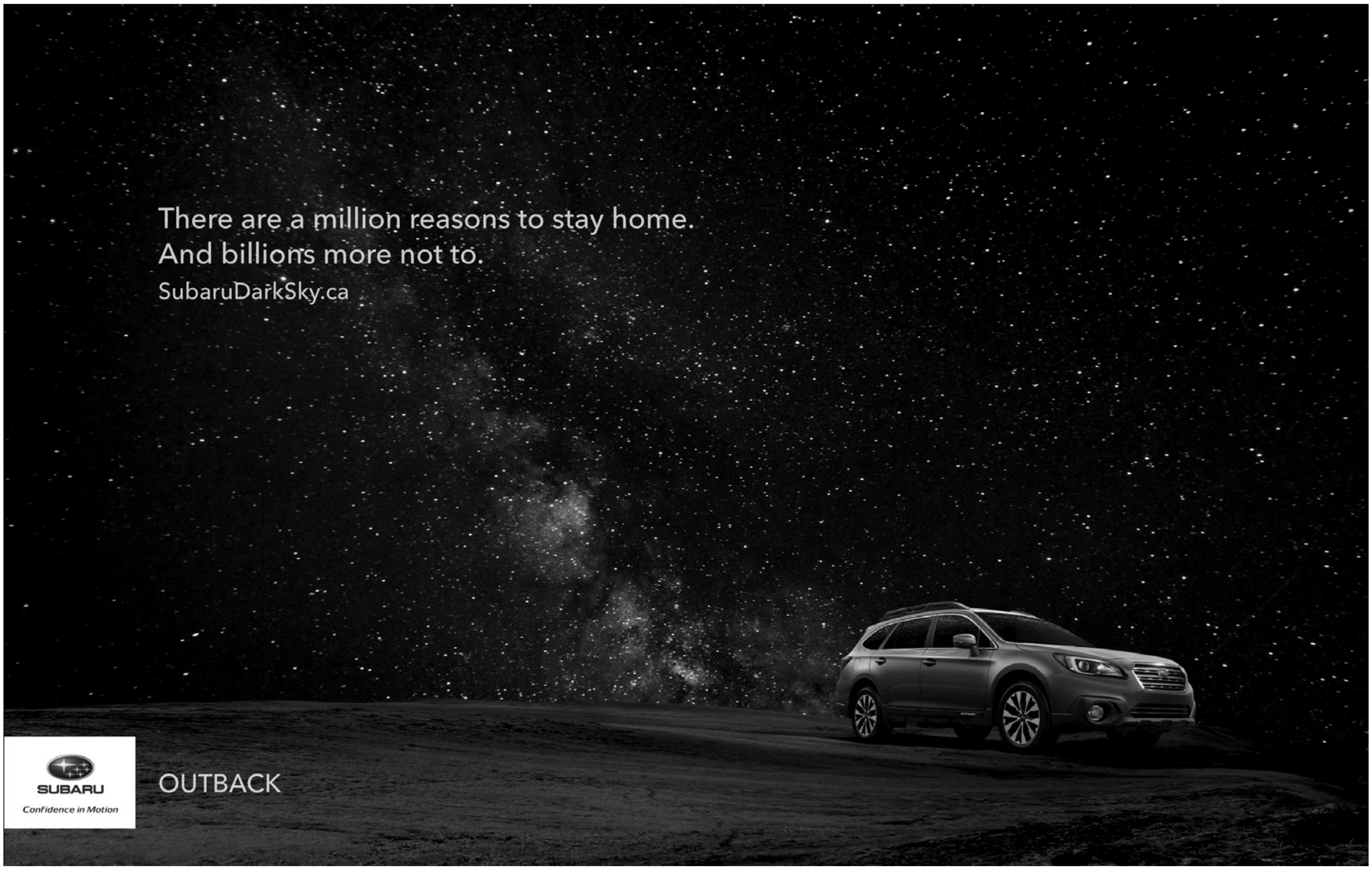
Compiled in part with material provided by the ESO.

The largest galaxy in the Universe?

An international team involving French researchers from the Laboratoire d'Astrophysique de Marseille and Canadian researchers from NRC Herzberg and Queen's University have studied Malin 1, a nearby galaxy that has been known only since the 1980s and that shows an extremely large disk of gas and stars. Malin 1 lies behind the Virgo cluster of galaxies, and was captured by the MegaCam camera during the Next Generation Virgo Survey being conducted using the Canada-France-Hawaii Telescope (CFHT).

Malin 1 is a prototype of a low-surface-brightness (LSB) galaxy: galaxies that are diffuse and of low surface brightness, a characteristic that makes them difficult to observe. Most RASC members would be familiar with the type in the form of dwarf galaxies, but Malin 1 is far from being a dwarf. Among the authors' conclusions is that "The stellar disk of Malin 1 extends at least out to 130 kpc in radius, confirming Malin 1 as a candidate for the title of largest known galaxy in the Universe…." The Milky Way has a diameter of 30 kpc.

LSB galaxies could make up a significant fraction of the galaxies in the Universe, as their intrinsic faintness makes them easily overlooked in galactic surveys. The CFHT survey obtained very deep images at six different wavelengths, extracting radial measures of the galaxy's luminosity in each band and the intensity ratio between the wavelengths (colours). These ratios are a measure of star-formation history. Using the extracted colour information, the researchers were



able to match the characteristics of Malin 1 to a model of galactic evolution.

The best model fit suggests that Malin 1 and its disk have been around for several billion years and that star formation has been low but constant over much of that interval, at a rate of about 1.2 M_{Sun}/yr. The result is significant, in that it clearly contradicts a scenario proposed a few years ago predicting that LSB giant galaxies are formed during violent interactions. Moreover, in the context of the cosmological formation of galaxies, numerous fusions and interactions should have perturbed the disk of Malin 1, but the MegaCam observations show only one galaxy candidate for gravitational perturbation in the field. The formation of Malin 1's structure and its survival for such a long time offers a challenge for cosmological simulations of the formation of galaxies.

Malin 1 contains a large quantity of gas that will fuel star formation at a low rate for billions of years to come, progressively increasing its stellar mass, unless another galaxy comes into the picture to interact with Malin 1 and totally change its destiny. Few galaxies, however, may play this role as Malin 1 is a relatively isolated galaxy.

Compiled in part from information provided by CFHT, CNRS, and LAM. The original paper may be found at http://dx.doi.org/10.1051/0004-6361/201629226. ✶

Figure 5 — Combination of 4 NGVS images of Malin 1 obtained with the MegaCam camera on the CFHT. An indication of the size is given in the figure to show the amazing size of the disk of the galaxy (in comparison, the Milky Way has only a diameter around 30 kpc). Image: Boissier/A&A/ESO/CFHT.

Featured Articles / Articles de fond

Percival Lowell's Last Year

by William Sheehan

Percival Lowell was always a controversial figure in the astronomical world. Despite his fame and following with the general public, his ideas and methods were largely rejected by professional astronomers of the day. The *Astrophysical Journal*, founded by George Ellery Hale and James Keeler, leading American astrophysicists, almost from the first refused to accept his contributions, while in a review of Lowell's 1909 lectures at MIT (published in book form as *The Evolution of Worlds*), Forest Ray Moulton, a University of Chicago expert on celestial mechanics, referred derisively to the "mysterious 'watcher of the stars' whose scientific theories, like Poe's vision of the raven, 'have taken shape at midnight.'" Similarly, when in 1910 Edward C. Pickering and other astronomers passed through Flagstaff on their way west to the Union for International Cooperation for Solar Research Conference in Pasadena, Pickering invited Lowell to come along. Lowell refused. "No," he told Pickering, "I am an astronomer!" He meant an astronomer in the old sense, someone who actually looked through a telescope, wielded a filar micrometer for accurate measures, and was versed in the methods of classical celestial mechanics. Lowell, especially in the last few years of his life, felt increasingly outside the main thrust of astronomy of his time, which embraced the methods of astrophysics. However, though isolated (in part by choice) and thrown on the defensive, his head, though bloodied, remained unbowed.

The greatest effort of Lowell's last decade, rivaling even his interest in Mars, which after 1909 was moving through a series of increasingly unfavourable oppositions, was the search for "Planet X"—itself inspired by the great 19th-century triumph of Adams and Le Verrier, who used perturbation theory to analyze the wayward motions of Uranus and were rewarded with the sensational discovery of Neptune. As such, the "X" search involved a mathematical investigation of the kind Lowell savoured, depending on techniques developed a hundred years before. He had mastered those techniques in his student days under Harvard's legendary professor Benjamin Peirce. Indeed, Lowell always prided himself in his mathematical prowess, and once called mathematics "the thing most worthy of thought in the world." But his attitude about mathematics embodied something of what we might now describe as the Dunning-Kruger effect, for though versed in old-style celestial mechanics, Lowell was largely ignorant of the new mathematical ideas that were entering physics through the contributions of men like Boltzmann, Gibbs, Poincaré, Planck, and Einstein, and were about to enter astronomy as well. These mathematical ideas included a heavy dose of statistics and were far more complicated than those with which he was familiar. Instead of assimilating these advances, however, he saw himself as the representative of a dying breed. "It is a popular delusion," he said in a lecture given in 1916, "that all astronomers must be mathematicians. The fact is they ought to be but are not. The mathematical astronomer is now the exception, due chiefly to the rise of astrophysics."[1] The astrophysicist, as Lowell saw it, was a mere collector, concerned with nothing more than mindless data-gathering, taking pictures of spectra and making photometric measures of stars to be stored in huge collections. Such work might lend itself to cooperative efforts and even—to use a word that for Lowell was anathema—unionization. (He hated labour unions with a passion, and even astronomical unions—such as George Ellery Hale's International Union for Cooperation in Solar Research—were thoroughly despised). But none of this collectivist effort would lead to great discoveries, he insisted. For that the highly individualistic and original "genius" was needed. But there could be little doubt in what category Lowell placed himself:


Figure 1 — Percival Lowell's last portrait, taken probably a few days before his death on 1916 November 12. Courtesy Lowell Observatory.

> *Now unions are excellent in their way for routine work. But though they push the lower men up they pull the upper down. And except for routine work what an unfortunate confession of individual incapability they make. To be willing to cooperate is to admit that one can do better in conjunction with others than he can do alone. No great man ever co-operated with another in the idea which made him great; the thing is unthinkable. Conceive Newton's Principia as a union outcome; and how many co-operators would it take to make one Clerk-Maxwell! That the banding together should be held advisable is a sad comment on the paucity of the age. Wolves hunt in packs, the lion stalks alone. It reflects too on the character of the work done. Just in proportion as the aim is low so may it wisely be widespread. The method has great advantages if the work is what you want. This is why we teach machines to do as much of it as we may. But as it becomes complicated and difficult fewer and fewer persons can be found capable of undertaking it until at last you have*

> *but the one man in the world who can, the genius who originates.*[2]

In the same lecture, the lion who stalked alone asked:

> *What is proof? Outside of mathematics, which is formulated logic, proof consists in an overwhelming preponderance of probability. Take, for instance, the law of gravitation, as being inversely as the square of the distance of the bodies apart. We call it proved and rightly, because almost everything stands explained by it and the few things that do not, like the motion of the apsides of Mercury, we are confident will eventually fall into line.*[3]

Ironically, as he wrote these words, Einstein, in Berlin, had already made the motion of the apsides of Mercury fall into line, though not on the basis of the Newtonian law of the inverse square but on that of the general theory of relativity. It is certain that Lowell had never heard of Einstein or of the general theory of relativity. Had he lived to a reasonable old age, he would undoubtedly have had to come to terms with them; however, it is more than likely that he would have railed against them continuously—and futilely—in the pages of journals like *Popular Astronomy*, as would do William H. Pickering, who had assisted him in founding his observatory and was another conservative Brahmin.

His "greatest disappointment"

Though Lowell's astronomical work at his observatory involved cooperation of a sort, he always made it clear that he was the manager and superintending intelligence. Others, including his staff astronomers and computers, were his employees. As such, they took their orders from the "lion," just as household servants would be expected to do. (Eventually the sheer success of V.M. Slipher in wielding the spectrograph led Lowell to grant him a somewhat freer hand; and Slipher was no longer charged with such menial tasks as taking care of the Observatory Cow or ordering Shredded Wheat for Lowell's breakfast table, as he once wired Slipher urgently to do from Chicago.)

In addition to the staff in Flagstaff, from 1910, Lowell employed several human computers, headed by MIT graduate Miss Elizabeth Williams, in a massive effort to calculate the position of Planet X. Most of the work was done in Boston, in his State Street office. By the end of 1912 and the beginning of 1913, the rigours of the undertaking were beginning to undermine his health. Not only did he have to postpone a planned visit to Flagstaff, for a time he was not even able to visit the Boston office. His secretary Wrexie Louise Leonard reported that he could manage "only a word now and then on the phone," and added, "he is weak and run down and must needs be careful and quiet." She confided to her Flagstaff colleagues, "He worries about the work—he wants to be *in it*!" And: "It is nervous exhaustion, and he is *up* and *down*! Some days he cannot even telephone. He gets nervous about the work and impatient for things to come from Flagstaff."

On this occasion, he was "down" for only six weeks, not the almost four years he was afflicted—also in part by sheer nervous exhaustion—when he returned from observing Mars from near Mexico City in April 1897. But his mood continued to fluctuate between episodes of optimism and despondency. Thus in January 1914, he wrote to his sister Amy, the poet, who seemed to share something of both his temperament and sensitivity to criticism, "So very sorry, dear, to learn that you are down….. I have been down and up and down. Am now hoping for another up."

No doubt he would have vouchsafed that "up" if only "X" had been sighted. When he wrote this, he was planning yet another try, caught up in the kind of frenzy that afflicts gamblers unwilling to accept defeat: just one more throw of the dice might rescue the situation. By April 1914, he and his assistants were busy initiating what has been called the "second search" for X, receiving on loan a 9-inch Brashear photographic doublet from the Sproul Observatory in Pennsylvania, which would be used to photograph the sky in positions where Lowell's latest calculations—as continually shifting as the pointer finger of a man with Parkinson's—indicated it was most likely to be found. In addition, Lowell was redoubling the Boston effort, and was now supervising the computations of four human computers.

Lowell was always high strung, and the tension on Mars Hill during the period of this frantic search must at times have been unbearable. He began planning his usual biennial trip to Europe for that spring, but it was delayed a month, until May 1914, because of his wife Constance's needing surgery for an ulcer. The outbreak of the European war in August prompted his early return. (He would never cross the Atlantic again.) As soon as he was back from Europe, he began wiring Flagstaff for news of progress in the search for X, but there was nothing to report. Lampland had made little progress because of a long siege of Flagstaff's July monsoonal rains, and now it was Mrs. Lampland's turn for surgery for an ulcer. "I feel sadly, of course, that nothing has been reported about X," he confided to V.M.

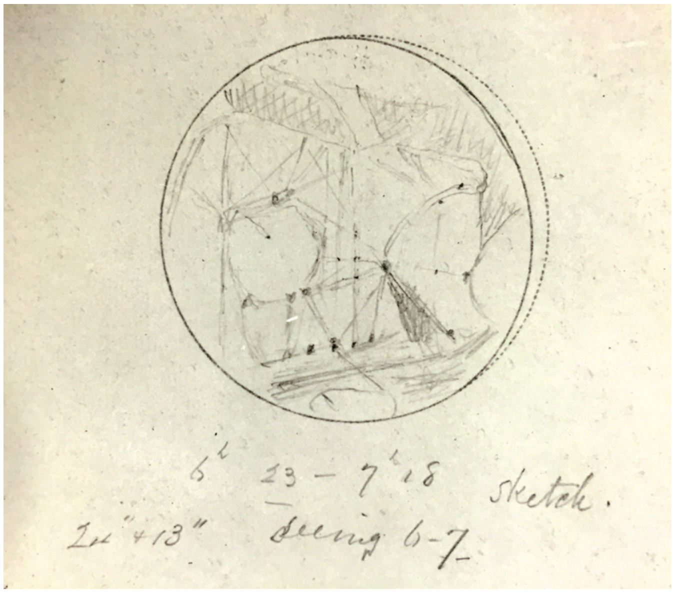


Figure 2 — One of Lowell's 1916 drawings of Mars, showing a new class of features that were described in a "News from Mars" note in the RASC Journal. *(Courtesy: Lowell Observatory)*

Slipher.[4] Sometime shortly thereafter, a discouraged Lowell, quietly and without fanfare, seems to have given up.

Lowell returned to Flagstaff, briefly, that fall, and on 1914 October 17, took his place on the chair next to the telescope in full sartorial splendor to observe Venus by daylight—an iconic pose captured for all time by then-visiting Northwestern University astronomer Philip Fox. He also embarked upon yet another project. He wanted to establish, under the sponsorship of the American Academy of Arts and Sciences in Boston, a new medal, to be awarded to a deserving astronomer working on traditional problems in astronomy. Clarifying his intention to John Trowbridge, the president of the academy, he wrote, "I beg to call your attention to the fact that [for this purpose] astronomer is used in its technical sense, and not including astrophysics which, of late years, owing to the effect that pictures have on people, has usurped to itself the lime-light to the exclusion of the deeper and more profound parts of astronomy proper."[5]

It was to the same academy that in January 1915 he presented a summary of his long and painstaking "X" calculations: the "Memoir on a Trans-Neptunian Planet." Though it became famous after the discovery of Pluto, it attracted little attention at the time, and the academy declined to publish it. An irritated Lowell had to publish it himself, at his own expense, the following September (as Lowell Observatory Memoir no. 1). To add insult to injury, his proposal to establish the medal was also rejected. Fuming to President Trowbridge, without, apparently, sensing the irony of his position, about the "stagnation and old-fogeyism" of the academy, he accused its leaders of being "a set of men certainly not broad [of] view or judgment."[6] One can forgive him if he felt that the astronomical community was treating him as a pariah. In the end, his offer to found the medal was withdrawn.

After January 1915, the search for Planet X disappears almost completely from the archival records. Though Lowell was never one to dwell—publicly at least—on his failures, the defeat must have bitten him hard. According to his brother (and first biographer) Abbott Lawrence Lowell, the failure to find "X" was "the greatest disappointment of his life." The pall of this disappointment was to darken the last year and a half or two years that remained to him.

On to New—Old—Directions

The X search, in which Lowell had re-analyzed the validity of the calculations that had led to the discovery of Neptune, reprised one of the major themes of the work of his Harvard mentor Benjamin Peirce. After Lowell gave up on X, he turned with a will to another of the themes Peirce had made his own: the structure and evolution of Saturn's system of rings and satellites.

Lowell's interest in Saturn went far back. While a Harvard student, he received as a gift from his mother Richard A. Proctor's *Saturn and Its Satellites*. According to Proctor, the subject "gathered additional interest for its bearing on the speculations of Laplace," since it was "not altogether impossible that in the variations perceptibly proceeding in the Saturnian ring-system a key may one day be found to the law of development under which the solar system had reached its present condition."[7] Soon after reading this, Lowell gave his Harvard graduation dissertation on Laplace's nebular hypothesis, and much later, in 1893, on his 4th and last visit to Japan with his 6-inch Clark refractor, he observed Saturn with his 6-inch Clark refractor from the garden of the 18-room house he rented in Tokyo.

After founding his observatory at Flagstaff in 1894, Lowell's initial interest was in the inner planets—Mercury, Venus, and, of course, especially Mars. Only after 1907 did he begin to devote an appreciable effort to the Giant Planets. Thus, in 1907, he verified delicate markings in the Equatorial Zone of Jupiter, which the English amateur astronomer Stanley Williams had first seen in the 1890s and referred to inauspiciously as "canals." (As an aside, there were also "barges" on Jupiter.) However, in 1907, another English astronomer, Scriven Bolton, observed similar features, renaming them "wisps." Bolton wrote to Lowell to confirm them, which he promptly did.

Also in 1907, Lowell observed the edgewise rings of Saturn. Over the next few years, as he became increasingly immersed in the intricacies of celestial mechanics because of the "X" search, he devoted more time to Saturn.

The rings had long presented an intriguing challenge to celestial mechanicians. At the end of the 18th century, Laplace had supposed that the rings, in order to remain stable, must consist of a myriad of solid ringlets, nested one inside the other. For the first half of the 19th century, visual observers of the planet would report—in addition to the very conspicuous Cassini division—minor subdivisions of the rings, possibly fugitive glimpses of the finer circlets of Laplacian conjecture. Charles W. Tuttle and Sidney Coolidge, volunteer observers of Harvard, saw these subdivisions especially in Ring B. Tuttle described the surface of that ring as “minutely subdivided into a great number of narrow rings…not unlike a series of waves.”

Then, in 1857, James Clerk Maxwell of Cambridge University convincingly showed, mathematically, that solid ringlets would not remain stable, no matter how finely subdivided. Maxwell asserted, “The only system of rings which can exist is one composed of an indefinite number of unconnected particles revolving around the planet with different velocities according to their respective distances.” By 1867, Indiana University astronomer Daniel Kirkwood—building on work done the year before in which he had shown that gaps in the asteroid belt corresponded with resonance positions with Jupiter—generalized his result by showing that in rings consisting of unconnected particles, as on Maxwell’s model, the orbits of particles at the ½ resonance with Mimas would be rendered unstable and swept clear. This would produce Cassini’s division, between rings A and B. In other places, it seemed that subtle shadings might be formed where Mimas and the other satellites of Saturn had thinned but not totally removed ring particles. The quest for such ring subdivisions was on, and the end of the 19th century saw a veritable outbreak of division finding.

Percival Lowell seemed to be in a perfect position to investigate the matter, definitively. He had a giant telescope, steady air, and a keen eye well trained to the detection of fine linear markings from his years of recording not only the “canals” of Mars, but linear features on Mercury and Venus. Beginning in 1909, and continuing in 1913–14 as the rings were further opening up, he and assistant astronomer E.C. Slipher found the B ring, “conspicuously striped amidst its shading, the dark curving lines of its plaided pattern being so definite as to permit of measurement.”[8] In addition, his immersion in celestial mechanics—and concern with resonances in the orbits of planets—as he pursued the “X” search motivated him to look for a resonance solution to explain the ring sub-divisions he and Slipher were noticing.

The Saturn ring investigation came to a climax in March 1915, when the ring system opened up to an angle of tilt toward the Earth of 26°56′.8, the most since 1899. Ring subdivisions were numerous. Lowell’s drawing shows about a dozen, nine in Ring B and three in Ring A. Some were conspicuous enough to lay the wire of the filar micrometer on, others, more delicate, were measured off drawings. Lowell found the three principal subdivisions in the B ring to correspond with 3/7, 2/5, and 3/8 resonances with Mimas, while the boundary between the C and B rings corresponded with a 1/3 resonance with Mimas. Indeed, a side by side comparison of the divisions in Saturn’s rings purportedly due to Mimas with the gaps in the asteroid belt owing to Jupiter shows an uncanny resemblance, so that, as James Elliot and Richard Kerr have written:

> *Percival Lowell had not only seen distinct “canals” on Mars, he also glimpsed dark patches and strips beneath the impenetrable clouds of Venus. As might be expected, Lowell found delicate details in the rings of Saturn, too; of course, most coincided with one resonance or another.*[9]

That isn’t quite the end of it, however. The ring subdivisions didn’t quite line up with the Mimas resonances. The whole ring system, in each and all of its parts, lay slightly too far out as compared with the computed positions of the resonances—in other words, the divisions were too far out for their periods—and Lowell did not believe that any observational error could explain this. But he had another trick up his sleeve. Mobilizing an impressive array of Félix Tisserand’s formulae, he showed that everything would come out right after all if, beneath the observable oblate spheroid of Saturn, a somewhat complicated internal structure was assumed. His conclusion was that Saturn consisted internally of “concentric confocal spheroids of differing densities increasing inward,” with the planet “rotating in layers with different velocities, the inside ones moving faster.”[10] He put it even more colourfully. Saturn was like “an onion in partitive motion.”[11]

Lowell seems to have been over the moon with this result. “The recent light thrown on the internal constitution of Saturn, brought out by measures on the divisions of the ring, shows the potency of mathematics,” he wrote. “Like the Röentgen Rays it renders visible what the unaided eye could never see.”[12] Despite invoking Röentgen, he could just as easily have recalled the way Le Verrier had revealed Neptune from his analysis of the observations of Uranus. The X search had failed—it had been the greatest disappointment of his life. Now he could claim vindication in the light he had thrown on the inner parts of Saturn.

He presented the results of his investigation in a handsomely—but self-published—Memoir. Unfortunately, his “Memoir on Saturn’s Rings” (*Lowell Observatory Memoir no. 2*) seems to have attracted about as little attention as the one on Planet X. It was, for that matter, not quite the Q.E.D. Lowell had imagined. One need only compare his 1915 drawing with a modern CCD image to see that something is lacking in the proportions and that the divisions, though about right, do not line up quite as they should. He was correct in supposing—as Kirkwood had first grasped—that Mimas, a relatively large satellite lying close to the rings, leaves its mark on the rings. (It is responsible for clearing material from the Cassini Division. Also, the boundary between the C and B rings is indeed in a 3:1 resonance with Mimas.) However, in general, Lowell’s 1915 results are not borne out—and nor, we need hardly add, does Saturn rotate, as Lowell supposed, like an “onion in partitive motion.”

If Lowell saw a real mountain peak and not a mere mirage, then it was a peak seen through mists and haze.[13] As with the canals of Mars and the residuals on which he had based his Planet X calculations, he had pushed marginal perceptual data too far in the direction of far-flung inference.

The Final Year

The publication of the Planet X calculations and the investigation of Saturn's rings were the great achievements of Lowell's penultimate year, 1915. The year that was to prove his last, 1916, was issued into Flagstaff by a huge snowstorm just before the New Year—the snow heaped up 50 inches as measured at V.M. Slipher's residence. Lowell was on Mars Hill at the time. Most years, unless there was a special event like a Mars opposition to observe, he would have been in Boston; but as he drew toward the end of his life, he increasingly regarded Flagstaff as his first home. He had by now established a "veritable colony" there, with three observing domes, four astronomers' houses (including his sprawling 18-room "Baronial Mansion") and the new administration building and library he and his interior-decorator wife Constance were busy planning together (this led to the first phase of what is now known as the "Slipher Building"). There was also a barn, and a cow. The grandeur of this colony was, he told his old Harvard friend Frederic Stimson, appropriate to his role of "envoy of Mars to Earth." His staff was unquestioningly loyal—though apt to compete among themselves, like attention-seeking siblings, for priority of place in the estimation of a parental figure. C.O. Lampland believed he deserved Lowell's greatest confidence, and competed, sometimes bitterly, with the Slipher brothers, who never quite seemed (to Lampland) to put in the long and unstinting hours that he did. Nor was the competition limited to the male side. Lowell's wife Constance seems to have resented the obviously affectionate (though not necessarily sexual) relationship her husband had long had with his secretary Wrexie, who, even after Constance became Mrs. Lowell, continued to have a bedroom of her own in the Baronial Mansion. Percival, understandably given his irregular hours, also had his own bedroom, and Constance yet a third. He was the eldest son, his mother's spoiled favourite, and the centre of attention wherever he went. Though capable of thoughtful gestures toward his staff, he was, by nature, formal and aloof, and seems to have been blissfully unaware of the tensions that the three-bedroom arrangement might occasion. Nor did he, apparently, draw any conclusions from the preponderance of ulcers on the hill, especially among the women—as noted above, both Mrs. Lampland and Mrs. Lowell suffered.

For Lowell, work was always first. He was an extremely competitive individual, obsessive, driven, perfectionistic, a workaholic. But he had his recreations too. After Lowell's death, Constance reminisced to Lampland:

> *You remember he was an enthusiastic gardener and always had a garden here at the Observatory. He had great success with many flowers and I recall especially fine displays of hollyhocks, zinnias, and a considerable variety of bulbs. Gourds, squashes and pumpkins were also great favorites. You will remember one year the especially fine collection of gourds and that bumper crop of huge pumpkins, many prize specimens being sugar fed. At times Dr. Lowell could be seen in the short intervals he took for outdoor recreation, busy with his little camel's hair brush pollenizing some of the flowers… Then the frequent, almost daily, walks on the mesa. Certainly he knew all the surrounding country better than anyone here. He would refer to the different places such as Wolf Canyon, Amphitheatre Canyon, Indian Paint Brush Ridge, Holly Ravine, Muellein Patch, etc… Trees were an endless source of interest to him… Cedars or junipers seemed to be favorite subjects for study, though other varieties or kinds were not overlooked….*
>
> *At every season of the year he always found something in wild life to fascinate him, and you will remember his observations and notes of butterflies, birds, squirrels, rabbits, coyotes, deer and other inhabitants of the mesa. These friends must never be disturbed or harmed. But it was permissible to hunt with a camera! … The Observatory grounds were a sanctuary for wild life."*[14]

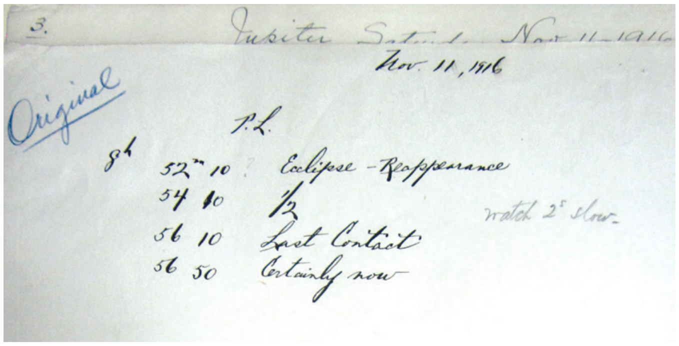
Wrexie would recall how she and Percival would write about one of these friends, whom they referred to as "Jack Rabbit, Esq."

Though in most other things he was a dyed-in-the-wool conservative, there was one sterling exception: in the area of conservation he was well ahead of most of his contemporaries. In his far-sighted realization of the fragility of the Arizona desert landscape, to which his views of Mars as a desert planet added piquancy, he resembled John Wesley Powell, and while he shared Theodore Roosevelt's passion for preservation he did not share the compulsive big-game hunter's insatiable blood lust.

Constance continues her personal recollections:

> *As you know, it is not easy for the observing astronomer to lead a strictly regular life in that the hours at the telescope often make it necessary to use, for the much needed rest, part of the daily hours usually given to work. His intense occupation with his research problems, however, was broken with great regularity for short intervals before lunch and dinner. These times of recreation were given to walks on the mesa or work in the garden. When night came, if he was not occupied at the telescope, he was generally to be found in his den. It was not always possible for him to lay aside his research problems at this time of day, but he did have some wholesome views on the necessity of recreation and a necessary amount of leisure to prevent a person from falling into the habit of the "grind." To those who came to his den the picture of some difficult technical work near his chair, such as Tisserand's Mécanique céleste, will be recalled, though he might at the time be occupied with reading of a lighter character. And occasionally during the evening he might be seen consulting certain difficult parts upon which he was pondering…*[15]

Tisserand's monumental four-volume work (published between 1889 and the year of his death, 1896) had, of course, been relied on extensively during the search for Planet X, but Lowell also consulted the French author while engaged in his investigations of the structure of Saturn's rings and for those that would make up a major thrust of his research in 1916, the motions of the four Galilean satellites and the tiny inner satellite Amalthea. So her recollections might well describe him in that final year.



3. Jupiter Sat Nov 11-1916

Original

Nov. 11, 1916

P.L.

8^h 52^m 10 Eclipse - Reappearance
54 10 ½
56 10 Last Contact
56 50 Certainly now

watch 2^s slow.

Figure 3 — On the night of 1916 November 11, Lowell and his assistant E.C. Slipher were observing the fifth satellite of Jupiter with the 24-inch Clark refractor. This document, carefully placed in a cigar box by Slipher and long forgotten until rediscovered by Lowell Observatory preservationist Mike Kitt almost a century later, records the last observation Percival Lowell ever made—of an eclipse of satellite Io. Appropriately, the second to last sentence reads, "Last Contact." Indeed it was—Lowell suffered a cerebral hemorrhage the following morning, from which he never recovered. Lowell Observatory.

Saturn, Mars, and the Genesis of Planets

Astronomically speaking, at the beginning of 1916, Lowell and E.C. Slipher were keeping up their measures of the divisions in Saturn's rings. At this time, Lowell, despite the same irrepressible enthusiasm he had always had, made some concessions to age; he preferred to keep "banker's hours" at the telescope, usually cutting out by 10 p.m. The hours from then until midnight—or beyond—were taken up by the young and able E.C. Slipher. Also, Mars was looming again. It came to one of its biennial oppositions on February 9. It would be Percival Lowell's last. As an aphelic opposition, the north pole was tilted toward the Earth, but Mars was never very close in 1916, though as Lowell's own observing logbooks testify, the curious planet did not always reveal the most when it was closest. Distance actually seemed to encourage the appearance of the spiderwebs. The skies during February were brilliantly clear, with the seeing often exceptional—Lowell noted nights of 8 or 9 on a scale of 1 to 10. He was joined at the 24-inch Clark not only by Slipher but by a volunteer observer and keen student of planet, George Hall Hamilton, who had left a position as professor of astronomy at Bellevue College in Nebraska just to observe Mars with Lowell. (He also would later marry Lowell's head computer on the X search, Elizabeth Williams; he died in 1936.)

Lowell was always good copy, and his observing reports, especially when concerned with Mars, were eagerly picked up by newspapers and journals (the *Astrophysical Journal* remaining an exception; as previously noted, it had long since refused his contributions, on principle). In addition to regular Bulletins from the Lowell Observatory, Lowell issued special observing circulars. One of these went out on 1916 March 30, and ran in *The Journal of the Royal Astronomical Society of Canada*, under the heading "The Latest News from Mars":

> *A curious set of features, secondary to the main canal network, have become apparent on Mars. Within some of the polygons made by the intersections of the larger canals a tiny dot has been descried at this observatory, joined to a corner and to the sides of the polygon by lines so slender they usually appear as a string of minute beads. The effect is of a centrally woven web, spun within the borders of the polygon, of a more minute order of tenuity than the polygon itself. Elysium was the first example of this phenomenon with the Fons Immortalis and five connecting spokes.*[16]

Perhaps unsurprisingly, both Hamilton and Slipher drew Mars much as Lowell himself did—just as, in the early days, Wrexie Leonard had closely duplicated the style and content of his drawings of Venus—and until the end of their lives would loyally, and apparently with conviction, defend his views about the planet. Hamilton, for instance, would write in 1920:

> *It is seen … that a globe like Mars might, if inhabited, need an irrigation system of vast proportions to support life, and such a system has been shown feasible, providing that beings who inhabited it were sufficiently advanced to undertake such a project…. This is seemingly the case; for we have every reason to believe that what we see on the surface of Mars shows definite proofs of artificiality.*[17]

The Genesis of the *Genesis of Planets*

As Mars and Saturn moved into less opportune positions for observation, Lowell began to work on the latest iteration of a long-meditated project that had preoccupied him, in one way or another, since his days as a Harvard student, when he had first become an enthusiastic devotee of the English philosopher Herbert Spencer. Spencer was an evolutionist—it was he, not Darwin, who coined the phrase "survival of the fittest"—and pursued a broad evolutionary ideology that he called a "System of Synthetic Philosophy" through ten massive volumes, on topics that included biology, psychology, sociology, and morality. His basic formula was that "evolution is definable as a change from an incoherent homogeneity to a coherent heterogeneity accompanying the dissipation of motion and integration of matter." As a consequence of the instability of the homogeneous, matter proceeded inexorably from its most simple and homogeneous manifestations (e.g. Laplacian nebula) to its most heterogeneous and complex (e.g. living organisms, the human mind). Lowell had adopted this appealingly intuitive ready-made scheme during his Japanese phase (1882–1893) by contrasting the advanced and individualistic societies of the West with the primitive and impersonal ones of the East, and then, beginning with *Mars* (1895), and continuing through *Mars as the Abode of Life* (1908) and the *Evolution of Worlds* (1909), he applied the same general scheme to the evolution of the planets, following the worlds of the Solar System from their birth in the swaddling clothes of the solar nebula through the exuberant restless stage of youth on to the final gasp of old age and utter inanition.

His evolutionary cosmogony he referred to as "planetology." In an early draft of *Mars and Its Canals* (1906), he described the bones of an idea he was attempting to put flesh on:

> *Two lines of the long chain of Evolution which leads from star to student have been considered by man: the Meteoric and*

> *the Nebular Hypothesis at the far end of it and the Genesis of Species at the near one.*
>
> *The first deals with the evolution of a nebula into a solar system; the second with the orderly development of organic life. Between the two lies a part of the road not as yet generally surveyed: the career of a cosmic body from a molten mass to a cold inert one, the life-history of what we call a world. Planetology we may style this inquiry into a missing link in the cosmic evolutionary process….*[18]

The *Genesis of Planets,* Lowell's most important literary effort of 1916, was written in the first part of that year. It is more than likely, had Lowell lived, that he would have developed it into a full-fledged book. Though he continuedto make observations of Saturn's rings until 1916 April 9, examined the asteroid Vesta on April 18, and made his last observation of Mars—ever—on April 21, he must have devoted a good deal of time during this period to writing the several drafts of Genesis that survive in the Lowell archives, and must have been done at the latest by April 23, when he and Mrs. Lowell left for Chicago on the Limited train, and continued on from thence to Toronto, where Lowell was to present a major invited lecture.

The lecture was scheduled to be given on Thursday, 1916 April 27, at 8 o'clock, in the auditorium of the Central Technical School at Harboard and Lippincott Streets, during a joint meeting of The Royal Astronomical Society of Canada and the Ontario Educational Association. The public was warned in advance that a "large attendance is expected." Lowell was to be inaugurated as an Honorary Fellow of the RASC, and was identified, in an announcement of the event, as the Director of the Lowell Observatory, Flagstaff, Arizona:

> *The Lowell Observatory was established over twenty years ago, chiefly for the study of the planets, and the investigations made there have led to the general recognition of Dr. Lowell as our greatest authority on Mars. His researches on the planets have given him a high place in the astronomical world while his books on Mars have had a very wide general circulation. Recently Dr. Lowell has made notable discoveries regarding Saturn and Uranus, and the lecture, which is of a non-technical nature, will include an account of these.*

Lowell would certainly have been a hot ticket in any case, but he probably offered his audience a welcome escape, with his "news from Mars," from the usual grim news from the Western Front. Canada, unlike the United States, was already in the war, and its troops were taking heavy casualties on the Somme. Even the *Journal* had felt a need to help with the recruitment effort, having, just the previous November, published a poem, "The Bugle," by the Toronto poet and physician Albert D. Watson, that ends with a summons:

> *The troopship in the harbor rideth ready,*
>
> *The tumult thickens. Hear the scornful word.*
>
> *The foe is mocking! Lift the anchor –steady.*
>
> *High tide. The ship's away! Are you aboard?*[19]

Despite the advertisement, Lowell's lecture was not quite of a non-technical nature, since it included mathematical formulae. He began with the origin of the Solar System, which he, and most of his contemporaries, still explained on the basis of the Chamberlin-Moulton theory (Moulton being the same person who had compared Lowell to the mysterious watcher of the night of Poe's Raven). In the beginning, he says, was a catastrophe. "Two suns met and we were the outcome."[20] The collision of the large heated body, the then sun, with another of its kind produced a dismembered body. From the "as yet ungathered remnants of the shock," the system of planets, including the Earth, formed. In previous writings—including *The Evolution of Worlds* of 1909—Lowell had confidently identified the spiral nebulae with these planetary systems in formation, but in an unforgivably brief comment, given both its significance to the history of astronomy and to the fact that it had been made by V.M.Slipher at his own observatory, he noted, simply, that "the spiral nebulae indicate themselves to be galaxies."[21] With only a brief nod to the new recognition, Lowell hastened on, relying on what he calls "pure reasoning" to disclose the remote antecedents of the Earth's history. The galaxies disappear, almost soon as they make their appearance, from the lecture.

Leaving the catastrophic beginning behind, Lowell proceeds with what happened next. The first stage in a planet's history, he says, is marked by the way that each planet, as it emerges from the disk of material left by the original catastrophe, acquires spin. The second stage involves the condensing of the matter brought together into an oblate spheroid. With the condensation of matter, because of the conservation of angular momentum, the spin also increases in the same way a stone attached to a string goes faster as the string is wound up. The increase in centrifugal force increases the oblateness of the spheroid. As the planet becomes non-homogeneous, the internal layers rotate faster and their spheroidal shape is accentuated.

Heat is also generated in the process of condensation. Indeed, so great are the planetary masses that this results in making them molten. The heat evolved expands through the body and is radiated away at the surface, producing cooling. This leads to the third stage when the body has so far cooled as to become liquid or solid throughout. The arrival of the planet to this stage marks the beginning of the fourth stage, which is the last and marks the end:

> *Up to now the planet's spin has been increasing. From this point on its rotational speed diminishes owing to the tidal pull upon its mass by the sun [sic.]. A tidal pull has acted upon it from its birth, but has hitherto been more than counteracted by the increased spin due to its shrinkage.*
>
> *The end is planetary death, when tidal friction has done its work and caused the body to turn the same side in perpetuity to the Sun. Mercury and Venus have reached this, the fourth stage in planetary evolution and are now white planet corpses, circling unchanging, except for libration, around the Sun.*[22]

Summarizing the main points, he concludes:

> *Thus the three stages of a planet's life-history are characterized by different degrees of rotational speed, oblateness and matter-distribution. In the course of the three the spin starts at a certain amount, rises to a maximum and sinks to a minimum at the end. The body's contour does the same, beginning as an oblate spheroid, increasing at first in oblateness, and afterwards diminishing to practical rotundity. Thirdly, the body originates homogeneous, becomes heterogeneous and thence grows more homogeneous again to a certain limit, beyond which it cannot pass.*[23]

He illustrates his scheme by pointing to Uranus as an example of the first stage, Saturn of the second, and Mars of the third. With regard to Uranus, a planet that had yielded very little to telescopic inquiry, he produces some genuinely new results. With his spectrograph, V.M. Slipher in 1910 had measured the rotation period, finding it to be 10 ¾ hours. At the same time, Lowell's measures of oblateness showed it to be almost as thickened in the middle as Saturn. (Its oblateness, from measures with the Clark refractor, was 1/11.5). From this mass and density, Lowell calculated that internally it was more homogeneous than either Jupiter and Saturn. Thus, it was younger than either of them. Saturn's internal differentiation and inhomogeneity, deduced from the divisions in the rings, were evidence that it had reached the second stage. As for a planet that had reached the third stage, he had been writing about such a world, and in much the same terms, ever since his first book *Mars* in 1895; Mars was an old world, decrepit, struggling, and on the threshold of planetary death.

He ended his lecture to the RASC and the Ontario Educational Association, in which he had shown how gratifyingly hand-in-hand theory and observation had travelled together in the study of the Solar System, by insisting:

> *Without the precision afforded by the best air the recent discoveries about Uranus and Saturn would have been impossible. It was to get just such first-hand data that the observatory at Flagstaff was founded. For only the best of materials in science can stand the test of time.*[24]

Though his Canadian audience was no doubt on its feet and roaring its applause, none of these results has, in fact, stood the test of time. He was not quite right about Saturn, or Mars, while in the case of Uranus, the rotation period adopted was off by several hours. Instead of an oblateness of 1/11.5, the actual oblateness, based on spacecraft measures, is 1/49. All his calculations used erroneous data.

Moreover, the familiar Spencerian framework Lowell used had, by the time he spoke, already become passé. Lowell's biographer David Strauss has pointed out that its assumption "that current conditions were the predictable outcome of a single principle working gradually and inevitably from past to present" was being rejected by a new generation of intellectuals because it left no room for "the cataclysm, chance events, or choice…as essential components of the universe."[25] Quaint as Spencer's formulation of evolution as proceeding from homogeneity to heterogeneity through the dissipation of motion may seem, it did capture, perhaps, as an image in a glass darkly, something of recent (highly mathematical) ideas about chaos theory and the "intrinsically random" appearance of ordered structures in a system as the consequence of the development of some instability in the system. Though no one talks any longer of the movement from homogeneity to heterogeneity, Spencer's intuition—and, in astronomy, Lowell's—captured at least the trend of much more sophisticated concepts that would be elaborated later. For instance, according to Russian astronomers A.M. Fridman and N.N. Gorkavyi:

> *In an unstable medium structures such as regular bands, spots, circles, spirals, vortices, solitons, or modons will spontaneously appear.… There are … many examples of self-organisation in the Universe: solar granulation, sand dunes on Mars, vortex formations such as the [Great] Red Spot on Jupiter, spirals in galaxies, and the structure of planetary rings. Finally, the stars themselves, star clusters, galaxies, and their associations are examples of the organisation of matter which initially was quasi-uniformly distributed.*[26]

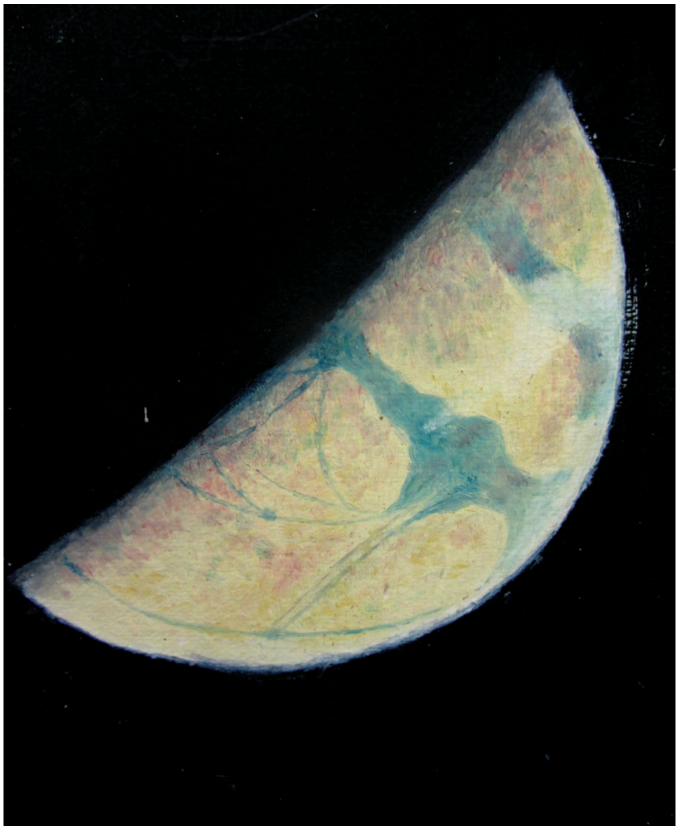


Figure 4 — A painting of Mars, showing it as it can never be seen from the Earth but as it might have looked from an approaching spacecraft if Mars were crisscrossed by canals as Percival Lowell believed. Of course, as Mariner 4 *in 1965 and other spacecraft have conclusively shown, the canals do not exist—and yet Lowell's Mars has had an enormous impact on science fiction and still resonates in present-day efforts seeking water and life on the planet. This painting is of uncertain provenance—it was found by Mike Kitt among a number of discarded items that included Lowell's last observation. The artist is unknown—though it may well have been Percival Lowell himself. (Courtesy: Lowell Observatory)*

There is a faint echo of Spencer and Lowell here.

The Grand Lecture Tour

It may be pushing things too far, but the preoccupation with celestial mechanics that marked the last decade or so of Lowell's career seems to reflect a basic feature of his personality—a recalibration back to an earlier set point. He seems to have lacked what the poet John Keats once famously referred to as "Negative Capability, that is when man is capable of being in uncertainties, Mysteries, doubts, without any irritable reaching after fact & reason."[27] He wanted things black and white, clearly defined—no ambiguity. This appears even in his drawings of the planets, where everything—even the notoriously diffuse and nebulous markings on Venus—was depicted as hard, sharp, clearly bounded, well-defined. There is nothing of nuance, nothing of shades of grey. Of course, this was the appeal of celestial mechanics as well. Mathematics seemed to offer the promise (in the end disappointed) of a definite unflinching solution. Probably his hankering after definiteness and certainty had something to do with the deep-seated Puritanism of his New England culture, but some of it may also have been owing to his rather severely obsessive-compulsive personality. He would not tolerate disorder, unpunctuality, delay. For a while, he tried to rebel against these constraints; but in the end these were the categories that formed his thought. There is an analogy with his sister Amy's poetry. She once described the aspiration of her imagist poems. They should be, she said, "Hard and clear, never blurred or indefinite."[28] In other words, they should be like mathematics, or Percival's drawings of the planets.

The doubts about his work took a toll on him. In his last year, Percival Lowell was not a happy man, and—to judge from his portraits—aging fast. In his last portrait, he looks more like 70 than 61. Parallelling his brother's comment about the failed "X" search, Lowell's old friend Frederic Stimson wrote after his death, "Mars went back on him and was a disappointment."[29] Nevertheless, at least to the world, he put on a brave—even arrogant—face, and for all the criticisms, never gave any hint that he thought he would end up on the losing side. He pilloried his professional peers as unimaginative hidebound old fogeys, unable to recognize the promise of a new idea. In contrast, the minds of youth were still open and capable of forming new impressions. He therefore turned with a will to the rising generation, setting out on September 27 from Boston on a lecture tour of the Pacific Northwest and the West Coast. There is a hard edge to much of what he says. There is certainly more than a little sour grapes.

His itinerary included the State College of Washington in Pullman, the University of Washington in Seattle, Reed College in Portland, the Agricultural College in Corvallis, the University of Oregon in Eugene, and Leland Stanford Junior University, and Berkeley in San Francisco. (The hotels where he stayed are known, and many of them are still standing; some are still hotels.) In each venue, the audiences were overflowing. The subjects of his lectures were: "Mars—Forecasts and Fulfillments," "Mars and the Earth," "Great Discoveries and Their Reception," and "The Far Horizon of Science." His standard refrain concerned the resistance of astronomical conservatives to new ideas. The road to discovery was not an easy one, he warned in one of his lectures:

> *There is to add to its forbiddingness no warm compensating reception at its end, except in one's own glow of attainment. For progress is first obstructed by the reticence of nature and then opposed by the denunciation of man… A really new idea is a foundling without friends. Indeed a doorstep acquisition is welcome compared with the gift of a brand new upsetting thought. The undesired outsider is ignored, pooh-poohed, denounced, or all three according to circumstances. A generation or more is needed to secure it a hearing and more time still before its worth is recognized.*[30]

Because of the deep-dyed conservatism of the astronomical establishment, the student would likely never be taught the newer things of science until they had passed from what was current into history:

> *Some people seem to think that recently discovered facts are too homeopathic for youth, and that such ideas must not be given to youthful students until they are so old that they are nearly worn out. But I believe in giving young people the newest things which can be found in no other place.*[31]

Of course, his ideas about Mars were always of the greatest interest. Lowell regarded them as among the new ideas opposed by conservative resistance. The reality was that it was in his own mind that they had long been hardened and become set. "Our observations have convinced us without a doubt that the lines on Mars which have caused so much discussion, are canals," he declared. "There is some form of intelligence on Mars. I do not mean human beings, but some intellect capable of accomplishing these feats."[32] As opposed to this matter-of-fact statement, he was still more than capable of working up a battening of beautiful prose, as in the following passage which seems almost to echo John Van Dyke's *The Desert*, though it is just as likely to have been drawn from his 22 year's personal experience of the desert landscapes around Flagstaff:

> *…Our terra firma gives to our globe its sense of home; partly for its very antithesis to the undomiciliate sea… To lack a contrast is to be sensible of a loss. On Mars we should miss the ocean….*
>
> *Such sameness of surface is deepened by the dead level of the land. As there are no oceans, so are there no mountains on Mars. The plainness of its features is unrelieved by piquancy of profile. Plateaus are the height of its attainments: something resembling probably the mesas of our southwestern deserts….*
>
> *To those who really commune with nature there is grandeur in this uniformity. It is the grandeur of vast expanse, bare of interposed detail to detract from its own unique impression, or to bar vision from its would-be range. The horizon may in truth be nearer, yet it seems more far. We have it in our deserts, whose very nakedness adds to their sublimity. Such accentuation of solitude is typical of Mars. For Mars is one vast desert relieved*

> *only here and there by tracts of vegetation. Our deserts grow in grandeur as one sees them more; so as one contemplates that desert world across the void of space its impressiveness increases. Distance robs it of its dread and in its opalescent sheen we see its beauty unmarred by sense of what its pitilessness represents.*[33]

After his exhausting tour, the train finally pulled into Flagstaff on October 19. He was back. Apparently in good health, and driven as ever, without allowing himself any time to rest or acclimatize to the altitude, he threw himself at once into a heavy schedule of work. His first priority was the observation of the Galilean satellites and of Amalthea, the fifth satellite of Jupiter. The latter had been discovered by E.E. Barnard in September 1892. Even with the full aperture of the 24-inch Clark, Amalthea was only disclosed from out of the glare of the giant planet by means of an eyepiece occulting bar. The project sounds pedestrian, but it was not mere stamp collecting. Lowell's purpose can only be guessed at, since the project was interrupted while in progress by his death. Apparently, though, he was hoping to show that, like Saturn, Jupiter had a highly differentiated interior, and might even be, as he believed he had demonstrated in the case of the ringed planet, "rotating like an onion in partitive motion." Little Amalthea, close to the giant planet's oblate sphere, would be a singularly good probe of any gravitational anomalies such as those that he believed had been revealed from his scrutiny of the positions of the subdivisions of Saturn's rings. At the time, the best theory of Amalthea's motion used an empirical model of a rapidly precessing ellipse, with orbital elements as determined by Hermann Struve of the Pulkova Observatory. However, it can hardly be claimed that its motion was satisfactorily known, and indeed a solution looking at the influence of factors other than Jupiter's gravitational potential, such as perturbations by the Galilean satellites, would not be forthcoming until 80 years after Lowell's death.[34] Under the circumstances, Lowell's investigation must be regarded as his investigation of Saturn's rings—singularly premature. As in the other case, the odds are great that he would have been able to torture from his data whatever result he wished, for the singular aptitude he had always possessed for making his observations agree with his expectations was fully intact as he passed into the seventh decade of his life.

Last Contact

Lowell first caught Amalthea at an eastern elongation on the evening of the same day he had returned from the grand lecture tour. There followed a continuous streak of clear weather for the next several weeks. Measures of Amalthea and the Galileans were taken by him or Slipher or both on October 19, 20, 21, 25, 26, 27, 28, 30, 31; November 1, 2, 3, 4, 6, 9, and 10. (On the nights of November 4, 6, and 9, Slipher observed alone.) It is worth bearing in mind that at 7,000 feet altitude, October and November nights can be very cold, and we can be sure that Lowell did not dress for the telescope as he had done when posing for the observing Venus by daylight portrait taken in October two years before.

Lowell was planning to take up his place at the telescope on the evening of November 11. That day, he received a package from Boston, sent by his youngest sister, Amy, a gifted woman who had never attended college because the family did not consider it proper for a woman to do so but who had acquired a taste for literature (and, from her far-travelling and much-admired older brother, for the art and literature of the Far East). In 1916, she was ensconsced in the Sevenels mansion in Brookline, which she had purchased from her siblings after their father's death. She had never visited Flagstaff. Massively overweight because of a glandular problem, with a close companion (and rumored lesbian) living with her, the actress Ada Dwyer Russell who constantly indulged a penchant for smoking fine cigars (again, like her brother), Amy was finding fame in her own right as a poet. Indeed, the package contained her latest (third) volume of poetry, *Men, Women, and Ghosts*. Percival wrote a note of appreciation:

> *Thank you for the thought of the thing, the thing being thought, well paged, and attended, that walked into my eyry in the remote, and I then introduced the welcome visit to Constance and she read to me the tale of the lone farmer's wife as I sat receptive of the comfort of my wood fires. It always pleases me to think how far one's printed thought travels—so may it to you whose child has entered where you never have.*[35]

That night he made the short walk from the Baronial Mansion to the Clark, where Slipher had already observed an elongation of Amalthea. At a few minutes before 9 p.m., with a watch that was, he noted, 2-seconds slow, Lowell recorded the reappearance of Io from eclipse:

November 11, 1916
P.L.

8^h	52^m	10	Eclipse – Reappearance
	54	10½	
	56	10	Last Contact
	56	50	Certainly now

It is poetically apt that Lowell's last recorded words in his observing log book were "Last Contact," and "Certainly now," for these were the last observations Percival Lowell ever made. (These pages were long lost, but were rediscovered by Lowell Observatory preservationist Michael Kitt in a cigar box, where they had been carefully placed for preservation by E.C. Slipher and then forgotten for over 90 years.)

The next day dawned a Sunday, and that morning a cerebral aneurysm exploded in his brain. (Cerebral hemorrhages ran in the family: his sister Amy, at age 52, and his cousin Guy, the first Sole Trustee of the observatory, at 57, would also die of cerebral hemorrhages). The doctor was called, but Lowell never regained consciousness. He passed away at 10 p.m. He had reached the age of 61 years, 8 months.

Incidentally, on the same fateful day Lowell passed, in France, the last action on the Somme of 1916 was getting underway. At almost the exact moment he expired, there was a "Bang! Bang! Bang!" and "all of a sudden, behind us," wrote one of the soldiers involved, "the whole sky was red."[36] This marked the beginning of what is known as the battle of the Ancre, the last futile gesture in the greatest, and bloodiest, campaign on the Western Front of 1916: the battle of the Somme.

After Lowell's death, V.M. Slipher would take over the directorship of the observatorywith the hardworking C.O. Lampland providing support behind the scenes. Two women were left to mourn Percival's passing for the rest of their lives. His secretary Wrexie would later write a book of fond reminiscences, *Percival Lowell: An Afterglow*, whose epigraph reads:

Preambient light—
Waning, lingers long
Ere lost within.
Just, kind, masterful:
Life's sweet constant,
Farewell.[37]

Whatever the nature of their rivalry had been, now it was Constance who had the upper hand. One of her first orders of business, after having her late husband measured for a coffin (he was exactly 6′0″ tall), was to dismiss Wrexie from the observatory. Constance donned black clothes, a black hat, and a black veil or shawl, which she would continue to wear for the rest of her life, and made sure the bedroom in which her husband had died was carefully preserved just as it was—a chalk inscription on the wall recording that "Percival Lowell's earthly existence terminated in this chamber upon the green couch." It was rumored that whenever she returned to Flagstaff she held séances in the Baronial Mansion to attempt to summon him from the Beyond, though the poltergeist-like nocturnal knocking was apparently owing to her habit of shifting her own bodily presence restlessly from bedroom to bedroom. After Lowell's death, she revealed a dark, grasping nature she had managed to conceal during his lifetime. She proceeded to engage in a series of legal maneuvers to break his will and to retain full control of his estate. In this determined, if misguided, effort, she "showed a seldom equaled record of sustained litigation," at any rate, this side of Dickens's *Bleak House*. By the time the litigation was finally settled and the lawyers were paid off in December 1925, the net value of Percival's once-substantial estate had been cut in half, and his observatory, carrying on under the direction of V.M. Slipher (with Lampland still working behind the scenes) was famously broke. During those years, Percival's hardworking staff—V.M. Slipher, C.O. Lampland, and E.C. Slipher—struggled in want and uncertainty, and in the end the observatory's future was secured only by an almost-miracle—the timely appearance in February 1930 of a moving speck in trans-Neptunian space discovered on a pair of plates exposed by a modest and incredibly hardworking Midwestern farm boy, Clyde Tombaugh, during the observatory's resumption of the long-suspended search for Planet X. This, of course, was Pluto, a planet (it was then a planet) that Constance wanted at one point wanted to name "Percival" and then "Constance."

After Wrexie moved back east, she lost money in the stock market crash of 1929 and spent her last years in the state hospital in Medford, Massachusetts. Constance lived on until her eighties in what had been, before their marriage, his bachelor's house at 11 West Cedar on Beacon Hill (as well as around the corner at 102-104 Mount Vernon Street, which had been her residence). She appeared, says William Lowell Putnam III, like a "benign witch," and living in "opulent squalor" as her relatives by marriage kept a cool distance from her, and those by blood hovered, she said, "like buzzards … waiting for me to die."[38]

Meanwhile, the Baronial Mansion, which Constance continued to visit from time to time, gradually went from rambling to shambolic. It was finally torn down as a fire hazard in the late 1950s. No one seems to know what happened to the green couch.

Percival, at first buried in an ordinary grave between the Baronial Mansion and the Clark dome, was reinterred in 1923 in a lovely mausoleum on which—in contrast to his observatory—his mourning widow spared no expense. He continues to sleep on Mars Hill in the shadow of the unique birthday-cake dome, recently cleaned and scrubbed and brilliant with a new coat of white paint and housing within the newly gleaming and refurbished Clark refractor.

A hundred years after his death, and despite Constance's having done her level worst, Percival Lowell's observatory still lives. ✶

(Endnotes)

1 P. Lowell, "Great Discoveries, and Their Reception," lecture text, ca. Aug. 1916, Lowell Observatory archives.

2 ibid.

3 ibid.

4 P. Lowell to V.M. Slipher, 1914 August 11; Lowell Observatory archives.

5 P. Lowell to J. Trowbridge, 1914 December 9; Lowell Observatory archives.

6 P. Lowell to E. B. Wilson, 1915 February 4; Lowell Observatory archives.

7 R. A. Proctor, *Saturn and Its System*. London, Chatto & Windus, 2nd ed., 1882, pp. v–vi.

8 P. Lowell, "Memoir on Saturn's Rings," *Memoirs of the Lowell Observatory*, vol. 1, no. 2 (1915), p. 3.

9 James Elliot and Richard Kerr, *Rings: discoveries from Galileo to Voyager*. Cambridge, Mass.: MIT Press, 1984, p. 32

10 Lowell, "Memoir on Saturn's Rings," p. 22.

11 P. Lowell, "The Genesis of Planets," *JRASC, 10*, 6 (July–August 1916), 281–293:290. The text was of an address Lowell gave in Toronto to The RASC on 1916 April 27.

12 Lowell, "Great Discoveries."

13 According to our current understanding of the rings, there are several other features that involve directly or indirectly resonances with Mimas. The bright inner edge of the tenuous G ring (unknown in Lowell's time) contains the half-kilometre moonlet, Aegaeon, which is held in place by a 7:6 co-rotation eccentricity with Mimas. (The ring's inner edge is about 15,000 kilometres inside Mimas's orbit). Mimas is in a 2:1 mean-motion resonance with the larger moon Tethys, and in a 2:3 resonance with the shepherd moonlet Pandora, which helps herd in the particles making up the F ring. In the A ring, the Encke and Keeler gaps are cleared by 1:1 resonances with the embedded moonlets Pan and Daphnis, while the A Ring's outer edge is maintained by a destabilizing 7:6 resonance with the small moon Janus.

It goes without saying that the interior of Saturn does not, in fact, rotate "like an onion in partitive motion." As with Jupiter, its atmosphere has a different rotation period than its core. The latter is deduced on the basis of periodic radio outbursts emanating from the rotating core's magnetic field, and must represent the bulk rotation. A recent analysis of Cassini data, in which measurements of Saturn's oblateness were relied upon instead of the radio outbursts, seemed to indicate the bulk rotation period was 10 hours, 33 minutes. This rotation period implied that the latitudinal wind structure was more symmetric than had previously been thought, containing both easterly and westerly jets, as on Jupiter.

14 Constance Lowell to C.O. Lampland; quoted in A.L. Lowell, *Biography of Percival Lowell*, pp. 153–154.

15 Constance Lowell to C.O. Lampland, in Lowell, *Biography of Percival Lowell*, p. 155.

16 [Unsigned] "The Latest News from Mars," *JRASC*, vol. X, no. 5 (May–June 1916), pp. 265–266.

17 G.H. Hamilton, "Mars Our Neighbor in Space," *Popular Astronomy*, Vol. XXVIII, No. 3 (March 1920), pp. 137–140.

18 P. Lowell, early draft of preface of *Mars and Its Canals*, 1905; Lowell Observatory archives.

19 Albert D. Watson, "The Bugle," *JRASC*, Vol. X, No. 2 (February 1916), p. 41.

20 P. Lowell, "The Genesis of Planets," *JRASC*, vol. X, no. 6 (July–August 1916), pp. 281–293:281.

21 ibid.

22 ibid., pp. 283–284.

23 ibid., p. 284.

24 ibid., p. 293.

25 Strauss, *Percival Lowell*, p. 267. Among the thinkers who saw a need to include chance or choice in their system—and who rebelled against the rigid determinism of Spencer's system—was Charles Sanders Peirce, a founder of "pragmaticism." Peirce was the son of Lowell's Harvard math teacher, Benjamin Peirce.

26 A.M. Fridman and N.N. Gorkavyi, *Physics of Planetary Rings: Celestial Mechanics of Continuous Media*, trans. D. ter Haar. Heidelberg: Springer, 1999, pp. 285–286.

27 John Keats to George and Thomas Keats, 21, 1817 December 27(?).

28 Hattie Bundy, sister of Bill and Mac Bundy, once said of her mother, Katharine Lawrence Putnam Bundy, Percival's niece, "Mother's sense of righteousness was very deep… How well I remember our fights over the dining room table…. For her, things were black and white. It's an outlook that descends directly from the Puritans and we all have it." Quoted in Kai Bird, *Color of Truth*, p. 36.

29 F. Stimson to B. Wendell, undated; Houghton Library of Harvard University.

30 P. Lowell, "Great Discoveries and Their Reception," lecture text ca. August 1916; Lowell Observatory archives.

31 P. Lowell, "The Far Horizon of Science," *The Stanford Daily*, 1916 October 18.

32 ibid.

33 P. Lowell, "Mars and the Earth," lecture text ca. August 1916; Lowell Observatory archives.

34 S. Brieter, "The theory of motion of JV Amalthea. I. Analytical Solution. *Astronomy and Astrophysics* 314 (1996), pp. 966–976.

35 P. Lowell to Amy Lowell, 1916 November 11; Houghton Library of Harvard University. The poem that Constance read to Percival by the wood fire was probably "Pickthorn Manor."

36 Peter Hart, *The Somme: the darkest hour on the Western Front* (New York: Pegasus Books, 2008), p. 510.

37 Note: Preambient light = Percival Lowell

Waning, lingers long = Wrexie Louise Leonard

Ere lost within = Elizabeth Langdon Williams

Just, kind, masterful = John Kenneth McDonald

Life's sweet constant = Lowell Savage Constance.

Williams and McDonald were the most dependable computers on the "X" search. Lowell's great-nephew and sole trustee, William Putnam III, notes that Constance's name is the only one for whom the letters are reversed; she was, he says, "the one who almost succeeded in completely negating [Lowell's] life work," through the endless lawsuit that she initiated after his death.

38 William Lowell Putnam, III, *Explorers of Mars Hill* (Kennebunkport, Maine: Phoenix Press, 1994), p. 104

First experience at the General Assembly

by Stan Taylor, Toronto Centre

When I first heard about The Royal Astronomical Society of Canada's Annual General Meeting and Conference for 2016 (RASC GA 2016), I was hesitant. This was to be a gathering of amateur astronomers from all across Canada. I was hesitant because I didn't speak the same language as the people whose posts I read on the RASCals emails. I was nervous that I would be, as a newbie, the village idiot in the group. As I listened to learned women and men speak at the conference in a language that I could understand, my confidence level rose significantly.

I took part in the 20-minute presentation for educators. I taught them to make an end effector (the mechanism on the end of the Canadarm) using Styrofoam cups, string, and masking tape. I was so busy teaching and concentrating that I rarely looked at the 18 ladies and gentlemen present. The photographer told me later that he noticed the "a-ha!" moment when each educator smiled as they realized they had just made an end effector; a model they could take back to their classrooms.

Another highlight of our 20-minute presentations was the inspirational talk by David Levy, the comet hunter. I had to have a picture with him.

I sat at a table during five-minute presentations and awards gathering later that evening, when some gentlemen joined me and to my surprise, David Levy was among them. We all talked about a variety of space-related topics for about two hours. What a treat it was for me to be chatting with this wonderful man who is a legend among astronomers.

It was at the social gatherings near day's end when I realized that each amateur astronomer was at a different level of understanding; that each was on a road to discovering the mysteries and wonders of the cosmos. I was among them. I was a fellow traveller.

Figure 1 — The author and David Levy.

Figure 2 — The author and Lt. Col. Jeremy Hansen.

Although I belonged to Toronto Centre, I had never been to a meeting. It was 90 kilometres to a meeting and, after doing science workshops in schools all day, I was tired and did not fancy a long trip to a meeting.

Lt. Col. Jeremy Hansen's talk was a wonderful story of his life to date. When his talk concluded, I had to have a picture with him. He didn't know me from Adam, but he was gracious as we stood beside each other: one a Canadian astronaut, the other a 75-year-young kid.

When I got home from four days at the RASC General Assembly in London, Ontario, I realized that I had learned a tonne. I have been teaching kids about space for more than 30 years, yet I have never seen a planet through a telescope. That all changed on May 19 at 4:41 p.m. during the conference. The Hume Cronyn Observatory in London has a 10-inch refractor telescope. The resident astronomer attached my iPhone 5S to an adaptor mounted in the eyepiece of the scope. We took several pictures of Jupiter between the moving clouds. To actually see Jupiter through a telescope is an adventure beyond words.

Thank you London Centre for an outstanding conference. Thank you Peter, Chris, and everyone else with whom I spoke. I'll see you next year at the RASC GA in Ottawa as we celebrate Canada's 150th birthday. ✶

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CFHT Chronicles

by Mary Beth Laychak, Outreach Program Manager, Canada-France-Hawaii Telescope.

I have substituted the regularly scheduled CFHT Chronicles column by an excellent article on the recent discovery of a planet around our nearest neighbour, Proxima Centauri. The author, Cam Wipper, is one of CFHT's remote observers and a Canadian. He writes regular columns for CFHT's blog Hoku (www.cfht.hawaii.edu/en/outreach/hoku). After the announcement of the Proxima Centauri discovery, Cam decided to start this series of articles. The rest of the articles will be found, along with this one, on our Hoku blog.

And now…

Destination: Proxima Centauri, Part I: Going Interstellar: Time, Distance, Velocity, & Acceleration

by Cam Wipper

Some of you may recall the iconic elongating stars as the Millennium Falcon accelerated to the speed of light in the movie *Star Wars*. For those who don't, Han Solo and Luke Skywalker escape from the clutches of the Galactic Empire above the desert planet of Tatooine as they accelerate beyond light speed.

In *Star Wars*, faster-than-light travel is routine and allows characters to travel to star systems across their galaxy. *Star Wars* is, of course, science fiction, but even in this world of make-believe, faster-than-light travel is still a complicated technology; it isn't as simple as dusting crops after all! The light-speed travel in *Star Wars* requires a special computer—the "navi-computer"—to calculate the route through the galaxy so that collisions with stars, planets, and black holes are avoided. Also, as seen in other films in the *Star Wars* saga, the hyperdrive engines that propel the ships to faster-than-light speeds are rather unreliable and break down frequently.

In our real world, we are relatively Stone Age. The fastest current spacecraft is the venerable *Voyager 1*. It is currently travelling away from the Sun at a speed of 17 kilometres per second or 38,000 miles per hour. While this sounds fast, it is only 0.0057 percent of the speed of light. To put such a small percentage into perspective, it is roughly the same comparison as the top speeds of the world's fastest production car, the Bugatti Veyron Super Sport, and that of a common garden snail. The Bugatti can reach 258 mph, while a garden snail races along at speeds between 0.003 and 0.010 mph (16-50 *feet* per hour)…and we are the garden snail. The following is another way to attempt to understand how fast the speed of light truly is: to travel at just 1 percent of the speed of light, 2,998 km/s (6.7 million mph), *Voyager 1* would need to accelerate to 175 times its current speed. To reach 20 percent of light speed—59,958 km/s (134 million mph)— *Voyager 1* would need to accelerate 3,500 times its current speed! We clearly have a long way to go, but we have reason to try to achieve these speeds. At 20 percent of the speed of light, it would be possible to reach other star systems in the span of one human lifetime.

The closest star to the Sun is a small red dwarf star named Proxima Centauri. It sits about 4.25 light-years away—roughly 25 trillion miles. At this distance it would take *Voyager 1*, travelling at 17 km/s about 75,000 years to reach Proxima Centauri. At 1 percent of the speed of light, it would still take almost 426 years to get there. If, however, we could get up to 20 percent of the speed of light, it would take only 21 years! A brave astronaut could leave Earth, visit Proxima Centauri, and return in less than 50 years! True interstellar travel would be possible and the human race would seem to be destined to spread across the galaxy…or would we? These calculations have left out a very important consideration: acceleration.

It would only take 21 years if you left Earth at 20 percent of the speed of light and continued at that same speed until you reached Proxima Centauri. To put it another way, this presumes instantaneous acceleration. While convenient for our calculations, in the real world, such acceleration would be obviously fatal. The human body can withstand any constant velocity (you feel the same sitting in a chair—0 mph—cruising down a highway—55 mph—or at 35,000 feet in a commercial airliner—575 mph); it is during acceleration that the body struggles. This was succinctly described by ex-*Top Gear*, and current *Grand Tour* host, Jeremy Clarkson when he stated, "Speed has never killed anyone. Suddenly becoming stationary, that's what gets you." The result of the sudden deceleration he is referring to is the same as our instantaneous acceleration: near-certain death. We should then factor acceleration into our travel-time calculations.

Acceleration is often described in terms of gravitational force or g-force. Acceleration due to gravity on Earth is approximately 9.8 m/s^2. A person, such as yourself while reading this article, is experiencing gravity trying to accelerate you at this rate. You are (likely) not accelerating because of what is known in physics as the "normal force." If you are sitting on a flat surface, it is pushing back against gravity at the same rate as gravity is pushing down on you and you feel this as your weight. As a result of these forces, you are experiencing 1.0g—the g-force experienced by every stationary object on Earth and the force at which the human body is evolutionarily adapted to withstand. In space, if you accelerated at this rate,

9.8 m/s^2, you would weigh the same and feel just as you do on Earth. Since this is what we know best, let's use this rate for our acceleration calculations. At this rate of constant acceleration, how long would it take to reach the speed of *Voyager 1*? One-percent the speed of light? Twenty-percent the speed of light? The answer is surprising.

As we know, *Voyager 1* is travelling at 17 km/s. From a resting position (i.e. velocity of 0, assumed for ease of computation; see equation list below article), if we accelerated at 9.8 m/s^2, we would reach 17 km/s in just 29 minutes! That's right: with the same acceleration as the force of gravity pushing down on you right now, a spacecraft could reach 38,000 mph in 29 minutes. It would be possible to reach 1 percent of the speed of light in 85 hours (3.5 days) and 20 percent of the speed of light in 71 days (just under 2.5 months)! That doesn't seem so bad at all! But wait…there is a huge cost to this acceleration: energy. In order to accelerate an object this quickly, it takes a lot of energy. To escape the Earth's gravity, the *Space Shuttle* needed to accelerate to at least 9.8 m/s^2. In doing so, it used almost 2 *million* pounds of fuel, which it exhausted in 8.5 *minutes*! With this incredible rate of fuel consumption, it would be impossible to carry enough fuel for the needed 29 minutes to reach *Voyager 1* speeds, never mind the 71 days required to reach 20 percent of the speed of light.

That's not the end of the story for interstellar travel though. We don't need to accelerate that fast. Nowhere near that fast. Once we escape the gravitational pull of the Earth, we only need to accelerate at 0.2 m/s^2 to reach Proxima Centauri! To put this in perspective, a car accelerating at this rate would take 2.2 minutes to go from 0 to 60 mph—most modern vehicles can do so in under 10 seconds. On a journey to Proxima Centauri, a spacecraft would need to accelerate, cruise at the top speed, and then decelerate again. Our spacecraft, accelerating at 0.2 m/s^2 would take 10 years to reach ~20 percent of the speed of light. In doing so, it would cover 1.06 light-years, about a quarter of the distance to Proxima Centauri. It would then need 10 years to slow down at the same rate as it approached Proxima Centauri, again covering just over a light-year. In the cruise phase, it would cover the remaining 2.13 light-years while travelling at 20 percent of the speed of light (1.06 + 2.13 + 1.06 = 4.25 light-years). This would take another 10 years. In total we could accelerate to, cruise at, and decelerate from 20 percent of the speed of light and reach Proxima Centauri in roughly 30 years! A return journey would take 60 years, still within the realm of one human lifetime. It seems that interstellar travel may be possible after all!

Now, it is worth acknowledging that there are a number of issues that have been glossed over here. For one: we made no attempt to use the complex physics of orbital mechanics in our equations. While this would have certainly increased the accuracy of our results, it is beyond the scope of this article and in reality likely would not have made a huge difference over the timescales (decades) and distances (light-years) we considered. Secondly, 0.2 m/s^2 is actually not as slow as it seems. Our current ion engines, used by spacecraft to travel between planets today, produce so little thrust that they only accelerate at 0.0005 m/s^2. We still need significant advances in propulsion technology to achieve these rates of acceleration continuously over many years. There may be solutions in the future though. Some incredible technologies are under development. Additionally, we have issues with Relativity (that Einstein guy) and small grains of dust (yes, dust!). Ignoring these for now, what would we find once we get to Proxima Centauri? Well, as was announced in late August 2016, a planet, known as Proxima b, is orbiting this star. It is in the habitable zone and may be like Earth…we might have neighbours just next door!

More on Proxima b, propulsion systems and the other issues with interstellar travel coming up in future installments of the 'Destination: Proxima Centauri' series here on the CFHT Hoku blog! This article was rather heavy on the mathematics (Sorry!).

For those interested, here are the various equations and solutions written out.

Proper adherence to the rules of significant figures and rounding were not always followed, these are simply "back of the envelope" calculations.

The approximate answer given in the article is listed in parentheses when different from the exact answer.

1. Key Equations and Constants:

$a = \Delta v / \Delta t = (v_f - v_i) / (t_f - t_i)$ $d = v_i t + (1/2)at^2$

Speed of light = 299,792,458 m/s (299,792.5 km/s)

1 percent of the speed of light = 2,997,924.58 m/s (2,998 km/s)

20 percent of the speed of light = 59,958,491.6 m/s (59,958 km/s)

2. *Voyager 1* velocity as a percentage of the speed of light.

17 km/s / 299,792.5 km/s = 0.00005671 x 100 (convert to percentage) = 0.0057 percent

Garden snail velocity as a percentage of the top speed of a Bugatti Veyron.

0.010 mph / 258 mph = 0.00003876 x 100 (convert to percentage) = 0.0039 percent*

*while the numbers are different, this is the same order of magnitude (within a factor of 10), as the *Voyager 1*/speed of light comparison. This is considered comparable.

3. *Voyager 1* velocity increase needed to reach 1 percent the speed of light (multiples of).

2,998 km/s / 17 km/s = 176.35 (175 times)

4. *Voyager 1* velocity increase needed to reach 20 percent the speed of light (multiples of).

59,958 km/s / 17 km/s = 3,526.94 (3,500 times)

5. Travel time to Proxima Centauri at 17 km/s (*Voyager 1* speed) with no acceleration:

4.25 light-years = 40,232,500,000,000 km (40 trillion km)

40,232,500,000,000 km / 17 km/s = 2,366,617,646,058 s = 75,045 years (75,000 years)

6. Travel time to Proxima Centauri at 1 percent the speed of light with no acceleration:

40,232,500,000,000 km / 2,998 km/s = 13,419,779,853 s = 425.5 years (426 years)

7. Travel time to Proxima Centauri at 20 percent the speed of light with no acceleration:

40,232,500,000,000 km / 59,958 km/s = 671,011,374 s = 21.3 years (21 years)

8. Acceleration to *Voyager 1* speed from rest at 9.8 m/s^2: (assume $v_i = 0$, set $t_i = 0$)

$a = \Delta v / \Delta t = (v_f - v_i) / (t_f - t_i)$

$9.8\ m/s^2 = (17{,}000\ m/s - 0\ m/s) / (t_f - 0\ s)$ $t_f = 17{,}000\ m/s / 9.8\ m/s^2$

$t_f = 1{,}734.7$ s

$t_f = 28.9$ mins (29 minutes)

9. Acceleration to 1 percent speed of light from rest at 9.8 m/s^2: (assume $v_i = 0$, set $t_i = 0$)

$a = \Delta v / \Delta t = (v_f - v_i) / (t_f - t_i)$

$9.8\ m/s^2 = (2{,}998{,}000\ m/s - 0\ m/s) / (t_f - 0\ s)$ $t_f = 2{,}998{,}000\ m/s / 9.8\ m/s^2$

$t_f = 305{,}918.4$ s

$t_f = 84.97$ hours (85 hours)

10. Acceleration to 20 percent speed of light from rest at 9.8 m/s2: (assume vi = 0, set ti = 0)

$a = \Delta v / \Delta t = (v_f - v_i) / (t_f - t_i)$

$9.8\ m/s^2 = (59{,}958{,}000\ m/s - 0\ m/s) / (t_f - 0\ s)$ $t_f = 59{,}958{,}000\ m/s / 9.8\ m/s^2$

$t_f = 6{,}118{,}163.3$ s

$t_f = 1699$ hours

$t_f = 70.8$ days (71 days)

11. Rate of acceleration needed so that it takes 10 years to travel one quarter of the distance to Proxima Centauri assuming start at rest ($v_i = 0$).

Distance to Proxima Centauri = 4.25 light-years.

One-quarter the distance = 4.25 / 4 = 1.0625 light-years

1.0625 light-years = 10,052,030,000,000,000 m (1.005203×10^{16} m)

10 years = 315,360,000 s

$d = v_i t + (1/2)at^2$

equation if $v_i = 0 \rightarrow d = (0)t + (1/2)at^2 = (1/2)at^2$ $d = (1/2)at^2$

$a = 2d / t^2$

$a = 2(1.005203 \times 10^{16}\ m) / (315{,}360{,}000\ s)^2$

$a = (2.010406 \times 10^{16}\ m) / (9.94519296 \times 10^{16}\ s^2)$

$a = 0.20215\ m/s^2$ ($0.2\ m/s^2$)

12. Final velocity after accelerating at 0.20215 m/s^2 for a quarter of the distance to Proxima Centauri.

(assume $v_i = 0$, set $t_i = 0$) $a = \Delta v / \Delta t = (v_f - v_i) / (t_f - t_i)$ $a = (v_f - 0) / (t_f - 0)$

$a = v_f / t_f$ $v_f = at_f$

$v_f = (0.20215\ m/s^2)(315{,}360{,}000\ s)$

$v_f = 63{,}749{,}556.1$ m/s

$v_f = 63{,}750$ km/s

$v_f = 21.2$ percent of the speed of light (conversion: 63,750 km/s / 299,758.5 km/s)

13. Time to travel middle half of journey to Proxima Centauri, assuming first and last quarter are spent accelerating and decelerating:

Distance to Proxima Centauri = 4.25 light-years. One half the distance = 4.25 / 2 = 2.125 light-years

2.125 light-years = 20,104,100,000,000,000 m (2.01041×10^{13} km)

20,104,100,000,000 km / 63,749 km/s = 315,363.378 s = 10.0001 years (10 years)**

**It may be surprising that this results in such a round number, and one identical to the time spent accelerating, but see equation 11. In that equation, we needed to double the distance term ("2d") while solving for the acceleration. This means that our rate of acceleration (and therefore our final velocity) is directly related to double the distance spent accelerating. Since we divided our distance into quarters, this means that our "cruise" distance and double the distance spent accelerating are the same length (2.125 light-years). As a result, the time spent accelerating, cruising, and decelerating are the same: 10 years each (The reason the answer isn't *exactly* 10 years, is simply due to rounding error). ✶

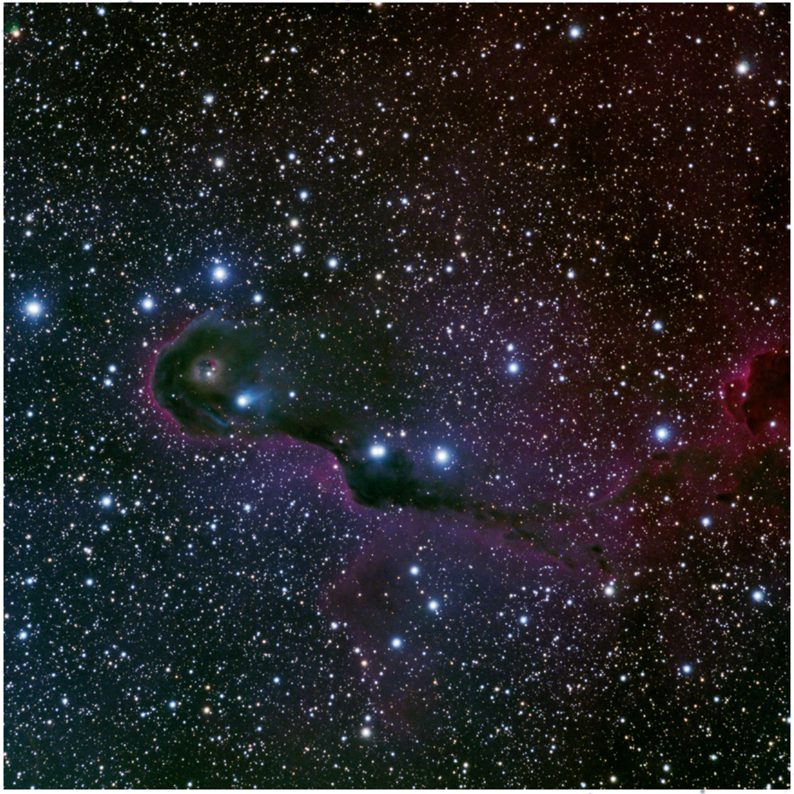

Figure 1 — The Elephant Trunk Nebula seen here was imaged by Andre Paquette using his Edge HD14 and U16M. It was guided with Skyris 274 and MetaGuide. Paquette captured the image with 2.6 hours of red, 2.3 hours of green, and 2 hours of blue, with 20 minute subs.

Figure 2 — Blair MacDonald captured the Dumbbell Nebula, known as M27, from three locations in Nova Scotia using a 200-mm SkyWatcher ƒ/5 Newtonian reflector with Paracorr for a total focal length of 1150 mm and a Canon 60Da for a total of 209 minutes in RGB (69x180 seconds). The image was processed using Images Plus.

Figure 3 — Dan Meek imaged IC 1848, otherwise known as the Soul Nebula from Calgary, Alberta. Meek used a Tele Vue NP127is telescope and QSI583wsg camera, with 12x900s each in Hα/SII/OIII.

Figure 4 — This image of our galaxy was taken by Drew Patterson using a Canon 6D Sigma 24-mm Art lens at ƒ/1.4 using ISO 1600 on an iOptron Sky Tracker. The single 60-second exposure was processed in Adobe Lightroom.

Astronomical Art & Artifact

Time on Display in Civic Landscapes: Québec City

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> *"For time cannot be perceived through itself, but only through human acts."—Isidore Hispalensis (ca. 560-636)*[1]

Abstract

Time symbolically and instrumentally represented can take intriguing forms in urban landscapes, particularly when different chronometric technologies survive to create a contrast. This paper briefly reflects on several prominent and contiguous institutional measurers of time in the historic core of Québec City. Other Canadian cityscapes could provide equal scope for temporal reflection. And time on display is invariably a component of astronomical tourism.

Measurable but not fully encompassed

Astronomy in Canada has been about time determining place for much of its duration (16th–early 20th century). The principal colonial powers in Canada during that era owed the founding of their respective "national" astronomical institutions, the royal observatories at Paris (1667) and Greenwich (1675), to a competitive desire to improve the reliability of navigation in support of commerce, and defence (Forbes 1975, 1-24; Debarbat 2012). The flavour of astronomy in the colonies was every bit as practical, if not more so; navigation at sea, wayfinding on land, providing time to railways, ships in harbours, jewellers, and the citizenry, charting coastal waters and coastlines, and determining boundaries and surveying settlements on land. These all involved finding and using time as accurately as possible. The extent of this can be seen in the founding of our one-time national astronomical institution, the Dominion Observatory at Ottawa (1905–1970). It was originally planned, procured, and politically piloted by surveyors—and a mechanic (Hodgeson 1989, 10-22; Thomson 1967, 261-264).

The layouts of many historic Canadian communities are themselves part of the monumental astronomical landscape of the country, for, as one official Canadian surveyor's manual of the Victorian period put it, "The land surveys...are to be astronomical" (Dennis 1871, 10; 7). This approach is also found in 17th- and 18th-century manuals (Wing 1699; Gardiner 1737). As timing astronomical events is integral to surveying by the stars, so the very streets themselves laid out in the original surveys are in some fashion observations of time inscribed on the land. And erected above those time-derived streets one can encounter astronomical monuments measuring and symbolizing time—sundials and clocks.[2]

Figure 1 — "1773" sundial glimpsed through the archway into the courtyard of the Séminaire de Québec. All photographs by R.A. Rosenfeld.

Successive temporal statements

In the historic core of Québec City, within the upper town, are two monumental time keepers located within striking distance of each other. One is the sundial, said to have been made in 1773, on the wall of the *aile de la Procure* forming a side of the courtyard of the oldest surviving building of the *Séminaire de Québec* (1678–1681, now the *École d'architecture de l'Université Laval*), and the other is the *l'horloge porte-bonheure*, or "Jura Clock," a new mechanical town clock for the city erected between 2008 and 2014. Both are time-telling installations, with obvious and not so obvious similarities and differences, but both have stories to relay beyond indicating the time of the present when consulted.

The sundial can be glimpsed through the archway into the courtyard of the *Séminaire* just off the *côte de la Fabrique* (Figure 1), next to the *Musée de l'Amérique francophone*, and the clock is on the grounds of the *Hôtel de ville de Québec* (Figure 3), a mere two minutes away by foot (ca. 160 metres). Walking from the sundial to the clock, one has the distinct impression of traversing the centuries between the *Ancien Régime* and the contemporary Québec of the *400e anniversaire*, but that journey is not quite what it seems.

The sundial

The sundial of the *Séminaire* measures ca. 1.5 metres wide by ca. 1 metre high. By type, it is a declining vertical dial (Savoie

Figure 2 — Close up of the "1773" sundial in the courtyard of the Séminaire de Québec, on the aile de la Procure.

2009, 89-94).[3] The frame, hour lines, Roman numerals, and inscription of the dial plate are executed in red paint on a white ground, the design is on a panel raised slightly from the wall, and the style (shadow-casting element) has the appearance of wrought iron (Figure 2). The general aspect of the dial plate is uncluttered, and minimally ornamented.

Most descriptions of the sundial date it to 1773, with the implication that the actual sundial of today is the sundial of 1773. This seems easy to accept upon first making its acquaintance, particularly when one is in tourist mode. Given that the sundial is rightfully officially included in Québec's "cultural patrimony," and features on the logo of UNESCO chair "*en patrimoine culturel*" at the University of Laval, it is all the more surprising that there appears to be a lack of any serious literature on the artifact (e.g. Bouchard, "Vive la différence;" Cadran solaire, Répertoire du patrimoine culturel du Québec; Chaire UNESCO en patrimoine culturel). Many indistinguishable online sources predominate nearly all expositions promoting cultural tourism. This is disappointing for tourists wishing to deepen their cultural experience through exposure to relevant researched context, and documentable facts, for upon further visual engagement with the sundial, a disquieting discrepancy will inevitably be sensed between the purported date of the sundial and its present appearance. Something about it doesn't look of the period.

Figure 3 — Jura Clock (2008–2014) on the grounds of the Hôtel de ville de Québec.

That something is the epigraphy of the inscription DIES NOSTRI QVASI VMBRA ("Our days on the Earth are as a shadow;" *Libri paralipomenon I* 29:15). The grammar and orthography are consonant with the 1770s, but the *sans serif* letter forms are manifestly not. French sundials from the continental *Ancien Régime* invariably have inscriptions and numerals with serifed script, whether the texts are carved, or painted. This is attested by the examples from Dom Bedos de Celles' *La Gnomonique pratique* of 1774, a significant text on the French practice of gnomics contemporary with the purported date of the *Séminaire*'s sundial (e.g. head-piece on p. 1, and pp. 11-15, 37—in particular, the sundial of the Abbey of St. Denis, dated 1765). Examples recorded in publications of the time are often a more reliable source for the appearance of 18th-century exterior mural dials than the surviving artifacts themselves, particularly for those with painted elements, given the effects of exposure to weathering and the "improvements" of successors. The dials of the Sorbonne are a case in point (Gotteland 1983; Gotteland & Camus 1993, 80).

To the results due to weathering, and deliberate renewals and alterations of sundial designs, accidents can also play a role in altering the instruments from their original appearance. The *Séminaire* rebuilt the *aile de la Procure* about 1820, and in 1865, a disastrous fire left little but the walls standing (Noppen et al. 1979, 56, 230). After the 1865 fire the slope of the roof, and the disposition of the dormers were altered, as was the elevation, by the addition of a storey and a half (Leahy 1986, 23).

The photographic evidence is interesting. Photographs were taken in the aftermath of the 1865 conflagration, and encouragingly, one shows a sundial in the exact place of the present sundial (Noppen et al., 1979, 230, fig. 12). The extent of fire damage to the sundial is difficult to read from the image. It is hard to believe the timekeeper would not have required some restoration. The sundial is more clearly seen in photographs from the first half of the 20th century, and there are notable differences with the appearance of the present instrument. In the photographs, the outer border of the sundial is rendered in a solid colour, as in an image from ca. 1900 (J.E. Livernois Ltée). And in one from 1949, the first letters of the words of the inscription are larger than the rest of the letters, the words are separated by indices, and some of the letter forms are different from the present inscription (e.g. in the earlier version the angle between the two ascenders of the first letter of "VMBRA" is greater, and they are joined at the baseline by an arc; the "S"s are more angular; and the crossbar of "E" is considerably shorter). The present sundial is not identical with the sundial of 70 years ago, or the sundial of 150 years ago. As has the building to which it is attached, the instrument has changed since its creation. Such non-periodic alterations to its appearance show another way in which it, along with most artifacts, registers the passage of time.

The earliest printed reference I could find to 1773 as the year of the creation of the sundial is in a publication of 1869, but it provides nothing beyond that bare statement; no document is cited, or quoted to support it (Anonymous 1869, 175). A sundial similar to the present one may very well have been added to the *aile de la Procure* of the *Séminaire* in 1773, for a similar one is portrayed in Richard Short's engraving of 1759, "A View of the Intendants Palace" (in Québec) (Traquair 1947, 46). Spherical trigonometry and astronomy of the most rudimentary sort were taught at the *Séminaire* in the late 18th century, although it was below the level needed to create a sundial (Pretre 1792, 4–7). If the students couldn't, perhaps the instructor could.

There is nothing inherently unlikely in the *Séminaire* having acquiring a mural sundial in 1773. If there is evidence for it, it would benefit Québec's cultural patrimony to have the evidence accessibly published. The sundial of today is, however, rather different from the sundial of the 18th century, should it have existed. That is not a bad thing. It means the sundial is a temporally living instrument, renewed as required by those responsible for it. It tells time as long as it is maintained. It is as much an instrument of our time as it is an instrument of 1949, 1864, or possibly 1773.

The clock

Surviving monuments of civic timekeeping in the "west" go back at least to the Tower of the Winds (*Horologion*) in the Athenian Agora (ca. 100 BC; Robinson 1943, 295, 297; Kienast et al. 2014), a building whose design influenced that of several prominent Enlightenment observatories. The archetypical civic clock since about AD 1350 is the turret clock, with the works wholly or partly in a tower and the dial and hands (or other indicators) made visible through size, and elevation. A good many medieval and later examples survive in working condition thanks to parts of various periods and efforts at maintenance (Schukowski et al. 2014; Dohrn-Van Rossum 1996). Their conception, creation, and continuance was due to a mix of reasons, both practical and symbolic. As material embodiments of time passing, town clocks were never trivial undertakings.

Figure 4 — Face of the Jura Clock.

Québec acquired its latest town clock as a gift in 2008 to mark the 400th anniversary of the settlement's founding. The donor was the République et Canton du Jura, one of the historic watch-making regions of the Swiss Confederation, and the gesture is part of the diplomatic relations between the two political entities. Hence the piece is known popularly as the "Jura Clock;" its more official name is *l'horloge porte-bonheure*.

The clock strikes the onlooker as alternatively novel, and traditional. Among the novel is the placing of the clock at ground level, allowing the viewer to get closer to it than is practically the case with turret clocks. Encasing it in glass further enables those interested to see something of its works, in contrast to the works of turret clocks in towers of stone, brick, concrete, or metal. In these characteristics it resembles Jens Olsen's World Clock in Copenhagen, also at the city hall and enclosed in a glass case at viewer level (ca. 1943-1955; King & Millburn 1978, 264–267). The Copenhagen and Jura clocks differ in that the former is indoors, and the latter is out-of-doors. The Jura clock also differs from most civic clocks in that its dial and the part of the works closest to it look like a scaled-up version of a modern wristwatch, rather than the more traditional public face of a turret clock (Figure 4).

Among its more traditional characteristics is that it *is* a civic clock. Also traditional is the choice of a mechanical movement. The object additionally follows the tradition of such things in representing a considerable financial outlay, and in requiring the skills of specialists to fashion it into working order.

Several aspects of the marketing of the clock are curious. A civic clock is by definition an amenity occupying public space, physical and social. The Jura clock was developed and made by several Jurassien technical schools, in a "private-public" partnership with two Swiss watch firms, for the government of Jura, as a gift to another democratic state. The more dominant of the luxury watch-making firms involved in the Jura clock gift has nevertheless claimed the lion's share of media presence and leadership for the creation of the clock. Its name is the only one prominently displayed on the clock, which has been endowed with a dial and hands resembling those characteristic of its wristwatches. It is as if the Jura clock is just another of its "exclusive" products, the "watch" it has made for Québec City to wear, helping to market the watches it makes for its customers to wear. The celebration of the 400th anniversary of the founding of Québec happened most profoundly and popularly in the cultural sphere. Was some of that cultural space carved out for something less profound, and less public?

There are amusing aspects to the presentation of the clock. "Unprecedented accuracy" is claimed for it, "more accurate than a quartz watch," its mechanical movement "of an unprecedented complexity," its making framed as an heroic feat of engineering, overcoming "unparalleled technical challenges" to scale up a mechanical-watch technology to the steroidal size required for a town clock (L'horloge du Jura; Horloge porte-bonheure). Had the makers wanted to achieve unprecedented (and unnecessary) accuracy for a town clock, they could have used one of the 20th- or 21st-century technologies superseding purely mechanically powered movements, such as a Shortt Synchronome style free-pendulum, a quartz oscillator, or one of the physical package realizations of an atomic standard. Judging by reports, the Jura clock was none too accurate out of the box (Québec's Jura clock mocked as an unreliable piece of art). To claim that a clock offering such a limited range of complications as the Jura clock is of unprecedented complexity suggests poor design—it can hardly compare to earlier astronomical clocks such as Jens Olsen's World Clock, or for that matter Richard of Wallingford's *Horologium astronomicum*, or Giovanni de' Dondi's *Astrarium*, both of the 14th century! And, to any of the established firms experienced in the maintenance and repair of turret clocks, the thought of scaling up wristwatch parts and technologies for the purpose would seem hugely amusing. They would not be wrong.

The Jura clock is an interesting addition to the technological urban landscape of Québec City, just not an untroubled one.

Time in the city

Devices that tell time through the apparent daily movement of the Sun across the sky, or an arrangement of gearing to traverse equal-hour divisions, are analog astronomical models of the daily rotation of Earth. The former instrument, a declining vertical sundial, is a technology that evokes for us earlier times, yet it works as well now as when it was first painted on the wall of the *Séminaire*. The latter, a recently installed clock employing some very modern materials such as artificial sapphire, ceramic compounds, titanium, and invar, is a mechanical movement in a long line of mechanical movements coterminous over much of their timeline with sundials. Neither is wholly new, or wholly old. Both are now part of the historic core of Québec City. And, to paraphrase Isidore of Seville, who is quoted at the beginning of this paper, it is our perception that provides the context for the sorts of time they tell in the city. ✶

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

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www.theglobeandmail.com/news/national/quebecs-jura-clock-mocked-as-an-unreliable-piece-of-art/article24024586/

(consulted 2016 October 11)

(Endnotes)

1 "Nam tempus per se non intellegitur, nisi per actus humanos;" Isidore of Seville 1911, lib. V, cap. xxx, 9. Translation by the author. The literature on time is varied and vast, and some inkling of its range can be had through comparing treatments in Jaszczolt & de Saussure 2013, Urban & Seidelmann 2013, and Albeverio & Blanchard 2014 . Quantification is not explanation, and time is the province of many disciplines. For a different view, and a fine introduction to time mostly astronomical and physical, see Bishop 2016.

2 One of the earliest officially approved Canadian manuals on surveying even included a chapter (VI) on creating sundials; Deville 1878, 91—95. This is in fact a continuance of a tradition in this genre of literature; e.g. Wing 1699, 342—357. And, somewhat turning the tables, in the early 18th century (the decades leading up to the conquest of New France) superior universal equinoctial sundials could even be employed to correct for the magnetic declination when conducting surveys(!); Hammond 1731, 151—158.

3 Or, according to the classification system in Archinard 2007, it is of the type *3.2.8-1. CADRANS SOLAIRES de DIRECTION, déclinant du septentrion à l'orient, mural* (523).

Imager's Corner

Resolution, Image Sharpness, and Interpolation

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

In this edition we will take a look at resolution, image sharpness, and interpolation. There are many misconceptions about resolution, camera pixel count, interpolation, and their effect on astronomical images. Some of the confusion revolves around the difference between image sharpness and resolution. In this paper, we will examine each and show that pixel count is not a guarantee of image sharpness or high resolution.

A Few Concepts

To understand all of these things we need to understand a few concepts. Cameras spatially sample an image, and the same theories that are used to describe sampling an audio signal in time apply to sampled images. The sample rate for an audio signal is described in terms of samples per second while for images can be thought of as samples per inch or samples per image. Just like in audio sampling there is a limit to what frequencies can be sampled at a given sample rate. Here the frequencies are spatial frequencies and are a measure of how fast the value can change pixel to pixel. The highest frequency that can be represented in any sampled system is equal to one half the sample rate. For images this means that some image detail spans two pixels. For stars, one pixel is on a star and the very next pixel is on the background.

What is resolution and sharpness?

Many feel that resolution is what produces image sharpness, but that is only partially true. Image sharpness is really an indication of well-balanced data in the spatial-frequency domain no matter the size of the image. Resolution is a measure of how many pixels cover a given detail in an image. First, let's take a look at resolution and sampling using my imaging system as an example. I use an eight-inch SkyWatcher imaging Newtonian with a Paracorr coma corrector, and I collect the photons on a Canon 60Da.

When light passes through a circular lens and comes to a focus it produces an Airy disk. Many of you are familiar with the diffraction pattern as you see it each time you look at a magnified star in a high-power eyepiece.

Figure 1 shows the typical view of an Airy disk as seen in a telescope. Two stars are considered resolved when the maximum of the central spot of one star lies on top of the first minimum in the Airy disk of the other star as shown in the plot below.

This is the absolute minimum separation that two stars can have and be detectable. Note that the two stars will look like an elongated star, not two separate stars.

The distance on the focal plane is $x = 1.22 \times \frac{\lambda \times f}{d}$ where λ is the wavelength, f is the focal length, and d is the lens diameter. If we use 559 nm for the wavelength (the centre of the visible-light spectrum) and substitute the focal ratio (F) for f/d then we have, $x = 681.98 \text{ nm} \times F$. For my scope ($f/5.75$), the resolution limit is 3.9 µm at the focal plane. Now with a focal length of 1150 mm, my optics yield a theoretical resolution of 0.7 arcseconds calculated from $\theta = 2 \times \operatorname{atan} \frac{3.9 \text{ um}}{2 \times f}$, where f is the scope focal length. Keep in mind that this is the theoretical best possible resolution for my system, assuming perfect optics and observing in a vacuum. Seeing on average is between one and two arcseconds, call it 1.5 arcseconds, which is about half the best I can expect with my optics and thus places the real limit on my optical system.

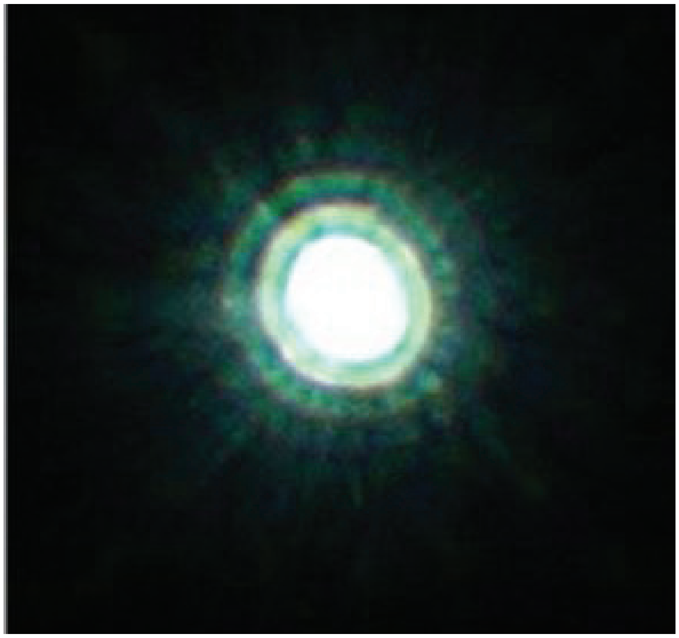


Figure 1 — Airy disk

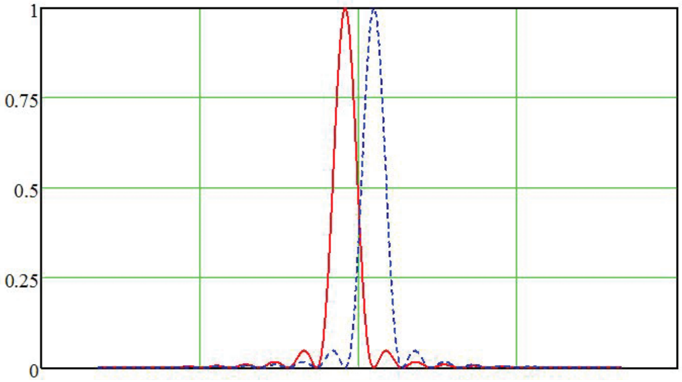


Figure 2 — Two stars just resolved

My camera employs a sensor with 4.3 µm pixels producing an image scale of 0.77 arcseconds per pixel with my optics. But, since it is a DSLR with an anti-alias filter that slightly blurs the image (let's assume over two pixels), then the resolution is about 1.6 arcseconds. This assumes that the camera completely compensates for the effect of the Bayer matrix, which of course it does not. With a resolution of around 1.6 arcseconds when coupled with my optics, it is clear that my camera and seeing place the limit on the resolution of my imaging system. The above discussion does not include any effect from the Bayer matrix and assumes that the de-mosaicing required may cause colour bleed but does not affect resolution. While this is not strictly true, all image elements are sampled in at least one colour, so de-mosaicing should be able to maintain a reasonable representation of the luminance of the image.

With a resolution of 1.4 arcseconds and seeing of about 1.5 arcseconds, I should be just able to resolve Epsilon Lyrae where the pairs are just over two arcseconds apart. As you can see from the image in Figure 3, the resolution is just about exactly what is predicted from the math with the pairs just resolved.

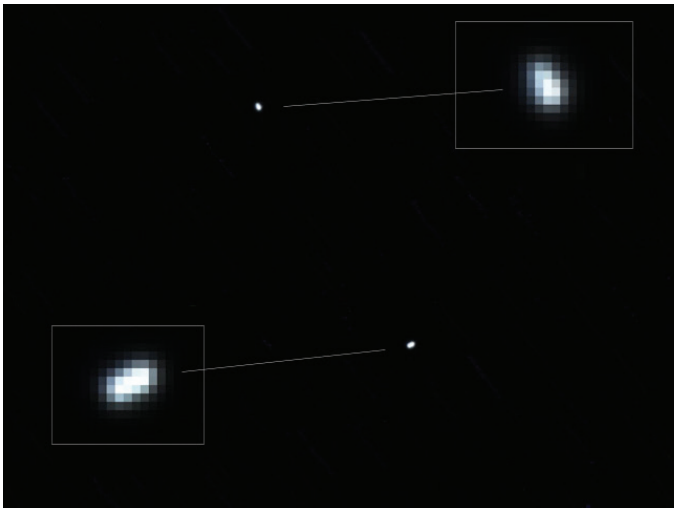


Figure 3 — Epsilon Lyrae imaged at prime focus with my imaging system

With a separation of 2.3 arcseconds for the upper pair and 2.6 arcseconds for the lower, the stars are very close to the resolution limit of my system. The stars blend together and form an extended object at the image plane and are just resolved. From the image you can clearly see how the light from the stars is spread out over several pixels. You can also see that the change in brightness takes place over about four pixels from the stellar core to the background, indicating that the highest spatial frequency present in the image is at least half the Nyquist frequency.

The above discussion shows that resolution is not just a function of the number of pixels in the imaging system. Everything in the optical chain, including the atmosphere, plays a part in determining the overall system resolution. After all, we put observatories on mountaintops for a reason.

Now that we have a working definition of resolution—*the smallest separation between two picture elements that can be discerned*—we can take a look at the much more subjective concept of image sharpness. To borrow a phrase—sharpness is one of those things you'll know when you see it. Sharpness and resolution may be linked, but sharpness and pixel count are not. It is entirely possible to have a high pixel count yet blurry image. What we need is some way to empirically measure image sharpness. Let's take a look at a few images; the first is a small image produced mathematically and contains vertical stripes. The other images are interpolated from this image to increase the pixel count, then cropped so they can be displayed at 100 percent.

The original image in Figure 4 is sharp with well-defined edges in the transition from the black to the white stripes. The next image is produced by using interpolation to increase the image size by a factor of two; a bi-cubic interpolation filter was used. Below is a 100-percent crop of a section of the interpolated data.

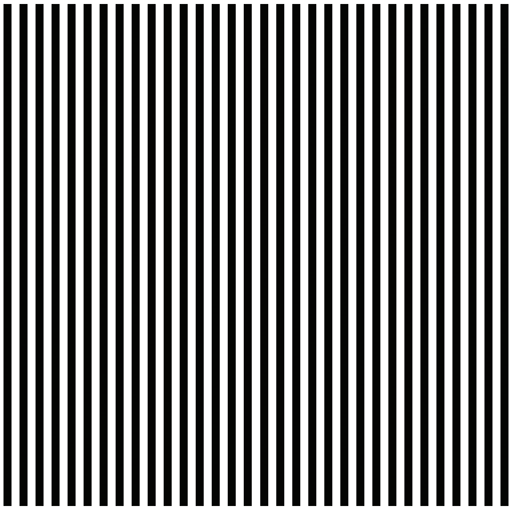


Figure 4 — Small striped image

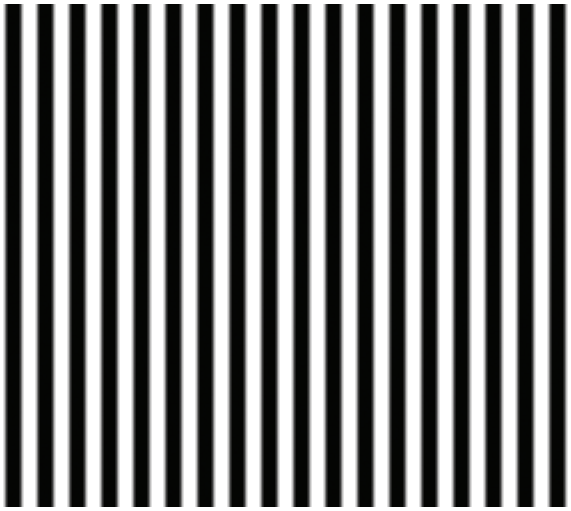


Figure 5 — Image interpolated by two

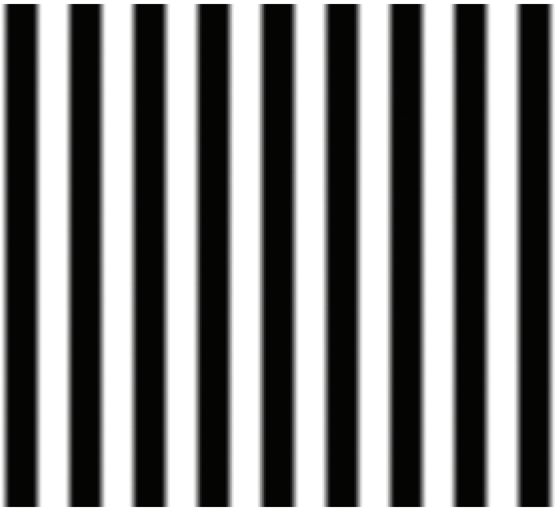


Figure 6 — Image interpolated by four

Note how the transition from black to white is not quite as sharp as the original. Finally, the last image is a 100-percent crop of the initial image interpolated by four.

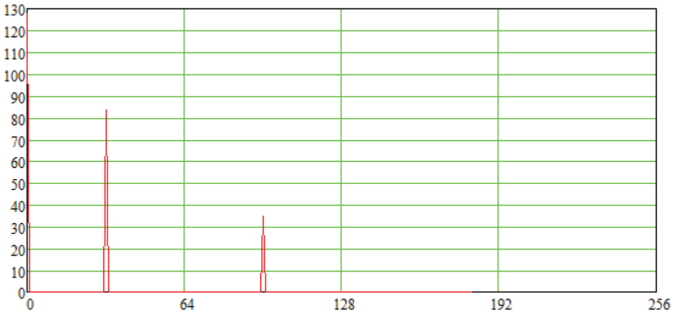


Figure 7 — Spectrum of the small striped image

If you closely examine each striped image, you will notice that, as the image size grows, the lines become less sharp. Now the question becomes, is there some measurement that we can use to judge image sharpness? The answer to this lies in the spatial-frequency spectrum of each of the images.

Examining the spectrum of the small image, Figure 7, we see that the Nyquist frequency is 128 and that the highest frequency contained in the image is close to Nyquist 96. Dividing the Nyquist frequency by the highest frequency of significant level gives us 128/96 or a ratio of 1.3. The frequency scale here is somewhat arbitrary and is simply the number of pixels from the centre of the 2-D spectrum. Now let's look at the spectrum of the slightly fuzzier image that has been interpolated by a factor of two.

Here, in Figure 8, the Nyquist frequency is higher at 256, the ratio is 1.6, and the actual image is slightly blurrier than the original. Finally, in Figure 9, examine the spectrum of the image that has been interpolated by four.

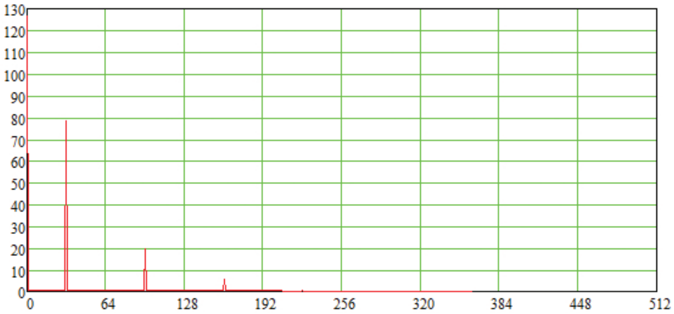


Figure 8 — Spectrum of image interpolated by two

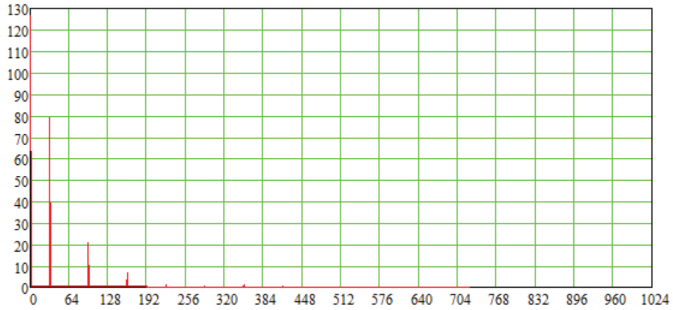


Figure 9 — Spectrum of image interpolated by four

Here the ratio is 512/160 or 3.2. There are spectral components above 160, but they are only about one percent of the main peak and of little impact on the image. Comparing the interpolated image with one that was drawn at the same scale shows the interpolated image is somewhat blurrier than the one drawn at the full pixel count.

The image in Figure 10 shows better edges and is a generally sharper version than the one shown in Figure 11. Examining the spectra of both images, Figure 9 and Figure 12, shows that the ratio of the highest frequencies to the Nyquist frequency is very different for both images. While the ratio for the image in Figure 11 is 3.2, the ratio for the image in Figure 10 is 1.06, with significant frequency content out to 480 as shown below.

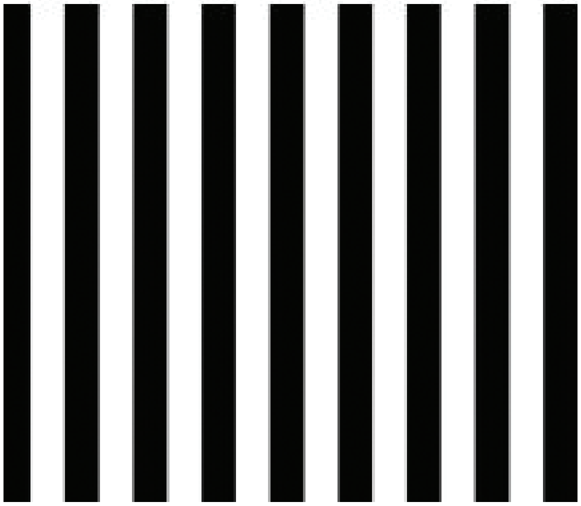


Figure 10 — Non-interpolated image

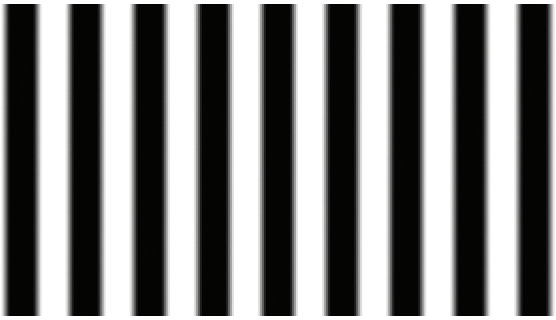


Figure 11 — Interpolated image

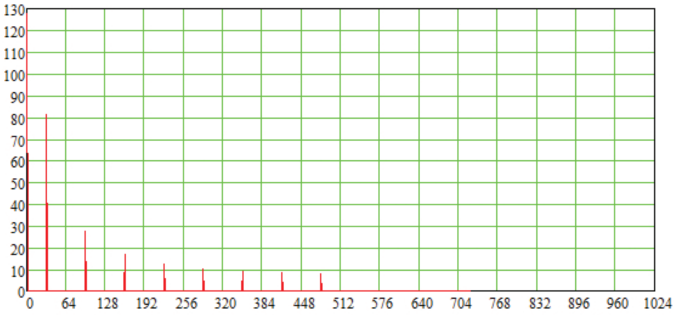


Figure 12 — Non-interpolated image spectrum.

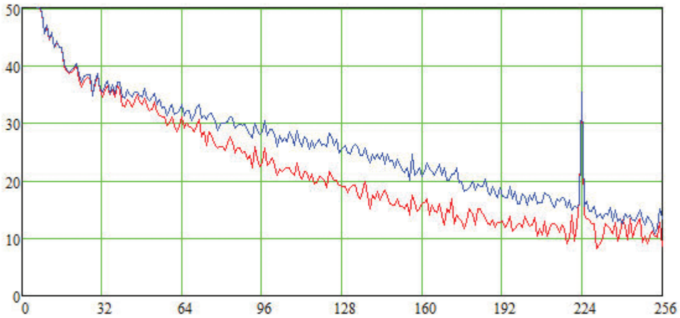


Figure 14 — Sharpened versus original M20 spectra. The data has been converted to dB (20*log(data)) to make the low-level data more obvious.

This points to a simple rule for judging image sharpness, the closer the highest frequency data, excluding noise, is to the Nyquist frequency, the sharper the image. The simple rule for evaluating image sharpness *is the higher the ratio, the fuzzier the image*.

In Figure 13 are two versions of an M20 image, the one on the right has been sharpened using a high-pass filter.

Now let's examine the spectra of the images to see what differences we see in their frequency content.

The spectral data in Figure 14 clearly shows that the ratio rule developed using simple striped images holds for real images as well. The sharpened image has more high-frequency content as the plot approaches Nyquist 256 (for these images).

The reason that interpolated images look blurrier than the original is explained by the image spectrum as well. Although interpolation increases the pixel count, it cannot make spatial-frequency components that were not in the original data As we add more pixels to an image, the Nyquist frequency climbs, but the highest significant frequency doesn't change, so the ratio rises, resulting in a blurrier image. Much of the missing sharpness in interpolated images can be restored by simple sharpening using deconvolution. This changes the relative balance between the low-frequency components and high-frequency edges, making for a clearer image. The two M101 images in Figures 15 and 16 show what good interpolation can do when you keep the spectrum in mind as you process.

Figure 16 was first binned by two then interpolated and sharpened to produce an image the same size as the original. Since the data was collected with my imaging setup, binning by two does not remove any data as the spectral components near Nyquist simply are not there to begin with. This is because the resolution of my system is about half what is required to produce spectral components at Nyquist. Since

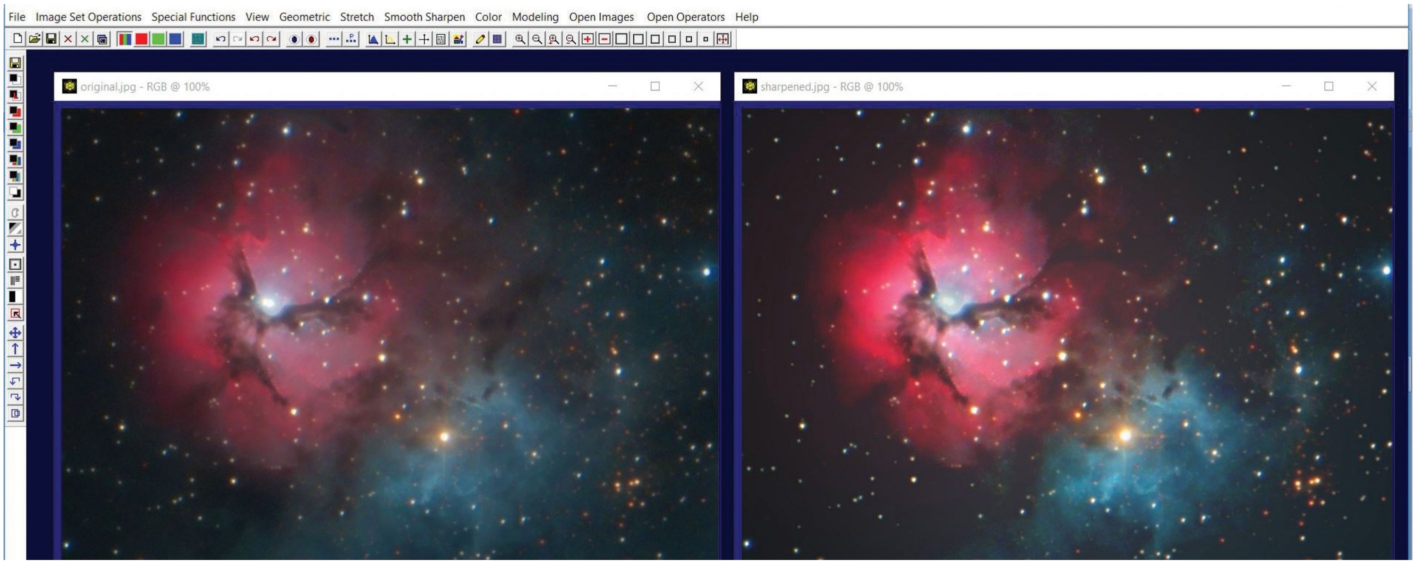


Figure 13 — Original image on left; sharpened version on the right

Figure 15 — 100-percent crop of a full-size M101 image

no image data is lost in the binning due to the limited resolution of my system, interpolation is able to produce an image very close to the original after just a little sharpening. Binning the image reduces the Nyquist frequency of the image by a factor of two, so the highest frequency data from my system is now near Nyquist for the binned image and interpolation will faithfully reproduce the original image. These kinds of results are only available by knowing the true resolution of your imaging system and selecting a binning size that respects the spectral content of the original image.

Figure 16 — Image made from a binned version of the original then interpolated and sharpened

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

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

Binary Universe

Let Them Trail

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

So, you want to try star-trails photography? This is probably one of the easiest (and cheapest) forms of astrophotography to tackle, in terms of equipment needed and post-processing work in software. And the results are often wonderful. So, get out the tripod, program the intervalometer, charge up those batteries, and get that data (don't forget your darks)! Then fire up StarStaX. www.markus-enzweiler.de/StarStaX/StarStaX.html

StarStaX is a free, multi-platform computer application by Markus Enzweiler. It runs on Mac OS X, Windows, and Linux.

The main purpose of this program is to merge or add or stack a series of photos into a single image. This is very useful for star trails. These days, with a digital camera, you shoot many frames—as opposed to a single very long shot—to capture star-trail data. But each single shot may show little or no trailing. When dozens or hundreds of shots are added together in StarStaX, the trails or paths of the stars emerge. If you have captured dark frames, you can reduce the camera noise from your final image. People comfortable with Photoshop can accomplish these same results; StarStaX is particularly helpful if one doesn't have Photoshop. It is very easy to use, fast, and a ton of fun.

Once the light (and dark) frames are transferred to the computer (and converted, if necessary), you can begin your activity in StarStaX (Figure 1), first loading in the respective files.

I have only used this computer app for star trails, but it can also be used in general image-blending tasks, for noise reduction, or dynamic-range expansion. I've seen people use it to stack lightning shots. Impressed? It can also help you make time-lapse videos! Once the images are loaded in StarStaX, then the stacking and blending can begin (Figure 2).

StarStaX supports a variety of blending modes. Lighten is the basic mode that can be used for star trails, but you would probably note, when zooming into the end result, star trails made up of small dots or short arcs with holes along the way. These gaps are the outcome of each relatively short exposure ending and the camera saving the image before opening the shutter again. The very useful Gap Filling mode uses interpolation and creates a smooth continuous line or trail without spaces or black lines. Just like old film photography days! Ideally, while shooting with your camera, you keep the interval between shots as short as possible, and the StarStaX program can easily merge the separate arcs together. An interactive Gap Filling option (Figure 3) is used after the initial stacking process, with green highlighting, to help the user fine-tune and achieve a pleasing result.

Unless you have clouds going through your shots, and for stars high up that aren't affected by atmospheric extinction, your arcs of star light will appear bright from start to finish (Figure 4).

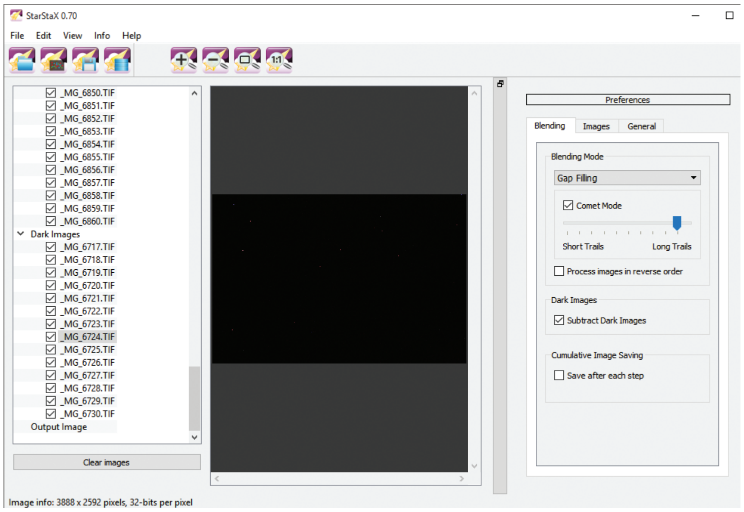
An interesting and fun feature of StarStaX is "comet mode." The most recently added image appears as normal, that is, it is set at full brightness, while the older images have their brightness decreased. The oldest frames effectively fade out. This neat visual appearance (Figure 5) gives, in a still image, a strong sense of motion or rotation.

The application supports the use of dark frames, meaning you can remove bad pixels and noise. That's quite handy as hot or cold pixels really stick out in time-lapse movies. Any dark images provided are automatically averaged and then subtracted from the light frames.

Making a smooth, seamless star-trails image is super easy:

1. Load in your light frames
2. Load in darks (if you remembered to take them)
3. Check your preferences and choose your settings: typically for star trails, I set the Blending Mode to Gap Filling; optionally, indicate you want Comet Mode
4. Hit the Start Processing button
5. Stare at the image building in real-time; it's fun but can be slow
6. Get some coffee
7. Inspect the result, easily and quickly zooming and panning
8. Dynamically adjust the gap filling by setting the Threshold and Amount sliders
9. Save your result
10. Share with the planet

Again, StarStaX generates an image in a cumulative way, that is, builds up an image progressively as each still frame is added. An intriguing adjunct to this is that you can ask StarStaX to output an image at each stage, i.e. the first image is the same as your first frame, the second image however has a small trail, the third image, a longer trail, and so on. This option is of great interest if you want to put your star trails data into motion, literally, loading your progressively built output images into some video assembly software. Just make sure you have lots of disc space on your computer: if you intend to make a time



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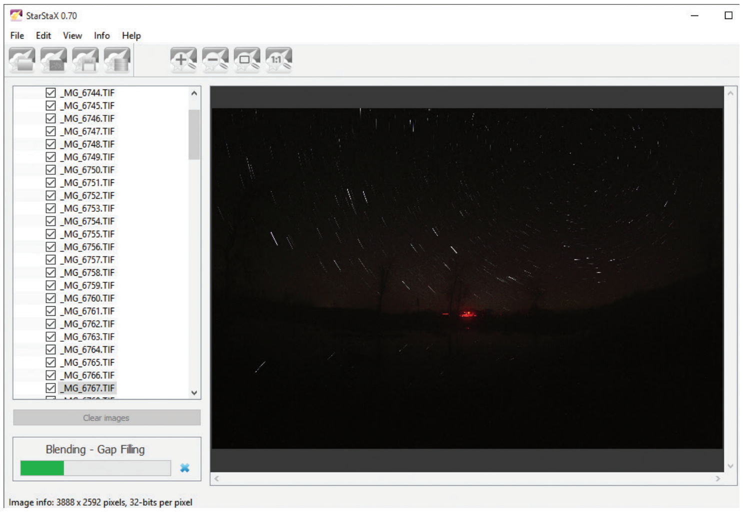
Output Image

Preferences
Blending | Images | General
Blending Mode: Gap Filling
☑ Comet Mode
Short Trails — Long Trails
☐ Process images in reverse order
Dark Images
☑ Subtract Dark Images
Cumulative Image Saving
☐ Save after each step

Image info: 3888 x 2592 pixels, 32-bits per pixel

Figure 1 — The StarStaX interface. The list on left shows the loaded images. Blending settings are configured on the right.



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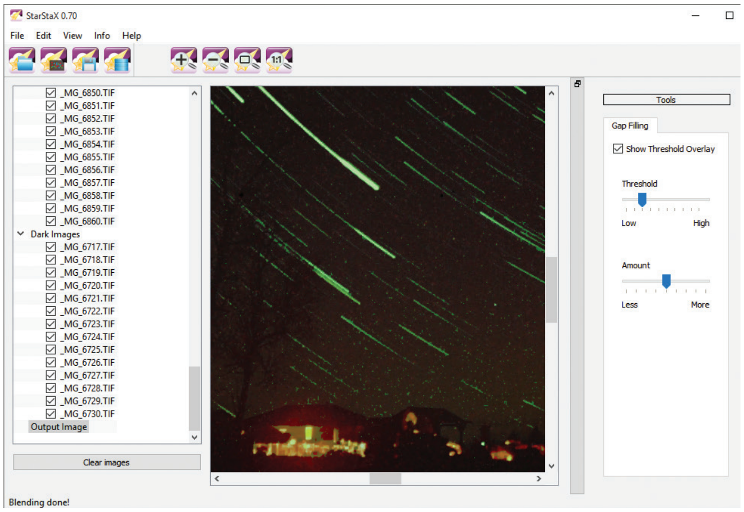
Blending - Gap Filling

Image info: 3888 x 2592 pixels, 32-bits per pixel

Figure 2 — It's fun to watch the trails build up or extend as the image files are processed.



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Output Image

Tools
Gap Filling
☑ Show Threshold Overlay
Threshold: Low — High
Amount: Less — More

Blending done!

Figure 3 — Stacking done. The gaps can now be dynamically adjusted in the Tools panel.

lapse of star trails, you will not be outputting a single stack file, but rather a video-frame file for each input image. In other words, if you captured 500 images (not counting the darks), you'll make 500 new images.

To be clear, StarStaX will not create a video file directly. Rather, it saves individual frames in the right sequence, and later you put them together with a movie-making app like MS Movie Maker, VirtualDub on Windows, Apple QuickTime, FFmpeg, or Time Lapse Assembler on the Mac. If you have Photoshop, you can use the animation feature within.

Of course, on paper media, we cannot enjoy the fourth dimension easily. So that you may examine a star trails movie I produced, in part with StarStaX, I have provided a link to a short low-resolution video on the interwebs (made at a different time but using the same process).

https://vimeo.com/137712683

Toronto Centre member Steve McKinney is an accomplished astrophotographer and, in addition to deep-sky images, he regularly produces inspiring star-trail shots and star-trail time-lapse movies. He made it very clear to me the "dual purpose" or result when grabbing many individual frames of the night sky from a fixed tripod. You can make a pleasing still stacked image or compelling short movie. And with StarStaX in comet mode, you can create even more interesting effects.

StarStaX recognizes a variety of input file formats including JPG and PNG. TIFF files, up to 16 bits per channel, may be used for the highest-quality results. RAW images are not supported at this time (but the developer intimates that may happen in the future). I often initially convert my RAW images to small JPGs to do a quick test, and if I like what I see, then I convert the RAWs to large TIFFs.

Output images may be saved using the aforementioned formats plus (with Windows) BMP. The Preferences includes a Compression Quality control.

StarStaX is still being actively developed. For a long time, I've used version 0.70 which was made available in December 2014. I used this version on my Windows 10 box for the screen snapshots.

The current version is 0.71, which was released recently primarily to better support Mac's El Capitan and Windows 10. It supports multiple processors and multi-core processors. The app supports a variety of user languages including English and French.

I have only two minor issues. I believe the main action buttons are in a funny order: I would think the Save As should be after the Start Processing. Also, in the Windows

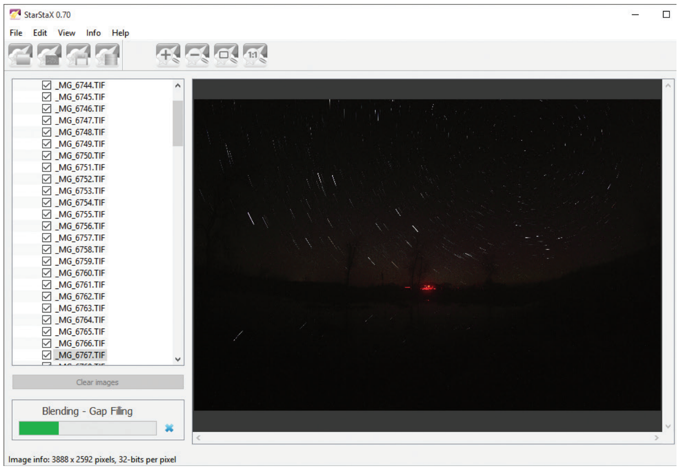

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Image info: 3888 x 2592 pixels, 32-bits per pixel

Figure 4 — Star trails produced in a "standard" way—bright from start to finish.

OS, the Tools or Preferences panel can be popped out from the main window, easily, using the small overlapping windows (Restore-style) button. Docking the floating panel, however, is not obvious; I discovered that double-clicking it puts it back. This may have been corrected in the latest version.

There are good resources for learning the tool, including built-in help screens, online documentation, an FAQ, and online tutorials. The author responded fairly quickly to my questions.

StarStaX is simple and straightforward. So, start making your attractive star trail stills or movies. If you're lucky you might also catch aurora, meteors, or fire flies. StarStaX makes easy work after you've collected all your good data. The price is right. Let us know how you do. (Visit www.astrobin.com/users/SmackAstro/ to view his gallery)

Update Bits

New versions of Backyard are available. Backyard EOS version 3.1.7 was released in late July. Then 3.1.8 was released in late August! I assisted in some cable testing to resolve a minor bug and this will be incorporated into the 3.1.9 version. Backyard Nikon 2.0.1 came out on August 23. ✶

Blake's interest in astronomy waxed and waned for a number of years but joining the RASC in 2007 changed all that. He volunteers in education and public outreach, co-manages the Carr Astronomical Observatory, and is a councillor for the Toronto Centre. In daylight, Blake works in the IT industry.

Figure 5 — Star trails produced with the "comet" effect—dim at the start and bright at the end. Canon 40D, Rokinon 8mm, 30 second subs, 120 shots.

Skyward

My First Mentor and a Streak of Light

by David Levy, Montréal and Kingston Centres

My first mentor

Over many years, as I tried to find my bearings in the night sky, I have been aided by mentors. Dozens, possibly hundreds, of people have helped me to find my way, and each one would be worthy of a long column. But of all these people, the one to whom I owe the most is my father. He had a passing interest in astronomy, but he liked to think that his interest spawned mine.

Of all Dad's influence, by far the most profound happened at dinner one evening early in the summer of 1960, when he told a captivating and unforgettable story of a book he had read as a young adult. Written by Arthur Preston Hankins and titled *Cole of Spyglass Mountain*, the book was a story of a young boy whose abusive father sent him away to a boarding school whose students were known not by names but by numbers: Joshua Cole's was 5635. One teacher at the school was interested in astronomy, and that teacher inspired Cole to follow the night sky. As Cole matured, he set up his telescope at railway depots and earned a steady income letting passengers look through his telescope. With increasing wealth, he built an observatory on a hill he called Spyglass Mountain.

One night at his telescope, Cole discovered evidence of intelligent life on Mars. At that very moment, a criminal intent on killing him broke into the observatory and began firing shots at Cole. As bullets ricocheted around the curved dome, Cole was seriously injured.

Dad's voice lowered a bit as he reached the climax of this beautiful story. As Cole lay in bed recovering from his injury, someone entered his room excitedly, carrying a stack of newspapers, all of which were trumpeting the story of how this "alleged fake astronomer" had beaten all the professionals to make this seminal discovery. Dad smiled broadly as he quoted the end of the book: "Is Mars a living planet? Cole of Spyglass Mountain famous in a night."

I have had many mentors, though my Dad's wonderful story is probably the most fertile piece of inspiration I've ever had in my life as a stargazer. The story had a direct bearing on my decision to begin my own search for comets five years after I heard it. There is an asteroid in the sky, discovered in 1981 by S.J. (Bobby) Bus. It orbits the Sun with sunrises and sunsets like here on Earth. The asteroid is numbered 5635, the same number that Joshua Cole bore while a student at the institution. Brian Marsden, late director of the Minor Planet Center, loved the idea of connecting these asteroid worlds with literature whenever possible, and he was enthusiastic about my proposal to name this particular asteroid Cole.

Figure 1 — The original Jarnac Cottage, owned by David's grandfather and visited by David's father, who did some stargazing there with the author.

I miss my Dad and think of him every day. As I recall each of the 23 comets in whose discoveries I played a part, and asteroid 5635 Cole, I am reminded of the joy in the sky my father shared with Joshua Cole and Hankins's wonderful story *Cole of Spyglass Mountain*.

A streak of light

It was a flash, a single streak of light that got me started in astronomy almost 60 years ago. The streak could not have lasted more than a second that clear evening of 1956 July 4. I was terribly homesick. At age eight, just four days into my first summer away from home, I had already written to beg Mom and Dad to rescue me from that lonely place. I did not understand at the time that they needed a break from me, and that no matter what happened, I wasn't going home until the end of the summer.

The sky was clear that warm summer evening as children and staff gathered around the softball field to enjoy a fireworks display in celebration of the fourth of July. As a young Canadian, I didn't know anything about what the United States Independence Day stood for. As the fireworks wound down, the youngest groups, including mine, were dismissed for the night. We began walking up the hill towards Bunk B.

As we strolled up the hill, my glance accidentally turned toward the darkening sky above me. Stars were coming out. I saw one bright star high in the east, and many fainter stars around it. It was beautiful, though I had no idea yet what this beauty would eventually mean to me. I just gazed upward.

Figure 2 — Comet Temple with meteor.

Then it happened. A streak of light scratched the sky flying toward that brightest star. Startled, I asked the others if they had seen it too. Since none of them had been looking upward, they all said no. Interestingly, none of the other children teased or made fun of my observation or me. Far ahead of its time, this particular camp had no place for bullying, and the children were always treated with respect. I looked again at the sky. Is it possible, I thought, that this shooting star was meant just for me?

I simply placed that little memory in my eight-year-old brain where it rested for about a year until 1957 October 4. I recalled it when I was told that the Russians had launched a rocket into orbit around Earth. To me, that dawn of the space age was intensely private because I could relate it to something I had seen personally. The image of the meteor rested again until June 1960, when a bicycle accident and a get-well present of a book about astronomy brought the memory to the forefront again. This time it stayed there. This time I was hooked.

I know now that my first meteor was from the Omicron Draconid meteor shower, an annual event confirmed at about that same time by a young astronomer named Brian Marsden. It is possible that my shooting star was the first visual sighting of an Omicron Draconid meteor. I've seen more since, and on 2005 July 4, photographed one that happened to be passing in front of Comet Tempel just minutes after the *Deep Impact* spacecraft crashed into the comet.

Over the next several decades I saw thousands more meteors. But I'll never forget that distant night, at the dawn of my life, where I saw my first shooting star that ushered in a lifetime passion for the night sky. ✶

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 over three dozen books, has written for three astronomy magazines, and has appeared on television programs featured on the Discovery and Science Channels. Among David's accomplishments are 23 comet discoveries, the most famous being Shoemaker-Levy 9 that collided with Jupiter in 1994, a few hundred shared asteroid discoveries, an Emmy for the documentary Three Minutes to Impact, five honorary doctorates in science, and a Ph.D. that combines astronomy and English Literature. Currently, he is the editor of the web magazine Sky's Up!*, has a monthly column,* Skyward*, in the local Vail Voice paper and in other publications. David continues to hunt for comets and asteroids, and he lectures worldwide.*

Dish on the Cosmos

Connecting the Cycle of Star Formation

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

This space is usually filled with new results from big radio telescopes or the promise of future facilities. In this installment, I want to relate some ideas that are more personally relevant to the work that I carry out for research. The Atacama Large Millimetre/submillimetre Array (ALMA) has just delivered some new data for my research work and they are beautiful!

These data have been a long time coming: as part of a team of astronomers from Europe and the United States, we requested observations of molecular gas in nearby spiral galaxies. Two years ago, we submitted a scientific request to a review committee that decided our work was appropriate for the telescope. The proposal was then queued with all the other approved observations and we waited several months for the data to start trickling in. Unlike with older telescopes, no one from the research team travelled to Chile and operated the telescope to collect the data. Instead, ALMA runs as a service observatory: we request that ALMA look at some targets and the staff does so. Indeed, one of the main duties of the telescope support staff in the modern era is to keep the pesky astronomer from touching the telescopes. It is not actually a bad idea since we are prone to break things. The fact that many observatories, including ALMA, are at high altitude means that poor decision making in the thin air is a serious consideration. Instead, we planned out our observations from our usual offices, sent the details off to Chile, and waited for the data to return.

A small taste of the results are shown in Figure 1. The image compares the best optical-light image we have of the galaxy M100, drawn from *Hubble Space Telescope* data, to the new ALMA observations. Since ALMA observes light from the submillimetre portion of the electromagnetic spectrum, we use false colour images to represent the intensity of the emission. In this case, we show the images of the galaxy in the emission from the carbon monoxide molecule (CO). This light is tracing emission from cold gas clouds that are mostly molecular hydrogen (H^2). However, at these cold temperatures (a mere 10–30 degrees above absolute zero), the bulk of the material in the cloud is invisible and we need to rely on tracer species. The CO molecule is the most abundant molecule that we can see in these clouds so we use it as tracer of where the molecular gas is found, how much of it there is, and how fast it is moving (using the Doppler shift). With the new ALMA data, we moved from a blurry vision of the galaxy to a crisp view that starts to compare well with *Hubble* imaging.

A few things leap out from staring at these two pictures. Notably, the molecular gas is seen along the spiral arms of the galaxy, right where the dark lanes of dust extinction appear in the optical data. The dust that blocks out the visible light is mixed in with the molecules, explaining the contrast in appearance. The molecular emission is also much stronger at the centre of the galaxy, showing two small spiral arms. The very appearance of the emission along the spiral arms steers us toward answering some of the questions we had at the outset of the study.

The big question behind our ALMA observations aims at understanding the cycle of star formation. When we look at this galaxy or at the stars in our own Milky Way, we are not looking at the first stellar generation. The hot early Universe started its evolution with only hydrogen, helium, and trace amounts of lithium. It was the action of stars that built up these light elements into heavier elements such as the carbon, nitrogen, and oxygen that are essential for life on Earth. The cores of stars produce energy by fusing light elements into heavier ones. Part of the material in the centres of stars, enriched by these fusion processes, gets ejected through stellar death (supernovae or planetary nebulae). This material moves out into the host galaxy and gets mixed in with other gas, ultimately cooling and condensing into the clouds of molecular material seen in the images above. The molecular clouds are under study because they are the hosts of the next generation of star formation. We observe young clusters and individual stellar systems forming in these clouds. The birth of stars also spells the end of life for molecular clouds as the harsh radiation dissipates the cloud material.

It is a good story, which prompted Carl Sagan to note that "We're made of star stuff," a statement that is literally true. Given a chemically simple early Universe, and the rich world we see around us today, it must have happened. The nagging question is really "How?" This question drives the images you see here, because we want to understand a vital link between stellar generations: how does the diffuse, enriched material of a previous stellar generation get mixed into the molecular clouds

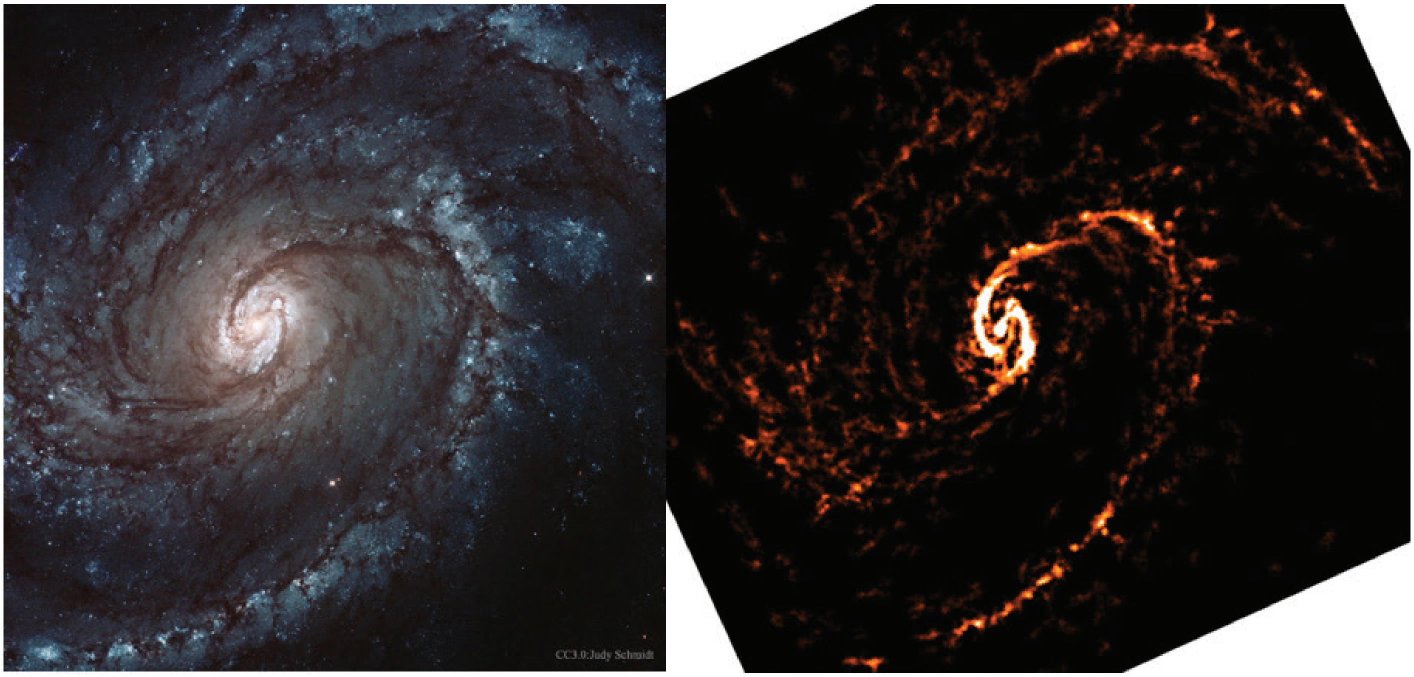

Figure 1 — A comparison of optical light from M100 to new ALMA observations in CO emission: (left) Hubble *optical imaging showing young clusters (blue light) and red extinction lanes from dust. (right) False-colour image of CO emission observed by ALMA. Most of the molecular emission lines up with the dust-extinction features seen in the* Hubble *data.*

you see in the image. Other work carries the story onward to show how those molecular clouds give rise the next generation of star formation. Here, we want to know where these star-forming systems come from.

The ALMA data contain important clues. By using the interferometric nature of ALMA, we can zoom into the resolution needed to see the individual clouds of gas in other galaxies. Studying other galaxies is important because we have a limited perspective on cloud formation within the Milky Way, being stuck inside the galactic disk. Other galaxies show how clouds are forming in the context of an entire system. In the case of M100, the clouds are mostly seen along spiral arms, which makes a kind of sense. The spiral pattern in galaxies is a wave passing through the disk and the gas in the galaxy flows into the wave and gets compressed. The compression of this gas condenses it to form molecular clouds, which then light up in CO emission. The bright glow seen by ALMA is because CO is a great refrigerant and the light we see is from the clouds being cooled down by this molecule and others.

There are clues that suggest other processes might be important: there are plenty of clouds outside of the main spiral arms. Where do these features come from? These features look like miniature spiral-arm features in molecular gas, which is a tell-tale sign of the galaxy's shearing motions stretching out gas features that are being pulled together by gravity. Some of the spiral arms appear to be split into two lines of molecular gas and show small features called "spurs" protruding out perpendicular to the arm. These features may be associated with sculpting by magnetic fields. Finally, the molecular clouds along some arms appear in small knots, which is a sign of the spiral gas front fragmenting under the action of gravity.

New data always lead to new questions as well as answers. Comparing the dust extinction features seen in the *Hubble* data compared to the molecular emission seen by ALMA, it is clear that not all of the places where there is a lot of dust (and presumably gas) has lit up in CO emission. Is this a question of timing and the molecules just haven't made CO yet? Or are these regions where the light of young stars has already destroyed the molecular gas? Or is the dust becoming a bad indicator of where the gas actually is and the features are less important than they appear?

The right mix of all these physical processes is governing how this galaxy is acting as a star factory. If we can figure out how star factories work, we can fill in one of the big gaps in the story of our Universe. All these new answers and questions are going to require a lot of thought and study to solve the puzzles. However, with these new images arriving, better answers are coming soon.

(Image Credits: *Hubble* image data from NASA and processed by Judy Schmidt for appearance on APOD; ALMA image by Erik Rosolowsky.) ✶

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.

John Percy's Universe

The Little Campus that Grew

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

Fifty years ago, in 1967, the University of Toronto established a new campus, overlooking the beautiful Credit River Valley in the growing city of Mississauga. Originally called Erindale College (after the local historical village), it is now University of Toronto Mississauga (UTM). In 1967, it had 155 students and two dozen faculty members, including a not-quite-Ph.D. astronomer named John Percy. Now, it is a mid-sized university campus with undergraduate, graduate, and professional programs, and more than 14,000 students. One of my projects for UTM's 40th anniversary was to co-edit an informal history (Percy and Abbas 2007), which is also available on-line[1]. I'm waiting to find out whether I will be called on to help with a 50th anniversary history.

In the early days, astronomy thrived at UTM, partly through the influence of Principal J. Tuzo Wilson, the eminent geophysicist (Percy 1993). In 1969, he established a program in Earth and Planetary Sciences at UTM. Tuzo's colleague Dave Strangway had been seconded to NASA as chief geophysicist for the Apollo project. This led to a public exhibition of lunar samples at UTM, seen by thousands of people who patiently waited in line. Strangway and Wilson realized that the UTM campus, being magnetically quiet, would be an excellent site for studying the magnetic properties of lunar samples. A laboratory that Tuzo called "the lunar labule" was built (Figure 1), incorporating equipment brought from the Johnson Space Flight Center in Houston. Rocks from all six Apollo missions were studied there. They showed that the Moon has ancient fossil magnetism, testifying to an early lunar magnetic field. UTM continues to be a leader in the study of rock magnetism, thanks especially to the work of geophysicist David Dunlop.

I remember when Dave Strangway brought his *Apollo 11* samples through Pearson Airport to UTM late one night (and had to return to the airport because unique but necessary paperwork had been overlooked). The next morning, a few of us gathered to inspect these precious samples. Contamination was not a problem, so we could actually hold them!

In 1968, René Racine joined me as UTM's second astronomer; his research interests were on observations of nebulae, clusters, and galaxies. In 1976, he moved to Université de Montréal and later to the directorship of the Canada-France-Hawaii observatory. He was replaced by John Lester who, after my "retirement" in 2007, has become UTM's "lone astronomer." His research is on the theory and observation of stellar atmospheres. In 1972–1973, I was on research leave in Cambridge, and my temporary replacement was Tom Bolton. It was during this year that he published his landmark paper, proposing that one component of the X-ray source Cygnus X-1 was a black hole (Bolton 1972)—the first black hole to be discovered.

With only 2.0 astronomers, it was difficult for us to offer a complete program in astronomy. Students could begin their program at UTM, but had to take their upper-year courses on the downtown campus. At UTM, we concentrated on two large introductory courses for non-science students, and two interdisciplinary courses for science students: Practical Astronomy, and Cosmic Evolution. More than once, we developed proposals for a campus observatory for teaching, research, and public outreach,

Figure 1 — The UTM rock magnetism laboratory (or "lunar labule") where the magnetic properties of rocks from the six Apollo *Moon missions were studied. Source: University of Toronto Mississauga.*

but funding never came. Nevertheless, we offered a variety of public outreach activities, including lectures, star parties for special events, programs for schoolteachers, and summer programs for children (Kingsburgh et al. 1988).

UTM's contributions to astronomy go beyond the work of its astronomers. Roberta Bondar, Canada's first woman in space, completed her Ph.D. in neuroscience in 1974 at UTM, under the supervision of Betty Roots, before going on to her career as a neurologist, astronaut, photographer, and author. Geologist Henry Halls carried out an important study of the Slate Islands meteorite impact crater on the north shore of Lake Superior (Halls and Grieve 1976). UTM Classicist and Principal Roger Beck is a leading authority on astronomy and astrology in Roman culture (e.g. Beck 2007). For many years, UTM offered a program in Professional Land Surveying, which included courses in Geodetic Astronomy.

As it enters its 50th-anniversary year, UTM's acting principal is chemist Professor Ulrich Krull, an award-winning researcher and teacher and promoter of public outreach, and an avid and well-equipped amateur astronomer! He and I arranged that the RASC Mississauga Centre should meet at UTM, and they still do. The Mississauga Centre also built on a partnership between UTM and The Riverwood Conservancy[2], a 150-acre park on the Credit River, just north of UTM, where it offers monthly star parties, lectures, and other events.

There is new opportunity at UTM for re-expanding the astronomy program; when we had a few hundred students, we had two astronomers. Now that we have over 10,000 students, we have one!

There's great potential, so I hope that the 50th anniversary marks the beginning of a new era of astronomy at UTM. ✶

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

Notes

http://hdl.handle.net/1807/10268

www.theriverwoodconservancy.org

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Awards Deadline

by James Edgar, Past President

(james@jamesedgar.ca)

The deadline for the RASC's National Awards Program—2016 December 31— is rapidly approaching. Now is the time to chat it up among Centre members and executive. Who out there deserves an award for recognition in the following categories?

SERVICE AWARD

The Service Award, established in 1959, is awarded to RASC members who have made significant contributions at the National and/or the Centre levels.

QILAK AWARD

Established in 2011, this award is intended to recognize individual Canadian residents or teams of residents who have made an outstanding contribution during a particular time period either to the public understanding and appreciation of astronomy in Canada or to informal astronomy education in Canada and to promote such activities among the members of the sponsoring organizations.

CHANT MEDAL

The Chant Medal is awarded based on a significant body of work of lasting value to the astronomical community and is named after C.A. Chant, a noted astronomer at the University of Toronto who helped to found the David Dunlap Observatory there.

KEN CHILTON PRIZE

Established in memory of Ken Chilton, this prize is awarded for a specific piece of astronomical research or work carried out or published recently.

SIMON NEWCOMB AWARD

The Simon Newcomb Award was established in 1979 for excellence in astronomical writing by an RASC member.

FELLOWSHIP AWARD

Established in 2013, this award is given to recognize long-term commitment to the Society.

Nominations for awards should be sent to the Awards Committee at awards20000@rasc.ca.

Be sure to obtain information on the procedures for awards nominations at www.rasc.ca/rasc-awards.

Second Light

Time Domain X-ray Astronomy

by Leslie J. Sage
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I have written about "time domain" astronomy previously—it is the study of transient events, mostly in the optical and radio. Over a decade ago, two X-ray flares were observed from the same source near, but not in, the elliptical galaxy NGC 4697. The first flare occurred several arcseconds away from a globular cluster, and there was no optical counterpart. A second flare from the same position happened about four years later. Over the course of about a minute, the luminosity of the source increased by a factor of about 100. Assuming that the flares originated close to NGC 4697 (and not some background source), the luminosities were $>10^{39}$ erg/s. To give you a sense of the scale, the Sun's luminosity is about 4×10^{33} erg/s. There was no clear answer about what might be causing the flares. Jimmy Irwin of the University of Alabama, and colleagues around the world, including Greg Sivakoff of the University of Alberta, who was the lead author on the NGC 4697 paper, searched the archives of Chandra and Newton-XMM X-ray observatories to look for similar flares. They found two such sources, inside either globular clusters or ultra-compact dwarf galaxies near elliptical galaxies (see the 2016 October 20 issue of *Nature*). The optical sources are faint, so it is hard to tell exactly what they are. One source flared to a luminosity of 9×10^{40} erg/s, while the other had a luminosity of 10^{40} erg/s. When not flaring, the X-ray sources appear to be neutron stars or black holes accreting gas from nearby stellar companions. But the properties are puzzling and do not match those of other known X-ray sources.

Source 1 is near the elliptical galaxy NGC 4636. The *Chandra Observatory* was observing the galaxy in 2003 when, part way through the observations, one of X-ray sources in the field of view flared. Before and after the flare its luminosity was about 8×10^{38} erg/s. The peak of the burst was over in just 22 seconds, with a luminosity of 9×10^{40} erg/s. Over the next 1400 seconds, the X-ray flux remained elevated. No other flares from this source were found in the archival data. Previous work had located the persistent source inside a faint globular cluster associated with NGC 4636.

Irwin found a second source, near the galaxy NGC 5128. At the beginning of the observation (centred on NGC 5128) in March 2007, the source had a luminosity of about 4×10^{37} erg/s, but about halfway through the observation this second source flared over 51 seconds to a luminosity of 9×10^{39} erg/s. It then subsided back to its pre-flare luminosity. That source is located in the object HGHH-C21 (also GC 0320) in NGC 5128. Its properties suggest that it is an ultra-compact dwarf galaxy (though it could be an unusually massive globular cluster). Further searching of the archives revealed four other flares associated with source 2.

The flares must be associated with very compact objects, because of the rapid rise times. The only way to get such a fast rise is for the light travel time to be much less than the rise time. Taking a rise time of 50 seconds, light would travel 0.1 AU, so the object has to be much smaller than that. Given the energy involved, it essentially requires a neutron star or black hole. Soft gamma repeaters and anomalous X-ray pulsars, which are thought to be highly magnetized neutron stars that sometimes flare to luminosities of 10^{40} erg/s, sort of fit the bill, but they have been exclusively associated with populations of young stars. Globular clusters are thought to contain only old stars that formed early in the history of the Universe. Ultra-compact dwarf galaxies might have some ongoing star formation.

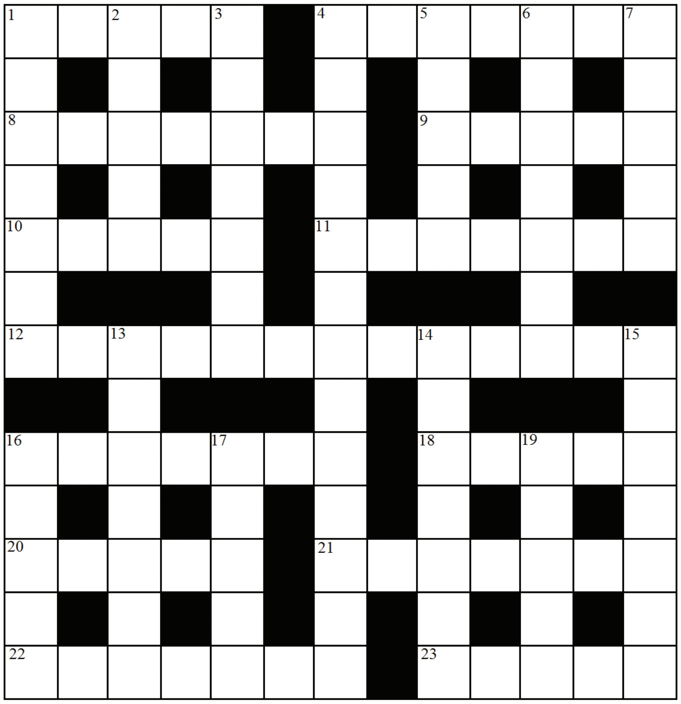
Irwin and his collaborators (three of whom are undergraduate students) searched the light curves of several thousand point sources near or in nearby galaxies, and came up with just these two. Nothing like these sources has been seen in the Milky Way. Whatever the explanation might be, it would seem that such sources are very rare.

I will end with a reflection that I have expressed before. My 30 years as an astronomer have taught me that the Universe is not only weirder than we imagine, it is weirder than we *can* imagine. Whatever the new time-domain telescopes like CHIME, Pan-STARRS, and ultimately the LSST reveal, they will find things that we have not even thought of yet.

Leslie J. Sage is Senior Editor, Physical Sciences, for Nature Magazine *and a senior visiting scientist in the Astronomy Department at the University of Maryland. He grew up in Burlington, Ontario, where even the bright lights of Toronto did not dim his enthusiasm for astronomy. Currently he studies molecular gas and star formation in galaxies, particularly interacting ones, but is not above looking at a humble planetary object.* ✶

Astrocryptic

by Curt Nason



ACROSS

1. Jeans monitored star, dim around the Eagle Nebula (5)
4. Stellar group seen around Red Planet, initially to the south (7)
8. Eco-writer's first reference to proof of Earth's rotation (7)
9. Place a nut in half of Orion's armpit (5)
10. Bell was confused about a feature on a star map (5)
11. Tapping followed the guys to the first star in a centaur's shoulder (7)
12. Tag uneven tusk broken by a big bang (8,5)
16. Cool shine from a family of stars (7)
18. Configuration of dishes detects a red beam (5)
20. Dirt around her head makes contact, ending totality (5)
21. One who might enjoy more than a view of NGC 3628 (7)
22. TV cop with an astronomical name (7)
23. Laurel's companion upset by a snake in spring (5)

DOWN

1. The French in doubt about the objective (7)
2. Wealthy person whose nepotic uncle looked up to NGC 7000 (5)
3. Was her asteroid found with her new telescope? (4,3)
4. Cobbler tax had a huge impact on astronomers, too (9-4)
5. Dark matter postulator would teasingly embellish your embarrassment (5)
6. Shortest UV rays monitored by divorcee with a broken meter (7)
7. Tidal Cape where one can resolve the Pup (5)
13. I cut an A off the original follower of Pyxis (7)
14. I chased around the home of Hypatia (7)
15. Sister is seen yet a tag somehow identifies her (7)
16. Constellation with a variable cluster missing RL stars (5)
17. No waiter with time has tossed side (5)
19. Planet must be half rock under with no hesitation (5)

Answers to October's puzzle

ACROSS

COMPACT (co(anag)t); **5** MINAS (desc.); **8** ANSER (homophone); **9** BROCCHI (coathanger); **10** ALIDADE (Ali+dad+e); **11** SOLVE (re-solve); **12** REGIOMONTANUS (anag); **15** TIE UP (2 def); **17** NATURAL (tan (rev) + Ural); **20** CYTHERA (an(the)ag); **21** EBOOK (anag); **22** EUROS (2 def); **23** NEMESIS (2 def)

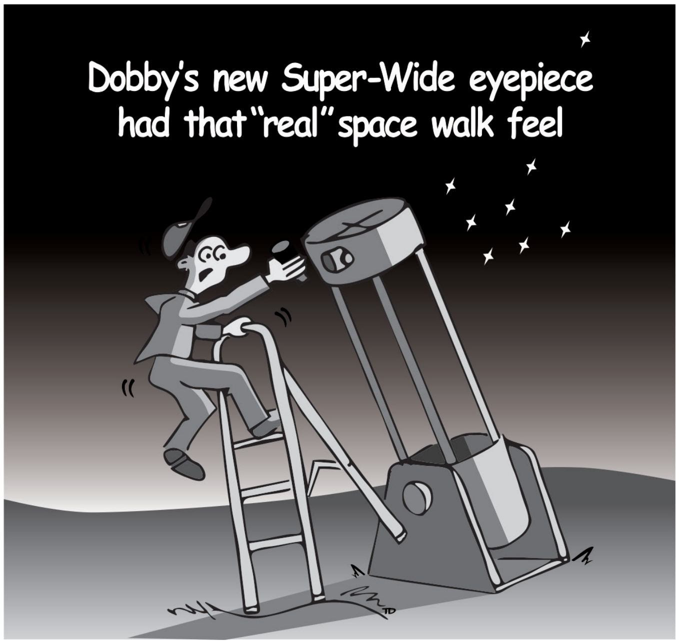
DOWN

CHARA (ch+Ara); **2** MISSING (M(ISS)ing); **3** ATRIA (hid); **4** TABLE MOUNTAIN (2 def);

5 MOONSET (anag); **6** NICOL (anag+L); **7** SPIDERS (2 def); **12** RETICLE (anag-c); **13** ORPHEUS (pro(rev)+he+us); **14** NORTON'S (no(rt)on+s); **16** ESTER (hid); **18** THERM (anag-o); **19** LAKES (anag)

It's Not All Sirius

by Ted Dunphy



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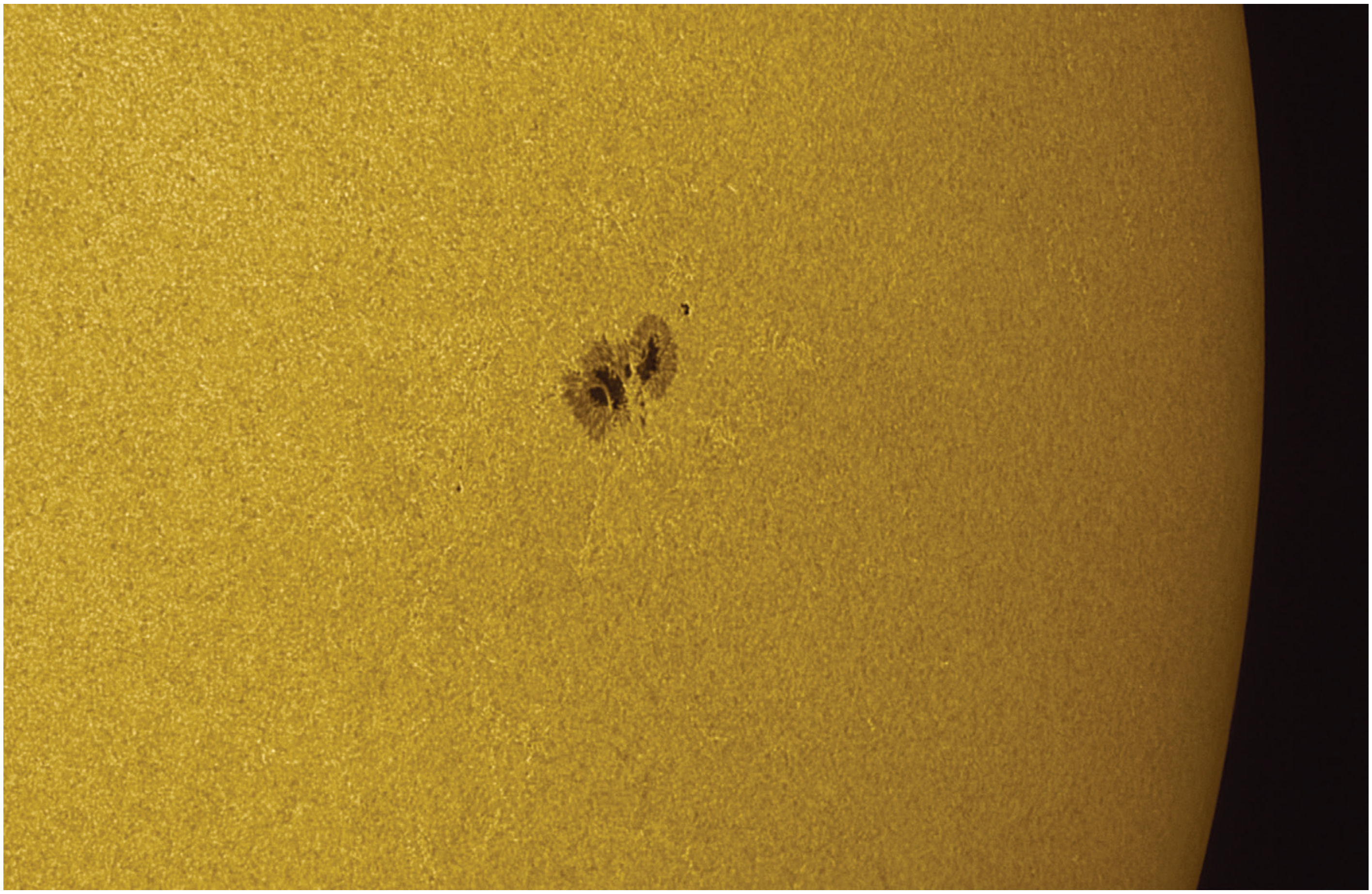
Great Images

by Gary Palmer



This image of sunspots was taken by Gary Palmer using a TMB 130-mm with a Daystar Quark Sodium filter together with an Altair Hypercam 174.

Journal

Great Images

The northern lights put on a show in October and Joe Gilker managed to capture a beautiful display from Camden Lake near Moscow, Ontario.