The Journal of The Royal Astronomical Society of Canada

Journal

Le Journal de la Société royale d'astronomie du Canada

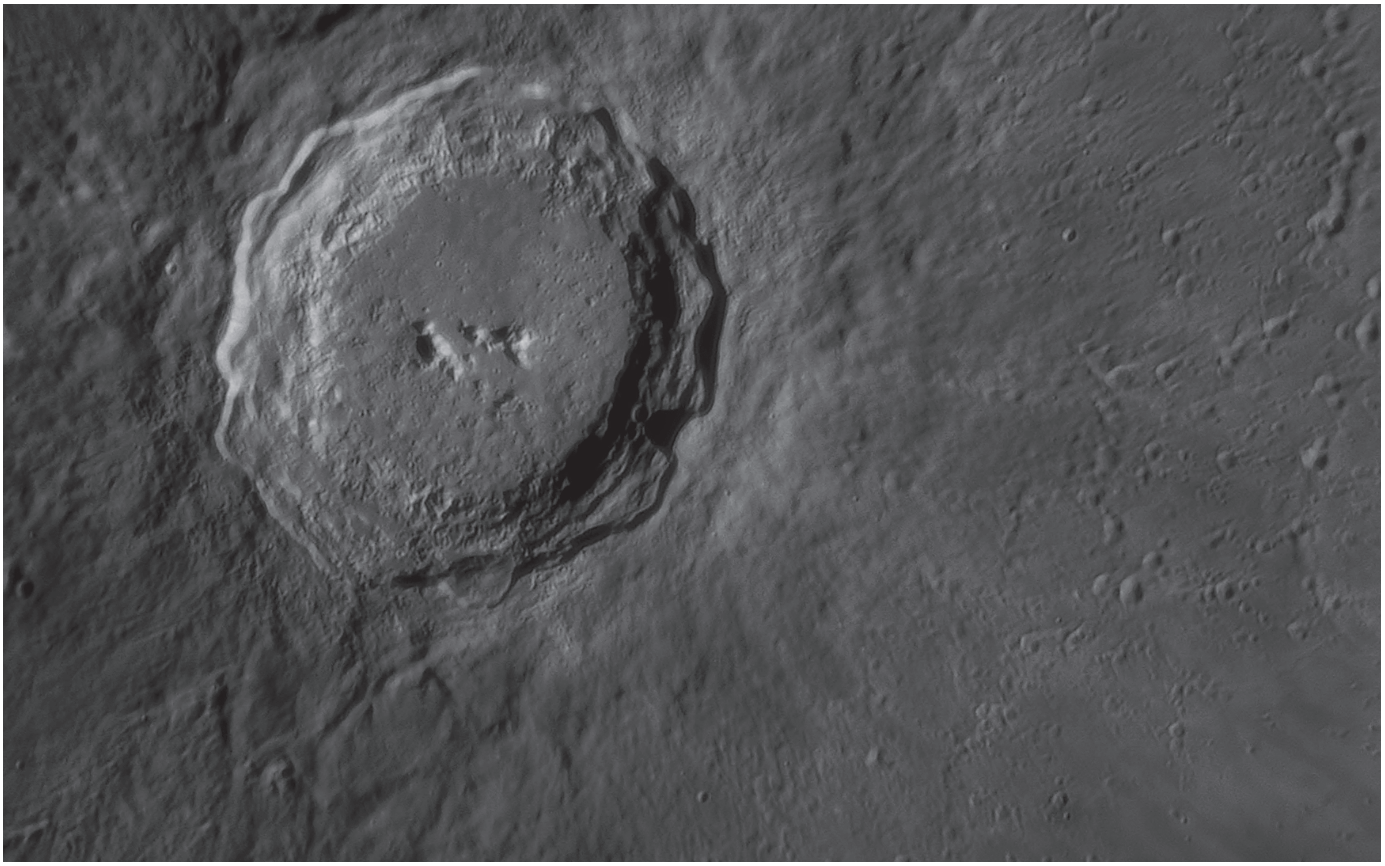
PROMOTING ASTRONOMY IN CANADA

April/avril 2016
Volume/volume 110
Number/numéro 2 [777]

The David Dunlap Observatory

The Best of Monochrome.

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



Raffaele Barzacchi imaged the mighty Copernicus crater using his 18" Dobsonian in Cogorno, Italy, while testing out his PGR GS3. Barzacchi was very pleased with his result, considering it was an evening of mediocre seeing with winds and clouds.

Journal
April/avril 2016 | Vol. 110, No. 2 | Whole Number 777

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

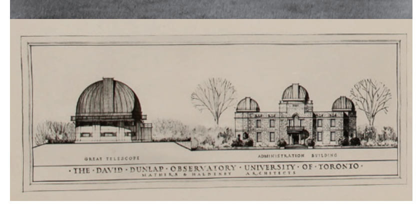
contents / table des matières

Feature Articles / Articles de fond

Columns / Rubriques

Departments / Départements

The David Dunlap Observatory in 1938.
Photo Courtesy of the University of Toronto Archives–Digital Image No: 2004-28-2MS.



The western elevation view of the proposed David Dunlap Observatory site from the architectural firm Mathers and Haldenby, Toronto 1932, showing the administration building and the large dome for the 74″ telescope. Photo Courtesy of the University of Toronto Archives.

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.

The *Journal* of The Royal Astronomical Society of Canada is published at an annual subscription rate of $93.45 (including tax) by The Royal Astronomical Society of Canada. Membership, which includes the publications (for personal use), is open to anyone interested in astronomy. Applications for subscriptions to the *Journal* or membership in the RASC and information on how to acquire back issues of the *Journal* can be obtained from:

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

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

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

Canada Post Publication Agreement No. 40069313
We acknowledge the financial support of the Government of Canada through the Canada Periodical Fund (CPF) for our publishing activities.

 ISSN 0035-872X

President's Corner

by James Edgar, Regina Centre (james@jamesedgar.ca)

What do you get for your membership dollars? We on the Board often hear the complaint from members that the fees are too high (a notion to which I don't subscribe), or that it's too expensive to be part of the RASC. And, "What do we do for Centres?" is another query that comes up from time to time.

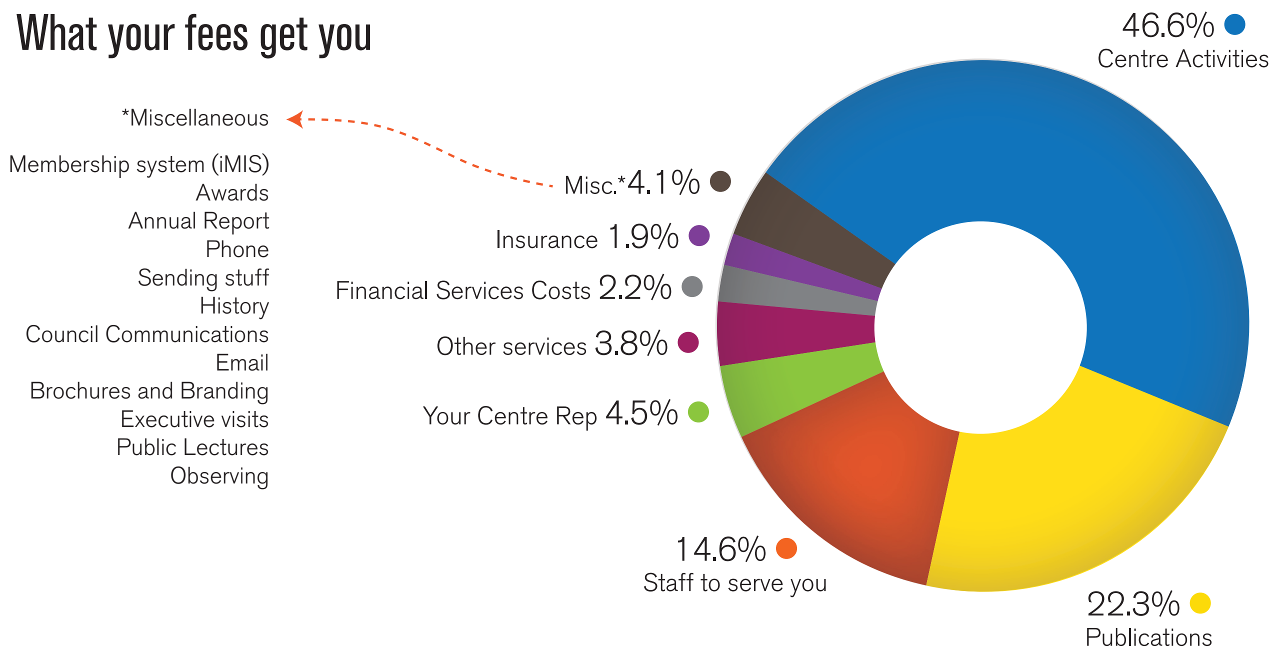
Here's a way of answering some of those questions, borrowing from a pie chart devised a couple years ago by Colin Haig, one of the Society's Directors. I've updated it a bit, as the numbers continually change, and even these may be inaccurate in the fine details, but they give a very good representation of the Big Picture. Based on an annual fee of $75 (yours may be more, and even less), here's how the dollars break down.

As you can see, a large part of the Regular member fee goes to the Centre to which the member belongs (Unattached members are different, in that their entire fee goes to the Society). Also, much of the remainder goes toward publications and staff salaries. Those top items account for a little more than 83% of the whole. And, all the rest are less than 17%, in ever-decreasing amounts.

It's interesting that observing, which is the mainstay of an astronomical society, accounts for only 1 cent of a member's fee. But, that's because the Society doesn't buy your equipment—you do. Centre fees account for much of observing dollars, including site insurance, cost of observatory ownership, and all the things that go into running a Centre. Over the years, the Society has arranged for fees to be collected at the national level, which frees up volunteer hours at the Centre level. And, the headache of collecting, accounting for, and managing fees isn't a headache at all. Oh, joy! The Society Office staff are the glue that holds us together, and, if you're in need of a "feel good" moment, give the office a call. I guarantee it's an experience that'll make you feel better. Tell them I said so.

Clear skies! ✶

What your fees get you



News Notes / En manchettes

Compiled by Jay Anderson

Phases of the Moon related to global rainfall

All of us are familiar with ocean tides, even if we don't belong to the one of the Centres on the east or west coast, but less familiar are analogous tides in the atmosphere. When the Moon is at the zenith or nadir, the Earth's atmosphere bulges upward, creating a slight rise in surface pressure because of the additional mass in the air column above. The pressure response to the atmospheric tide was discovered in 1847; the temperature rise was first described in 1932. The tiny meteorological responses to this twice-daily stretching of the atmosphere seemed to be out of reach of observation, though several researchers were able to detect uncertain evidence of changes in rainfall in some regions of the globe. In 2010, researchers at Arizona State University, using data from across the United States, detected a tiny increase in the average stream flow of an ensemble of 1200 watersheds that peaked a little before quarter Moon. The explanation for the phenomenon, if it was real, remained elusive.

Now, a new study, by Tsubasa Kohyama and John Wallace of the University of Washington and published in *Geophysical Research Letters*, reports on the detection of a pattern in global tropical precipitation that follows the same pattern as that of pressure and which can be attributed more reliably to the atmosphere's semi-diurnal tide. Their study, which relies on numerical modelling of the atmosphere and satellite observations of precipitation, has determined that the explanation lies

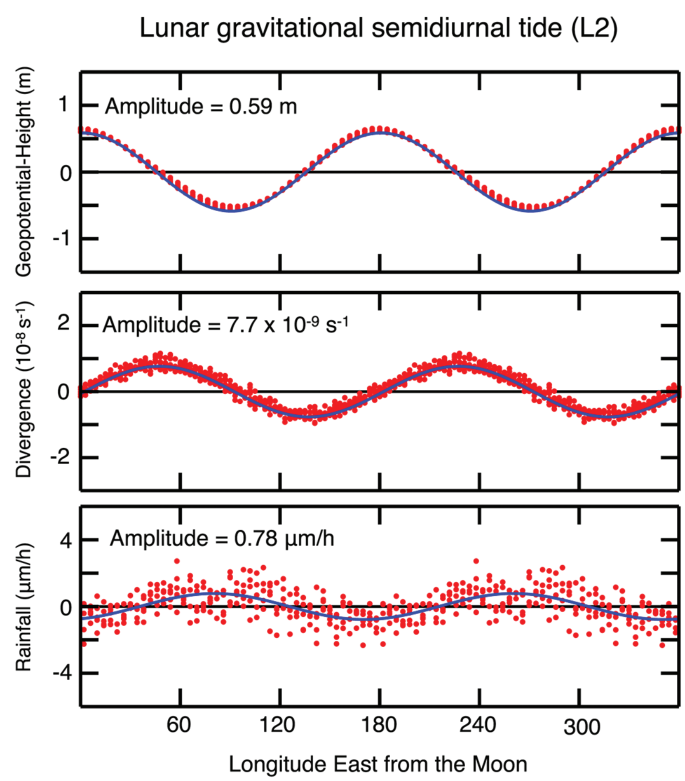


Figure 1 — Satellite data over the tropics, between 10° S and 10° N, shows a slight dip in rainfall when the Moon is directly overhead or underfoot. The top panel shows the air pressure, the middle shows the rate of change in air pressure, and the bottom shows the rainfall difference from the average. Image: Tsubasa Kohyama/University of Washington.

in the adiabatic temperature changes (changes in which no energy is available from external sources) associated with the daily tides. An increase in pressure causes a small but measureable rise in temperature, which you can discover for yourself by placing a thermometer into a plastic drink bottle and squeezing the bottle—the temperature inside will rise a degree or two after a minute or so of exertion.

A warmer air column can hold a greater amount of moisture, and so as the atmospheric temperature rises, humidity declines, as there is insufficient time for additional moisture to evaporate into the column. A lower humidity translates into a reduced rainfall, though the difference is too low (about 1 percent) to be generally noticeable. Conversely, when the Moon is on the east or west horizon, the air column shrinks, pressure declines, and precipitation increases (Figure 1).

The impact of the lunar tides is about 1/20th of the similar daily tides caused by the Sun, which is driven by heating and cooling of the surface and atmosphere during the course of the day and night.

See Geophysical Research Letters (2016). DOI: 10.1002/2015GL067342 for the original paper.

Compiled from notes provided by the University of Washington.

Big dust from a big star

VY Canis Majoris is a highly evolved red hypergiant star that at one time was considered the largest known star, though it has now lost that distinction to UY Scuti and six others. If placed at the Sun's location, its surface would extend beyond Jupiter, though the "edge" of such a large object has a pretty

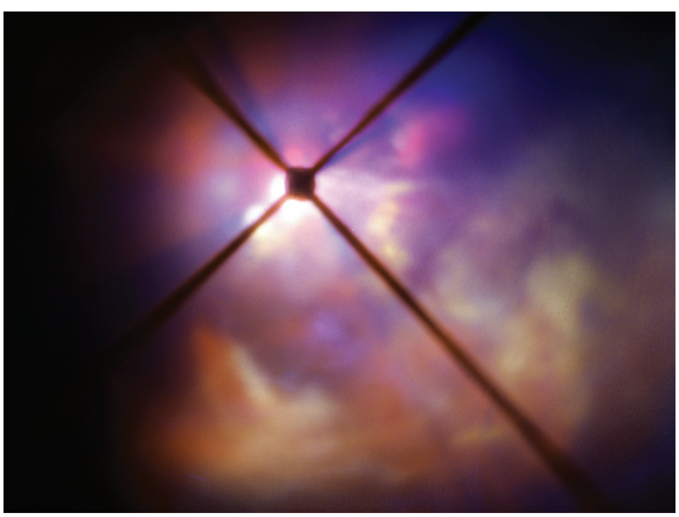


Figure 2 — This image shows the appearance of VY CMa in the SPHERE instrument on the VLT, clearly revealing how the radiation from the star lights up the clouds of surrounding material, allowing the properties of the component dust grains to be determined more accurately than previously. In this view, the star itself hides behind an obscuring disk. The crosses are artefacts due to features in the instrument. Image: ESO.

uncertain definition. It is surrounded by an extensive and complex filamentary nebula with many knots and clumps of material formed from massive, periodic outflows of dust from the star—about 30 times the mass of the Earth each year.

All massive stars expel material as they expand in the latter years of their life—material that is pushed outward away from the parent star. Later, when the star explodes, some of the dust evaporates and the rest is cast into interstellar space. The mechanism that pushes the dust away from massive stars has been attributed to radiation pressure, but typical dust grains are too small for radiation pressure to create the necessary force to overcome stellar gravity. To do so requires large dust grains—grains with a surface area broad enough to have an appreciable radiation intercept.

Using the SPHERE (Spectro-Polarimetric High-contrast Exoplanet REsearch) instrument and adaptive optics on the European Southern Observatory's Very Large Telescope (ESO VLT) at Paranal, astronomers have been able to see the structure of the dust clumps very close to VY CMa and measure its polarization. Analysis of that polarization revealed these grains of dust to be comparatively large particles, 0.5 micrometres across, about 50 times larger than the dust normally found in interstellar space.

"Massive stars live short lives," says lead author, Peter Scicluna, of the Academia Sinica Institute for Astronomy and Astrophysics, Taiwan. "When they near their final days, they lose a lot of mass. In the past, we could only theorize about how this happened. But now, with the new SPHERE data, we have found large grains of dust around this hypergiant. These are big enough to be pushed away by the star's intense radiation pressure, which explains the star's rapid mass loss."

The dust particles must be large enough to ensure the starlight can push it, but not so large that it simply sinks. Too small and the starlight would effectively pass through the dust; too large and the dust would be too heavy to push. The dust the team observed about VY Canis Majoris was precisely the right size to be efficiently propelled outward by the starlight. The size of the dust grains also means much of it is likely to survive the radiation produced by VY CMa's inevitable demise as a supernova. This dust then contributes to the surrounding interstellar medium, feeding future generations of stars and encouraging them to form planets.

Compiled with notes provided by the European Southern Observatory.

Opportunity still knocking

The Mars rover, Opportunity, continues to deliver science and imagery as it endures its 7th Mars winter and celebrates its 12th year of operation. Thanks to a timely gust of wind that cleaned its solar panels at the start of winter, Opportunity has

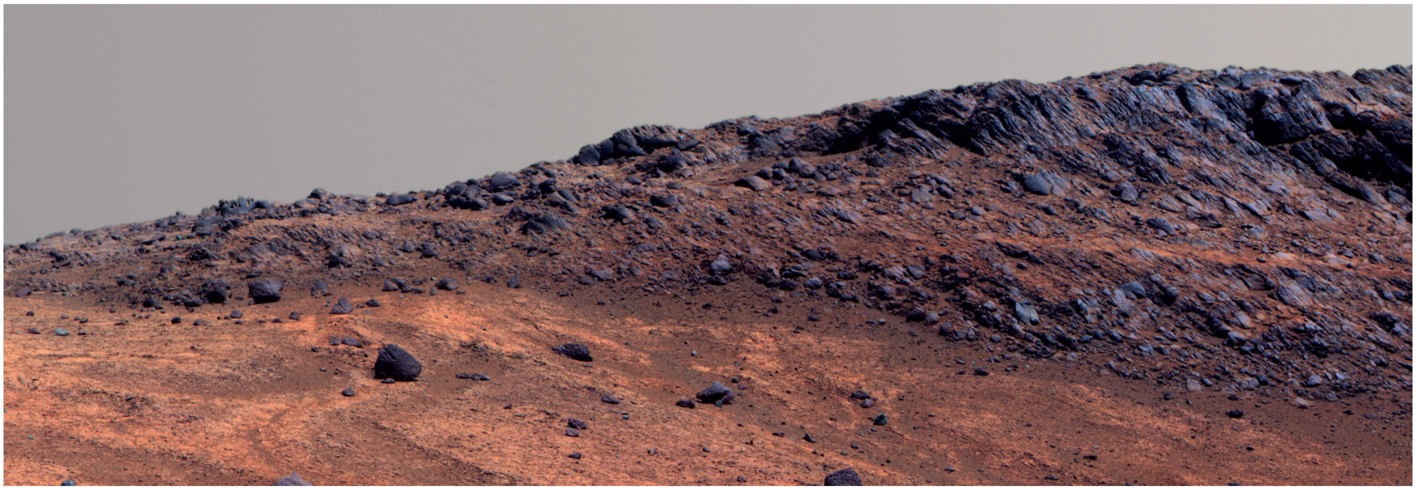


Figure 3 — A view of "Hinners Point" above the floor of Mars's Marathon Valley, captured by Opportunity's cameras. The dark rocks on the point dip downward toward the interior of Endeavour, to the right from this viewing angle. The strong dip may have resulted from the violence of the impact event that excavated the crater. Brighter rocks make up the valley floor. The reddish zones there may be areas where water has altered composition. Image: NASA.

been able to conduct an active cold-season science campaign instead of hibernating to await the return of the Sun to higher altitudes. At mid-winter, the solar panels generated more than 460 watt-hours per day, up about 40 percent from earlier in the Martian winter, allowing Opportunity to conduct operations such as driving and rock grinding throughout the winter. During Opportunity's first Martian winter on the Endeavour rim, power generation dipped below 300 watt-hours for more than two months, and the mission refrained from power-intensive activities for more than four months.

Opportunity has been exploring the western rim of a 22-kilometre-wide crater named Endeavour since 2011. This winter, it is examining rocks on the southern side of "Marathon Valley," which slices through Endeavour Crater's rim from west to east. This is a location where observations by NASA's *Mars Reconnaissance Orbiter* have mapped concentrations of smectite clay minerals that would have formed under wet, non-acidic conditions. Such conditions are more conducive to the development of Martian life forms billions of years ago when the planet was believed to be much warmer and wetter.

Smectites are a group of clay minerals that expand as they adsorb water and contract as they dry out. The structural layers of swelling clays have a small negative charge and therefore attract water molecules or other polar molecules into the interlayer area, forcing the layers apart and causing the material to expand in one dimension. Most RASC members would be familiar with smectite clay in the form of clumping kitty litter, but it also finds uses in paint, lipstick, and toothpaste.

Earlier inspections by Opportunity have found compositions there are higher in silica and lower in iron.

In January, researchers used Opportunity's rock abrasion tool to remove surface crust from a rock target called "Private John Potts" (the team is using names of members of the Lewis and Clark Expedition's Corps of Discovery as informal names for targets in Marathon Valley). The grinding was followed by in-situ examination of the composition of the rock by instruments on Opportunity's robotic arm.

Compiled with material provided by NASA.

Young/old globular clusters

Globular clusters are one of the most popular objects in the amateur astronomer's pantheon of observing targets. These balls of stars are typically very old—among the oldest entities in the Milky Way, with ages ranging up to 12 or 13 Gy. And therein lies a mystery, for some globulars have a stellar population that is much younger, indicating that star formation is ongoing or has been episodic in the more recent past. The conventional explanation for the presence of multiple populations focused on colliding stellar winds from older giant-branch stars as triggers for later star formation.

Three of the errant globulars, NGC 1783 and 1696 in the Large Magellanic Cloud and NGC 411 in the Small Magellanic Cloud, were studied by a team led by Chengyuan Li (Kavli Institute for Astronomy and Astrophysics and Department of Astronomy, Peking University) using imagery from the *Hubble Space Telescope*. Colour-magnitude diagrams constructed for the three clusters trace out a dominant older population of stars, but also show one (NGC 1696, 411) or two (NGC 1783) younger populations in the same sample of cluster stars. In NGC 1783, for instance, the research team found populations with ages of 1.4 Gy, 0.89 Gy, and 0.45 Gy. The younger stars are well distributed throughout the clusters, suggesting an external origin, rather than formation from internal processes. This is supported by the small mass of the clusters, which is too small to capture stellar winds from an aging red-giant population.

Figure 4 — An image of NGC 1783, one of the biggest globular clusters in the Large Magellanic Cloud, taken with the Advanced Camera for Surveys (ACS) on board the NASA/ESA Hubble Space Telescope. *Image: NASA.*

The authors postulate that the new stars formed from dust and gas captured from giant molecular clouds as the clusters orbited their separate galaxy homes. The total mass of the younger stars is only 0.2 to 2 percent of the parent cluster, an amount small enough to be captured from external sources according to the authors' modelling. "We have now finally shown that this idea of clusters forming new stars with accreted gas might actually work," said co-author Richard de Grijs, "and not just for the three clusters we observed for this study, but possibly for a whole slew of them."

Compiled with material provided by Northwestern University, Evanston, Illinois. The research paper is published in the January 28 issue of Nature.

Dawn in high resolution

Just before Christmas, the *Dawn* spacecraft dropped into its lowest orbit—256 km above the surface—around the dwarf planet Ceres. The new position allowed cameras to sample the surface with a resolution four times better than the previous higher orbit. The first images revealed the cratered and fractured surface in vivid detail with a resolution of about 35 m per pixel. *Dawn* will remain in this orbit indefinitely.

In addition to the visible imagery, *Dawn* instruments also conducted high-resolution studies with gamma-ray and neutron detectors and a visible-infrared spectrometer (now being used only in the infrared). Earlier in the month, the spectrometer revealed that the unexpected bright spots on Ceres were composed of a material consistent with salts, and scientists proposed that it was a type of magnesium sulphate called hexahydrate. Elsewhere, the spectrometer revealed the presence of ammoniated clays, prompting speculation that Ceres could have first formed near Neptune and migrated inward to its present position. Ammonia is too volatile to exist comfortably at Ceres' current distance from the Sun, though it can be stable if chemically bonded to other minerals. An alternative explanation offers that Ceres may have been supplied with ammonia from more remote regions, perhaps by comet collisions. Ceres is quite different from other asteroid-belt occupants—it's big, it's round, its density is similar to Pluto's, and it has water, all characteristics that suggest a more distant childhood.

One of the finest images obtained so far is of Kupalo, a relatively young, 26-km-wide crater that shows streaks of bright material exposed along its crater walls. These could be salts, similar to the composition of the 130 bright spots detected on the planet. At the current distance from Ceres, it will take some time for *Dawn* to complete photographing the surface. ✶

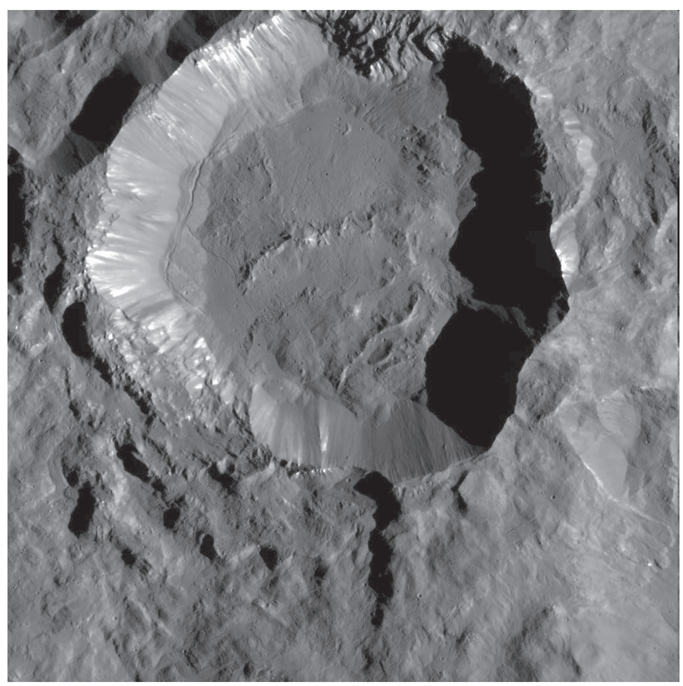


Figure 5 — Kupalo Crater, one of the youngest craters on Ceres. The bright material exposed on its rim and walls resemble the appearance of bright areas seen elsewhere on the dwarf planet. Its flat floor likely formed from impact melt and debris; the lobate flow at the top of the image that breaks down part of the crater rim is caused by a younger impact crater just out of sight above the image. Image: NASA.

The David Dunlap Observatory at 80

by Lee Robbins, Librarian, Department of Astronomy & Astrophysics, University of Toronto (robbins@astro.utoronto.ca), and R.A. Rosenfeld, RASC Archivist (randall.rosenfeld@utoronto.ca)

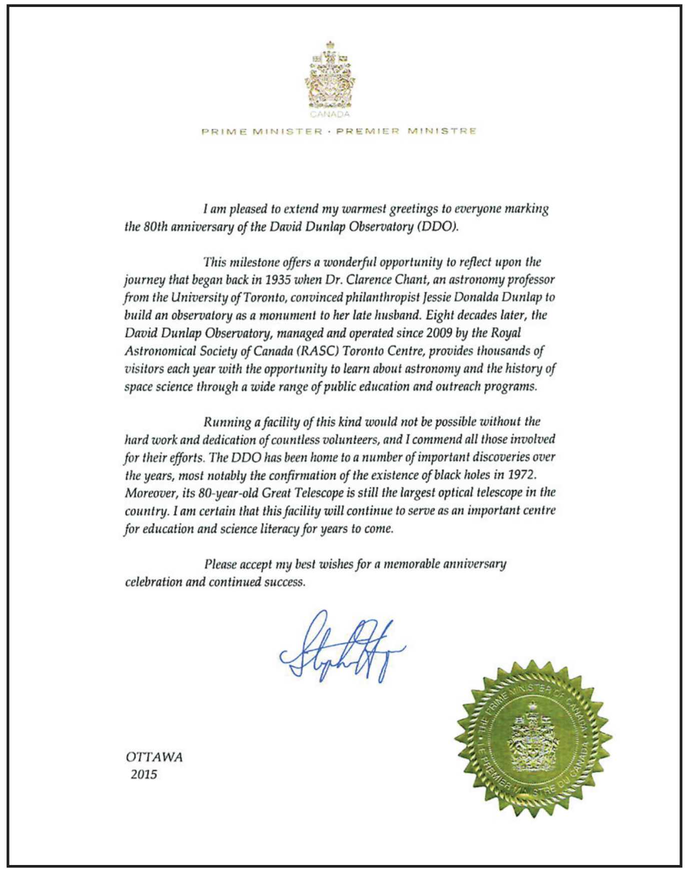
Abstract

Eighty years ago this last May 31, the David Dunlap Observatory (DDO) was officially opened before an assembled crowd of 1300 invited astronomers, university and political figures, and members of the general citizenry. The 74-inch (1.88-m) reflector at its heart remains the second-largest optical telescope ever erected in Canada.[1] To mark that event, a curated exhibition of rare astronomical artifacts tied to the building and use of the observatory was mounted concurrently with a symposium featuring reminiscences of former University of Toronto DDO staff, discussions of the cultural and scientific legacy of the installation, current programs and plans of the DDO RASC Toronto Centre staff, and innovative projects of the Dunlap Institute for Astronomy & Astrophysics, University of Toronto.

The Event

On Saturday, 2015 June 13, members of the University of Toronto's Department of Astronomy & Astrophysics, the Dunlap Institute for Astronomy & Astrophysics, and the Toronto Centre of the Royal Astronomical Society of Canada (RASC) celebrated the 80th anniversary of the opening of the David Dunlap Observatory (DDO). The event had its genesis more than a year prior in discussions between Lee Robbins, Librarian of the Department of Astronomy & Astrophysics at the University of Toronto, Randall Rosenfeld, Archivist of the RASC, Karen Mortfield, Public Affairs Coordinator for the Toronto Centre of the RASC, and Michelle Johns of the RASC Toronto Centre. About 80 invited guests participated in the day-long event, including 3 generations of the Dunlap family.

The occasion included displays of rare artifacts from the observatory, highlighting key elements of its conception, construction, and the scientific harvest of the dome in the early years (ca. 1935-1972).[2] Various films produced at or about the DDO over the decades were shown, including a Pathé reel of the construction of the 74-inch telescope in England by Sir Howard Grubb, Parsons and Co. Ltd., a short interview with Clarence Chant, the DDO dedication ceremony in 1935, and the National Film Board of Canada (NFB) documentary *Universe* (1960).



CANADA

PRIME MINISTER · PREMIER MINISTRE

I am pleased to extend my warmest greetings to everyone marking the 80th anniversary of the David Dunlap Observatory (DDO).

This milestone offers a wonderful opportunity to reflect upon the journey that began back in 1935 when Dr. Clarence Chant, an astronomy professor from the University of Toronto, convinced philanthropist Jessie Donalda Dunlap to build an observatory as a monument to her late husband. Eight decades later, the David Dunlap Observatory, managed and operated since 2009 by the Royal Astronomical Society of Canada (RASC) Toronto Centre, provides thousands of visitors each year with the opportunity to learn about astronomy and the history of space science through a wide range of public education and outreach programs.

Running a facility of this kind would not be possible without the hard work and dedication of countless volunteers, and I commend all those involved for their efforts. The DDO has been home to a number of important discoveries over the years, most notably the confirmation of the existence of black holes in 1972. Moreover, its 80-year-old Great Telescope is still the largest optical telescope in the country. I am certain that this facility will continue to serve as an important centre for education and science literacy for years to come.

Please accept my best wishes for a memorable anniversary celebration and continued success.

OTTAWA
2015

Figure 1 — Reproduction of the letter of congratulations from former Prime Minister Stephen Harper, on the occasion of the 80th anniversary celebrations of the DDO.

Figure 2 — The portraits of David and Jessie Dunlap unveiled by Bryan Gaensler and Paul Mortfield, a gift from the Dunlap Institute for Astronomy & Astrophysics.

Figure 3 — Photograph of three generations of the Dunlap family standing inside the 74-inch telescope dome.

Paul Mortfield, President of the RASC Toronto Centre, kicked off the event, welcoming all the guests and speakers, particularly the Dunlap family, and the then local Member of Parliament, Costas Menegakis, who presented members of the RASC with a letter of congratulations from Prime Minister Stephen Harper (Figure 1).

Bryan Gaensler, Director of the Dunlap Institute for Astronomy & Astrophysics, presented the Toronto Centre with excellent framed reproductions of the Joshua Smith (1880-1938) paintings of David (1934) and Jesse Dunlap (1924), as a gift from the Dunlap Institute for Astronomy & Astrophysics (Figure 2). The originals of these paintings originally hung in the DDO administration building, and today are part of the University of Toronto Art Collection (University of Toronto Art Collection 2006-084; University of Toronto Art Collection 2006-092).

David M. and J. Moffat Dunlap, grandsons of David Alexander Dunlap and Jessie Donalda Bell Dunlap, headed up the representation of the almost dozen members of the Dunlap family at the event. David M. Dunlap addressed those present on his family's relationship with the DDO, how pleased they were to see the gift that brought forth the DDO eight decades ago productively reinvisioned for the 21st century in the creation of the Dunlap Institute for Astronomy & Astrophysics, while at the same time witnessing the flourishing of the DDO as an instrument for education and public outreach (EPO) in the capable hands of the Toronto Centre of the RASC (Figure 3).

Short summaries of the presentations by the other speakers follow below. Several of the talks offer valuable material not previously recorded on the work and character of the DDO when it was an academic institution.

The morning and afternoon sessions were agreeably divided by a buffet lunch in a tented area on the sunny DDO grounds. A celebratory cake in the shape of the observatory was displayed to, and dispatched by, the guests. During the lunch break, attendees were specifically invited to view the curated exhibition of artifacts, visit the DDO telescopes (the 74-inch, and the recently restored 19-inch R.K. Reynolds reflector), and see the historical films.

The David Dunlap Observatory—The Prehistory

John Percy

Although the University of Toronto received its charter in 1827, its founders could not agree on whether it should be Anglican or secular, and it was not until 1853 that the university and its University College were firmly established (Friedland 2013). Coincidentally in 1853, the Toronto Magnetic and Meteorological Observatory (TMMO) was established on present university land by the Province of Canada, on the site of an 1840 British Admiralty magnetic observatory, constructed of logs, and the surviving stone building was commissioned (Beattie 1982, 109-110). The "Met Office" moved north to expanded quarters on Bloor Street in 1908–1909, and the 1853 TMMO building was saved from demolition by being moved a short distance, and became the present day Stewart Observatory.

Initially, astronomy and the other sciences were taught (rather descriptively) under the rubric of natural sciences. Practical astronomy was offered by the School of Practical Science (i.e. engineering, not formally part of the university until 1906), and mathematical astronomy was taught in the fourth year of the university's mathematics program. In 1878, James Loudon, Professor of Physics, created the first laboratory in Canada for undergraduate physics students, but it was not until 1887 that a separate Department of Physics was established. Clarence Augustus Chant (1865–1956), the "father" of astronomy at the University of Toronto, was one of the first beneficiaries of this new department and its laboratories; he received his B.A. in physics there in 1890.

Chant rejoined the department in 1892 as a lecturer. The university was growing rapidly at the time, as professional schools (such as education, engineering, and medicine), and religious colleges (St. Michael's, Trinity, Victoria, and others) affiliated with it. In the next three decades, Chant established a separate budget for astronomy, developed lecture and laboratory courses in observational astronomy and astrophysics, and created a separate Department of Astronomy—even though he had begun as a junior faculty member, was not a researcher, and was the only astronomer in his department. Knowing something of university administration and politics, I find his accomplishments remarkable. He spent 1900–1901 at Harvard, where he obtained a Ph.D. and a strong introduction to "modern" astronomy and astrophysics.

Meanwhile, public interest in astronomy and other sciences had been growing; it had been promoted by the York Mechanics Institute (1830), the Royal Canadian Institute

(1849), the Toronto Astronomical Club (1868), and—in the university—the University College Literary and Scientific Society (1854). Chant was not only an excellent teacher, but was also an enthusiastic and effective communicator to the public, through lectures, popular articles, and a best-selling book *Our Wonderful Universe* (1928; 1940, and numerous foreign language editions). He was also the guiding light for The Royal Astronomical Society of Canada (incorporated in 1890) for half a century. In 1924, he was joined on faculty by astronomer Reynold K. Young (1886-1977), a Canadian with a Ph.D. from the University of California, who was a prolific researcher. Chant could now, through his lectures and articles, promote the need for a major observatory for the university and the city for the purposes of astronomical research, training advanced students, and public education.

A glimmer of hope appeared after one of his public lectures in 1921, in the form of David Dunlap, who expressed an interest in the observatory project. Dunlap was a lawyer who had become wealthy as a result of mining ventures in Northern Ontario. Sadly, Dunlap died in 1924, but in 1926, Chant approached Dunlap's widow Jessie and persuaded her to donate to the university an observatory that would be a memorial to her late husband. As for a site, the university campus, and even city parks were no longer suitable for a major observatory, so Chant and Mrs. Dunlap went for a drive and settled on a site in the country, in Richmond Hill, not too far from the city. The rest is history; on 1935 May 31, the David Dunlap Observatory opened, housing the second-largest telescope in the world.

The Dunlap Institute for Astronomy & Astrophysics: Past, Present, and Future

Bryan Gaensler

The Dunlap Institute for Astronomy & Astrophysics is very much a 21st-century research institute at the frontier of our understanding of the Universe. Nevertheless, it is a matter of pride that all our activities are still very firmly rooted in the vision established by Jessie Donalda Dunlap when she established the David Dunlap Observatory 80 years ago.

Specifically, the Dunlap Institute's programs and initiatives across astronomy have four clear themes: innovative technology, ground-breaking research, training the next generation, and public engagement in science. In pursuing these topics, we aim to ensure that the generosity of the Dunlap family is translated into a legacy of discovery and knowledge about the cosmos extending for many centuries.

In modern astrophysics, innovative technological approaches sometimes involve enormous structures of glass and steel, and at other times require unique approaches in computing and software. The Dunlap Institute embraces and combines both approaches. One of our flagship projects is the Canadian Hydrogen Intensity Mapping Experiment (CHIME), a radio telescope 100 metres across that we and our collaborators have recently constructed in British Columbia. But CHIME is unlike almost any other telescope you've ever seen; it has no moving parts, and the images are constructed not by steering or pointing the telescope, but via the combining of billions of signals per second in a powerful new supercomputer. Using CHIME, we aim to understand the nature of the mysterious Dark Energy that dominates the cosmos, and that is causing the Universe to accelerate in its expansion (Dunlap Institute for Astronomy & Astrophysics, CHIME).

In sharp contrast, the Dunlap Institute has led the development of the innovative Dragonfly array. Dragonfly is a robotic telescope that uses lenses, rather than traditional mirrors—lenses that are just 40 cm across, 5000 times smaller than the giant telescopes now under construction in Chile and Hawaii. And yet, through superb optics and exquisite calibration, Dragonfly has discovered new galaxies fainter than any ever previously detected (Dunlap Institute for Astronomy & Astrophysics, DRAGONFLY).

Our astrophysics research is focused around the use of innovative instruments like these to see the Universe in new ways. One recent example is the Gemini Planet Imager (GPI), with which we have achieved one of the holy grails of modern astronomy; directly imaging planets orbiting other stars. While thousands of these "exoplanets" have been discovered, the vast majority are detected indirectly, through the way they affect the light of their parent stars. Direct imaging of these worlds is extremely challenging, because they are enormously fainter than the adjacent star. However, GPI masks out the light from stars, allowing us to see the faint planets around it. Using GPI, we are not only seeing new distant planets, but are also seeing the rings of debris around stars that denote planets in the process of formation (Gemini Planet Imager Exoplanet Survey).

Much closer to home, we are using radio telescopes to make spectacularly detailed images of the Earth's ionosphere. Astronomers usually view the ionosphere as an annoying foreground, much like streaks on a dirty car windshield. But by focusing on the streaks rather than the view behind them, we have discovered that the Earth's ionosphere is riddled with giant tubes of plasma, along which energetic particles spiral downward toward the ground from the depths of space (Dunlap Institute for Astronomy & Astrophysics, Distant Radio Galaxies Reveal Hidden Structures Right Above Our Heads).

While pursuing this frontier research, we maintain an unwavering focus on training the next generation of scientists and engineers. Part of this training is of course through our science, which almost always involves young students, and postdoctoral researchers. But research skills are not built just through experience or osmosis; we also run dedicated research training activities throughout the year. Our annual Dunlap Instrumentation Summer School draws students from all over the world, teaching them hardware skills that they will never find written in any textbook. This is a unique event, unlike anything else offered across the worldwide astronomy community (Dunlap Institute for Astronomy & Astrophysics, Summer School). And we have extended our activities globally, having run two very successful summer schools in Nigeria over the last couple of years (Dunlap Institute for Astronomy & Astrophysics, West African Summer School). Further engagement with Africa is now in the planning stages.

Finally, we have never lost sight of the fact that we have a deep responsibility to the wider community. Astronomy is the "gateway science," with a unique capacity to excite and inspire. To this end, the Dunlap Institute is heavily engaged in a huge range of outreach activities, ranging from the traditional public lectures and viewing nights, to "Astronomy on Tap" in the pub; from solar viewing on the sidewalk, to major events such as the Transit of Venus and lunar eclipses, each attracting upwards of 10,000 people.

The future is exciting. The Dunlap Institute continues to expand, both in its number of personnel, and in the scope of its ambitions. As we move into the era of billion-dollar telescopes, on-line education and citizen science, we aim to remain at the forefront of discovery, education, and engagement.

The Long Road to the Dome

R.A. Rosenfeld

In North America, the first great age of civic and collegiate engagement with astronomy materialized on the townscape in that aspiring prestige construction, the astronomical observatory. This epoch commenced before the American Civil War, and ended before Canada's entry into the Second World War. Edifices of skilled industry intended to impart, symbolize, and even occasionally produce science, civic and college observatories were popular with patrons of diverse means wishing to endow their own Uraniborgs for personal, local, or memorial glory. The *urbs* of Toronto, with its university and astronomical society, was no exception.

Exceptional, however, was the interval separating desire from fulfillment. Looking back from 1935 May 31, it must have seemed to the members of the city's astronomical community as if they had just emerged from over 40 years unwilling sojourn in the wilderness of perpetual disappointment. What they got in the end was not what they'd originally wanted; it was both more, and less.

In 1892, the Society attempted to entice Hart Massey to place an observatory atop Massey Hall (*TAPST* 1892 [1893], 84). The industrialist was politely sympathetic, but progress on the concert venue was too far advanced to accommodate an observatory. The site, while conveniently accessible, would not offer the most pristine of skies, and traffic may have affected the stability of the mount, particularly if the observatory was a late addition past the time to install a pier suitably isolated from sources of vibration. Had it been built, the Society's Massey Hall observatory would in time have been Toronto's less striking analogue to the Urania Zürich (1907; Mirwald 2014, 215-220).

During 1894–1896, members attempted to develop a proposal to establish a popular observatory (*TAPST* 1894 [1895], 79; *TAPST* 1895 [1896], 62; *TAPST* 1896 [1897], 24-25). It fared no better than the previous essay.

By 1898, The Toronto Astronomical & Physical Society could launch a campaign for a "People's Observatory" in early summer, with a $100 seed grant from the City of Toronto (Lindsay 1898; Anon. 1898). The desired instrument, as specified in the printed prospectus for the campaign, was a refractor equivalent in aperture to the *carte du ciel* astrographs and guidescopes (10 to 13-inch O.G.; Académie des sciences 1887, 102-103; Chinnici 2008). Among the trustees of the project listed in the prospectus is one "C.A. Chant, B.A." The document makes no mention of the use of the projected facility for research, or higher education—a fault pointed out by A.T. De Lury, Andrew Elvins, and others (APST Regular Meeting minutes 1898 June 14, 438-439; APST Council minutes 1898 July 19, 3). The Urania Observatory in Berlin was cited as a model for the "People's Observatory" of Toronto (APST Regular Meeting minutes 1898 June 14, 439). It is interesting to note that the successful *Volkssternwarten* in German-speaking continental Europe were the likely inspiration for a "People's Observatory" for Toronto (these are treated in Mirwald 2014; for Berlin, see 140-181). Unfortunately, this campaign failed to meet the minimum requirements for minimal success.

Ever optimistic, like a coyote in pursuit of a roadrunner, the observatory backers tried a fresh initiative in 1903. A committee was formed, which included the Director of the Meteorological Service of Canada, a Deputy Provincial minister and FRAS, an IAU member, and one current and two past RASC presidents (Rosenfeld 2013, 264). This was to be a cooperative project between the RASC and Trinity College (the then Provost was a Society member, and future council member); the College agreed to donate the land. The principal instrument was to be a 12-inch O.G. refractor (in the same aperture class as the instrument in the previous plan), and the observatory was to serve as the headquarters of the Society (Rosenfeld 2013, 265). Success once more eluded the observatory's promoters.

A personal triumph for Chant at about this time (1905) was the establishment of the sub-department of astrophysics in the university, but the lack of progress in achieving an observatory somewhat hampered the observational aspect of the program. As an interim measure, Chant sought and received access to the Meteorological Observatory's equatorially mounted 6-inch O.G. refractor, their transit instrument, and several of their staff as instructors (Chant, 1952, 753-754). That same year, Chant went on a pilgrimage to American observatories to examine their equipment, and seek advice from their directors. Lewis Boss, of the Dudley Observatory, recommended to Chant that a students' observatory be situated on or near the campus, and a research observatory "should be easy of access"(!), advice that struck him as sensible (Chant, 1952, 757).

The next try was in 1914, with Chant assuming the mantle of principal observatory promoter. As in the previous endeavour, the observatory was to be a joint university and RASC installation, but it differed in the increased grandeur of its movers' aspirations. The "Royal Astronomical Observatory" would be sited in "Observatory Park," located overlooking the Cedarvale Ravine bordering Bathurst Street, and would house 20-inch and 9-inch telescopes (almost certainly refractors), and the RASC library. "Sketch plans" were drafted by the noted architectural firm of Sproatt and Rolph. The timing was not of the best, however, and the commencement of the Great War meant the plan appeared to cop it, to use the trench slang of the time (Chant 1952, 765-770; Broughton 1994, 162).

The effort was revived in 1919. An astronomical delegation appeared before the city's Board of Control, including RASC members prominent in the city, such as the Provost of Trinity College, the Rev'd T.C.P. Macklem, and the Director of the Meteorological Service, Sir Frederick Stupart. Chant had prepared a memorandum on the observatory, which was distributed to enlist support. The memorandum, delegation, and other efforts had some success, for the city donated the land. The city's broadsheet dailies bestowed their blessings on the scheme, as did the Assistant Superintendent of the Canadian Geodetic Survey, and the Chief Astronomer and Director of the Dominion Observatory in the nation's capital (Chant 1952, 778). Chant also managed to secure Edward Emerson Barnard, an Honorary Fellow of the RASC, and one of the great and good of astronomy—famous for his comet discoveries, his finding of the fifth moon of Jupiter (Amalthea), and his much reproduced astrophotographs—to give two well-attended lectures in Toronto in March of 1920, to help publicize the observatory campaign (Chant 1952, 779-780). Another Honorary Fellow, George Ellery Hale, offered moral support, and fund-raising advice (Chant 1952, 781). Despite the prominent endorsements, the donated land, and Barnard's star turn, the effort failed like all those that came before. Why?

Oliver Wendell Holmes, who died the year the DDO was opened, is famously quoted as saying: "I like paying taxes. With them I buy civilization" (McGee 2011, 50). Most of the wealthy elite of Toronto demurred from the sentiment of the American jurist, preferring passive-aggressive revolt against buying civilization for others. One prominent banker told Chant that the newly instituted imposition of income tax on the rich robbed them of any desire to be philanthropically generous (Chant 1952, 783-784). The banker doubtless knew his clients. In 1906, Chant estimated he required $18,000 for a 20-inch refractor, and $8,500 for its enclosure. By 1922, he had revised the wish list to a reflector with a 60-inch primary mirror, which would have required nearly $200,000 (Chant 1952, 787-788). Depending on how one tallies up the observatory attempts, this was either the fourth, or the seventh time unlucky.

In 1921, David Dunlap, a member of Toronto's financial elite, *did* express interest in Chant's project. The basis for his interest seems to have been a genuine personal regard for astronomy, which Chant gently cultivated. He invited David Dunlap to became a RASC member, and advised him of rudimentary astronomical resources for astronomically curious members of his circle (Chant 1952, 783; 785-787). Unfortunately, David Dunlap succumbed to ill-health a year and a half after making Chant's acquaintance, apparently well before his interest could turn to active patronage. To many, the prospect for an observatory in 1924 may have seemed little better than it was in 1892. There was a difference this time, however, and that difference was Jesse Donalda Dunlap's choice to become the patron of the observatory project her late husband had heard Chant describe.

There were few models for female patronage of astronomical projects, and none of them were Canadian. Catherine Wolfe Bruce's (1816–1900) support for astronomy in the United States and Western Europe was outstanding (Payne 1900)—although she did not found any observatories, she provided funds for expensive equipment, programs, publications, and salaries, the last three being rarely funded by others. The only female founder of a North American observatory of whom I am aware, prior to Mrs. Dunlap, is Blandina Dudley (1783–1863), who established the Dudley observatory in memory of her husband, C.E. Dudley (1780–1841), in 1856 (Wise 2004, 15-16). C.A. Chant would have been well aware of both precedents, and might have cited them to Mrs. Dunlap when approaching her for patronage for a major Canadian observatory in memory of her husband.

In the Canadian context, endowing a research institution in the physical sciences was rare, and having a woman do so was unprecedented. Mrs. Dunlap could have chosen any variety of means to create a legacy for David Dunlap. Had she followed her husband's pattern of philanthropy, she would have been expected to endow the Methodist Church, or a medical institution, or an art gallery, or museum, or an ornithological cause in his name, rather than an observatory. In the obituary in *The Globe* those are all mentioned as interests of his and recipients of his past support, but nothing is said of astronomy (Anon. 1924). It is greatly to Mrs. Dunlap's credit that she took the unorthodox decision to found the David Dunlap Observatory in memory of her husband. The crucial factor that made the difference between the all-too-numerous failed attempts of the previous four decades, and the successful campaign resulting in the David Dunlap Observatory, was Jesse Dunlap's inspired patronage. Without her, the saga of the unbuilt observatory would doubtless have continued.

Mrs. Dunlap's gift may very well have inspired at least one other donation of a Canadian observatory, Frances Amelia Cronyn's gift of the Hume Cronyn Memorial Observatory to Western (1940).[3] Both C.A. Chant and Mrs. Dunlap participated in its opening ceremonies. One wonders if Chant reflected that the Cronyn Observatory was exactly the model of the observatory the Toronto astronomical community tried so hard to obtain over the first three decades of their effort: it was both Western's university observatory, and London's civic observatory; it was equipped with a 10-inch O.G. refractor; it was sited in easy proximity to the city's core; and it was planned to run with RASC involvement. What Toronto got was a major research telescope, on a site too far removed to take on the range of EPO functions of a *Volkssternwarten*. Pursuing greater "power of penetrating into space," to use William Herschel's colourful phrase, while certainly a prime research imperative, is not without its costs (Herschel 1800).

Universe: a Cinematic Triumph

R.A. Rosenfeld and Mike Reid

The National Film Board of Canada's (NFB) documentary *Universe* (1960) was a remarkable achievement in its time, and is still worth seeing today (NFB Universe). The DDO featured in the film as the portal through which Solar System and galactic vistas could be imaginatively conceived out of the sober stuff of science. Partly shot in a university setting, the film's life continues within that setting, for one of us screens portions of it in a basic astronomy survey for non-science students. Astronomy has developed hugely since the film was made, yet this artifact of a pre-dark-matter and pre-dark-energy cosmology can still provide teaching points centred around the non-fixity of the techniques and results of science, different choices in data-centred representations of remote phenomena, and the use of media for relaying science. The film is a journey "there and back again," and its context and making invite inquiry.

Imagine it's the 1950s…

Students sometimes have to be reminded that *Universe* was made before WiFi, digital editing programs, and CGI. Special effects were analogue, manufactured through the clever manipulation of physical constructs through varying factors, such as lighting, shooting angle, and velocity. In *Universe*, the urban-core landscape of Toronto functions as the locus of the "ordinary," the place where familiar activities are done by familiar beings, us, on a human scale in our manufactured landscape. Except that the passage of time has added another layer of alterity to what the original audiences experienced, for the city is both familiar, and unfamiliar. The cityscape feels the same, yet most of the structures have been replaced or altered, the tram cars are there, but they look vintage, the men wear fedoras, but there are no hipsters.

In retrospect, the 1950s seem more notable for cinematic science fiction than cinematic science. Robert Wise's classic *The Day the Earth Stood Still* (1951), with its alien Klaatu, his message of world peace for an anxious world, his robot Gort, and their flying saucer designed by Frank Lloyd Wright (Ruse 2015, 186), looks as vintage as Toronto's 1950's tram cars. Its visual aspect no longer possesses the persuasive force to evoke a possible future. This decade also saw the beginnings of *real* space exploration, namely the successful launch of Sputnik 1 on 1957 October 4. With it came the promise of actually "travelling" to the vistas imaginatively presented in *Universe.* The succession of scientific probes that have become the habitual extension of our senses, in seeing and touching space, is one promise of 1950's futurism, which we are presently living.

It is remarkable that the extension of "sight" into other wavelength regimes, combined with continual improvements in resolution, data storage, and processing during the intervening decades, has not entirely eroded the apparent verisimilitude of the space vistas presented in *Universe.* Who were its creators, how did they realize their project, and what was its immediate influence?

Creating Universe

Roman Kroitor and Colin Low provided the primary creative impetus for the film. According to Low, the idea to do "a film about an astronomer" originated with Kroitor (NFB Colin Low). Kroitor received academic training in philosophy and psychology, and was interested in experimentation and technical innovation in film (McSorley 2006; Langdon 2012—he would go on to invent the SANDDE stereoscopic 3-D animation technique, and co-invent the IMAX film system). Low, too, was willing to innovate, and later noted:

> "*…in Paris in 1949, I met Berthold Bartosch, the famous pioneer animator. He was planning a new film that he said*

was on the cosmos. His equipment was very simple but very ingenious, and he showed me how he planned to execute it with three-dimensional models. I was struck by his audacity and ingenuity…I remembered some of Bartosch's ideas on time exposure and the importance of extreme depth of field. The 35 mm rushes on asteroids began to look very good in action. The asteroids were clinkers from the furnace travelling on a panner that we built for Grant Munro for a puppet film that he was making" (NFB Colin Low).

A few more details on methods have been published: "For *Universe*, the surfaces of the moon and neighbouring planets[!] were created by such unconventional techniques as working asbestos powder and flour into a cardboard base" (James 1977, 546). It is interesting to note that *Universe* was made by Unit B, the sponsored films and animation studio, and not Unit D, the scientific and cultural films studio.

Kroitor and Low's vision required considerable ongoing experimentation during the years of production (1953–1960), and that meant expert skill, and the funds to pay for technicians, and materials. The special-effects team was headed by the inventive and versatile Wally Gentleman. The original budget estimate was $60,000, a very large outlay for an NFB documentary at that time. In the end, the film cost $105,146 (Evans 1991, 76-77; Jones 2005, 80). The "sky-rocketing" costs nearly imperilled the film (clearly the worlds of film and big-science share this ever-present danger).

The original purpose of *Universe* was "not so much to convey facts about the universe as to invoke a sense of wonder about it" (Jones 2005, 80), and it fit well into the venerable Enlightenment quest for the sublime. A commentator in the decade after its release wrote: "Model animation combined with photographs and drawings create an interplanetary landscape that has been matched only by in-space photographs of the real thing" (James 1977, 491). *Universe* was a success in more ways than one.

Stanley Kubrick was so impressed by the special effects that he discussed his project with Low, hired Wally Gentleman, and secured the narrator of *Universe*, Douglas Rain, to voice Hal in *2001: Space Odyssey* (Jones 2005, 81). NASA ordered 300 or more prints of *Universe* for training and EPO, it won 23 awards including an Oscar nomination, and by the early 1990s was the second-most widely distributed and lucrative NFB production (Evans 1991, 76-77; Jones 2005, 81).

The "film about an astronomer" did in fact feature an astronomer, Donald MacRae (1916–2006), who became director of the DDO five years after *Universe* was released, and was important in building up the department, and Canadian involvement in the next generation of telescopes after the 74-inch, both optical and radio (Seaquist 2006). Don MacRae's role in *Universe* was just one aspect of his commitment to EPO—he was also instrumental in securing funding for the McLaughlin Planetarium. Unit B was known for its practice of "Direct Cinema" (a less intrusive form of *cinéma vérité*), and the scenes of urban Toronto are certainly part of the stuff of that tradition. At first glance the scenes with Don MacRae might persuade that they are also examples of Direct Cinema, but there are hints that that they are products of artifice: "Roman Kroitor and Dennis Gillson had shot a great live-action sequence of the astronomer and the observatory. I had pushed for lighting that would match the spectacular effects" (NFB Colin Low).

Figure 4 — Helen Sawyer Hogg and the DDO 74-inch telescope (reproduced courtesy of the University of Toronto Archives).

For much of *Universe*'s original audience, Don MacRae working with the 74-inch was their first exposure to a "realistic" filmic sequence of an actual professional astronomer acquiring data. Wherever *Universe* was screened in the post-Sputnik space age, Don MacRae in the DDO formed *the* image of the astronomer at work for many school children, and adults. That is a quieter cinematic triumph than an Oscar nomination, but it is no less significant.

Helen Sawyer Hogg

Christine Clement

In my remarks about Helen Hogg today, I do not intend to provide a complete biography. That information is available from a number of sources (Clement & Broughton 1993; Cahill 2009; Department of Astronomy & Astrophysics, Helen Sawyer Hogg). Rather I intend to share with you a few of my own memories and reflections on Helen's life and career.

I begin with this beautiful photo of Helen standing beside her beloved David Dunlap 74-inch telescope (Figure 4). Over a period of 35 years—until she was 65 years old—Helen observed with this telescope. More on that later. Lee Robbins, the U. of T. astronomy librarian, located this in the Helen Sawyer Hogg collection at the U. of T. Archives. And Paul Mortfield pointed out that Helen is holding a copy of the RASC *Observer's Handbook*. This is very fitting because the RASC, and the Toronto Centre in particular, held a special place in Helen's heart. January 1951 was a low point in her life—after the sudden and tragic death of her husband Frank, who was the director of the DDO when he died.

Helen's friends in the Toronto Centre gave her encouragement when she needed it badly. For the previous 10 years, Frank had written a weekly astronomy column for the *Toronto Star* and Helen played an active role in the preparation. She typed it, edited it, and sometimes even wrote it! What was to become of the column after Frank's death? Members of the Toronto Centre had the answer: Helen should write it! They conducted a fervent letter-writing campaign to the *Toronto Star* suggesting that she be invited to write the column. Back in 1951, the ability of women to carry out professional activities was not recognized in the way it is today. So the support of the Toronto Centre made a big difference. She continued with the column for the next 30 years—until January 1981 (Sawyer Hogg 1981a; 1981b; RASC, Eric Briggs, With the Stars). On looking back later in life, she acknowledged that the column would never have lasted for such a long time without the interest of her loyal readers, many of whom were members of the RASC.

During her years at the DDO, Helen also carried out an active research program with the 74-inch telescope. Beginning in the summer of 1935, she photographed globular clusters in order to identify and investigate their variable stars. Over the next 35 years, she obtained approximately 2700 photographs of 52 globular clusters.

It was interesting to be in the dome with her because her knowledge of the night sky was legendary. She knew exactly where all "her" clusters were located and on nights that were partly cloudy, she knew which ones she could reach in the breaks between the clouds. The DDO site was not ideal for observing variable stars in globular clusters, but Helen knew how to make the best of it. In 1971, the program was transferred to the Las Campanas observatory in Chile where the sky was darker and clearer. Also—in May, June, July—the prime season for observing globular clusters, the nights were longer there—which was advantageous for deriving accurate periods of variable stars.

Helen's globular-cluster program was conducted at the Newtonian focus, located at the top end of the telescope. In order to access the camera, the observer had to perch in the Newtonian cage—about 30 feet above the concrete floor (Figure 5). Some tricky manoeuvres were required to make the operation run smoothly and efficiently.

Figure 5 — Helen Sawyer Hogg at the Newtonian focus of the 74-inch telescope (reproduced courtesy of the Department of Astronomy & Astrophysics, University of Toronto).

When making photographic observations, it is necessary to load an unexposed plate into a plate holder, and remove it when the exposure is completed. This exchange takes place in the darkroom located on the floor below. Helen devised a clever scheme for transporting the plates up and down; she used a sturdy handbag attached to a long rope.

Another challenge was to guide the exposure. For this, the observer had to be positioned close to the camera, but the cage was attached to the dome, not the telescope. Thus, as the telescope tracked westward, it would drift away and the dome had to moved, but not too much! "Move the dome west 2 inches!," Helen would sometimes call out from her high perch. This was a challenge for telescope operators who had never worked during a session with the Newtonian focus. Generally, when one moves the dome, one moves it a few feet. But this was not feasible when the observer was in the Newtonian cage. If the dome was moved too far, she would crash into the telescope.

Most of you are aware that Helen grew up in New England. Her involvement with globular-cluster research began when she arrived at Harvard in the fall of 1926 to work with Harlow Shapley. She was very productive during her time at Harvard.

Shapley had made a name for himself in 1917 when he determined that the Sun was not at the centre of the Milky Way—a conclusion he reached based on observations of globular clusters (Sawyer Hogg 1965). His work was carried out at Mount Wilson, but in 1921 he moved to Harvard to become director of the observatory.

One of the benefits of his move to Harvard was that he had access to Harvard's extensive collection of globular-cluster photographs, offering an opportunity to strengthen his conclusion about the scale of the Milky Way. However, he had to find the right person to work on the project. It took him almost five years to solve that problem.

The solution came in January 1926, when the renowned Harvard astronomer Annie Cannon paid a visit to Mount Holyoke College in South Hadley, Massachusetts. At the time, Helen Sawyer was an enthusiastic astronomy major in her senior year. She was invited to lunch with Annie, and asked to show her around. After that, one thing led to another, and in September 1926, Helen arrived at the Harvard College Observatory to help Shapley with his book on star clusters (Sawyer Hogg 1988, 11-13).

In her collaboration with Shapley, Helen studied variable stars, but she also used the Harvard plate collection to derive general properties of clusters—integrated magnitudes, magnitudes of their brightest stars, angular diameters, degree of concentration—in order to understand how these parameters are related to a cluster's intrinsic brightness so that its distance can be determined.

In those days, the best method for determining a cluster distance was to estimate the brightness of its RR Lyrae variables, but that was not a viable method for most clusters.

Shapley's 1917 analysis included 68 clusters, but only 5 had RR Lyrae stars (Shapley 1930, vii-viii). His Harvard analysis with Helen included 93 clusters, 19 with RR Lyrae stars, but not all of these variables had been fully investigated, i.e. their periods had not been determined. There was more work to be done!

During her years at Harvard, Helen met and married Frank Hogg, a fellow graduate student and a Canadian. In 1931, a year after their marriage, they moved to Victoria, where Frank took a position at the DAO. In the course of carrying on her research with Shapley, Helen had recognized the importance of identifying and investigating variable stars in globular clusters. At the DAO, she was in a perfect position to do this herself. So in 1931, she set up her own observing program using the 72-inch reflector at the DAO. Then, when the family relocated to Richmond Hill in 1935, she continued the program with the DDO 74-inch.

As we all know, Helen made a name for herself as a newspaper columnist and as an expert on RR Lyrae variables, but she also had considerable impact with some of her other scientific publications. After her experience with Shapley, she was an expert on the general properties of globular clusters, and was often invited to write review articles on the subject (e.g. Sawyer Hogg 1959).

She also recognized that there was a great need for bibliographies summarizing globular-cluster research—long before the days of the Internet, or the Harvard Astrophysics Data System. In addition, she published catalogues of variable stars in clusters to enable researchers interested in the subject to get a clear picture of exactly what work had been done.

She carefully monitored every piece of literature that was received in the Observatory library. When new material arrived, it was placed in a special drawer and not put out for general circulation until Helen had gone through it. As a result, she kept up to date with recent developments in the field, and this was valuable for her bibliographic work, and for her newspaper columns.

Throughout her life, Helen travelled to some very interesting places, and in 1958 she made it to Samarkand, the centre of the empire of Timur, also known as Tamurlane the Great. Its heyday was in the 14th and 15th centuries.

In 1958, the General Assembly of the International Astronomical Union was held in Moscow. It was a time when the Soviet Union was opening up to westerners after the death of Stalin. And one of the post-conference tours was to Samarkand. Samarkand had astronomical significance because, in the first half of the 15th century, it was ruled by Timur's grandson Ulug Beg, who was a mathematician and astronomer. The organizers of the 1958 conference wanted the visiting astronomers to have a chance to see Ulug Beg's observatory, which among other instruments, featured a monumental quadrant ("Fakhrī sextant") built into a hill. That was why Helen went.

In the mid-20th century, the living conditions in Central Asia were very primitive, so it was quite an adventure. If any of you have attended a banquet in Russia or the Soviet Union, you will know they like to propose toasts—and the tour to Samarkand was no exception. For each toast, the men were required to empty their glass of vodka, and then it was refilled for the next toast. Helen reported that the men in their group were "under the weather" the following morning. Sometimes there are advantages to being a girl.

Attending the conference in the Soviet Union gave Helen the chance to make personal contact with astronomers behind the Iron Curtain, and she made the most of it. She corresponded regularly with astronomers in Moscow, Prague, and Budapest, and did everything she could to make sure that their papers were cited—something western astronomers were not always willing to do during the Cold War.[4]

In recognition of her life-long achievements, Helen received many awards and honours, including appointment as a Companion of the Order of Canada in 1976.

Reminiscences of Radio Astronomy at the DDO 1956–1966

Ernie Seaquist

My presentation in celebration of this 80th anniversary describes briefly the radio astronomy work at DDO during the decade 1956–1966. The work was a collaboration between the Departments of Astronomy and Electrical Engineering of the University of Toronto, with Donald A. MacRae and J.L. Yen as the respective co-leaders. It was initiated to allow graduate students to train in the relatively new field of radio astronomy, and to produce research at the level of a Master's degree. Though the work included both solar and cosmic observations, the principal effort was in the latter area with focus on absolute measurements of the flux densities of strong radio sources, such as Cas A, and Cyg A, and the galactic-background emission. Such absolute measurements are essential to calibrate the larger surveys of discrete radio sources and Milky Way surveys.

The work was conducted in the field to the immediate east of the DDO administration building, but some of the later work was carried out at the University of Toronto site of the Algonquin Radio Observatory (ARO). Figure 6 shows the various antennae that were used in the DDO work (circa 1960), together with the "radio shack" that housed the receiver

Figure 6 — Image of the DDO radio observatory, taken looking east from the roof of the DDO Administration Building, ca. 1960. The two antennas on an east-west baseline to the left are wire mesh parabolic cylinders used together with one of the pyramidal horns in an early phase of the interferometric work on discrete sources. At centre right are the two pyramidal horns arranged as an east-west interferometer and used in the final phase of this work. They are shown straddling the mounting tower for an unrelated "zig-zag" antenna used for solar measurements. The radio shack housing the receiver is clearly visible. The antenna to the immediate right (south) of the radio shack is a prototype segment of an east-west array intended to be part of a much longer array at 707 MHz at the Algonquin Radio Observatory. This array was never built, and the prototype section was never used as a radio telescope on its own (reproduced courtesy of the Department of Astronomy & Astrophysics, University of Toronto).

operating at a frequency of 320 MHz (approximately 1 metre wavelength). The principal antennae used were the two pyramidal horns to the right of the centre of the photograph, which were aligned east–west as an interferometer with a baseline of 60 metres. Interferometric measurements are superior to single antennae for measurements of point-like sources. The pyramidal horn was used because of its simplicity, and its accurately determined collecting aperture, essential for measuring absolute fluxes. Figures 7 and 8 show details of one of the two pyramidal horns and the horn reflector antenna that was used at ARO. The latter antenna was especially well adapted to absolute measurements of extended galactic emission, and was of the same type used by Penzias and Wilson for their discovery of the Cosmic Background Radiation (CBR).

The primary measurements conducted were of the absolute flux densities of the discrete sources Cas A and Cyg A at 320 MHz, which led to the publication of an accurate flux primarily for Cas A (MacRae & Seaquist 1963). A second important set of measurements was made of the absolute brightness of the North Celestial Pole at 320 MHz and 707 MHz, using respectively the pyramidal horn and horn reflectors (Wall, Chu, & Yen 1970). Such measurements required careful calibration of the antenna side lobes, so background spillover thermal emission from the ground could be subtracted.

Figure 7 — A close up of the west element of the pyramidal horn antenna interferometer used for the Cas A absolute flux measurements and the antenna used for measurements of the absolute brightness of the North Celestial Pole at 320 MHz. The dimensions of the aperture are 2.76m x 3.70m. This type of antenna was used because its electrical collecting aperture area can be readily computed from the electromagnetic theory of waveguide apertures (reproduced courtesy of the Department of Astronomy & Astrophysics, University of Toronto).

An interesting note about the latter measurements was brought to light by one of the authors, Jasper Wall, sometime after the aforementioned discovery of the CBR. The existence of the CBR and its approximate brightness of 3K were inferable from the DDO and ARO measurements because the radio spectral index (or ratio of fluxes at the two frequencies) were significantly influenced by the CBR, so that it was consistent with the spectral index of galactic synchrotron emission only after the CBR contribution is first removed from each measurement (Wall 2009).

Work at DDO wrapped up in the mid-1960s largely due to increasing levels of radio interference from traffic on nearby roads, and shortly thereafter by the emergence of the 46-metre radio telescope at ARO, Canada's first national facility for radio astronomy, open to all Canadian astronomers.

The David Dunlap Observatory: Present & Future

Paul Mortfield

When the Dunlap observatory and lands were sold in 2008, the new owners of the property posted a note looking for an organization to run the facility. This was a wonderful opportu-

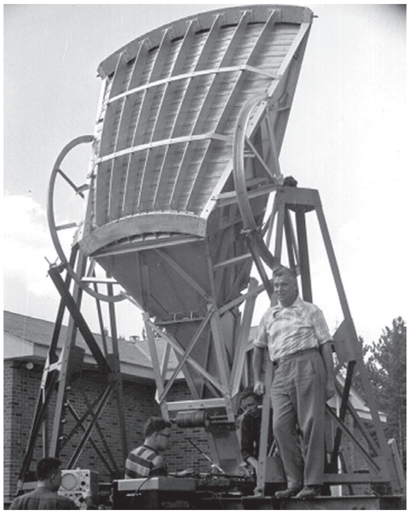


Figure 8 — An image showing preparatory work on the horn reflector antenna at the University of Toronto site of the Algonquin Radio Observatory. It was used to measure the absolute brightness of galactic emission at 707 MHz at the North Celestial Pole (reproduced courtesy of the Department of Astronomy & Astrophysics, University of Toronto).

nity for the Toronto Centre of the RASC to step up to a challenge. The Toronto Centre, a registered charity, has a long history of providing astronomy education and outreach programs around the greater Toronto area, including assisting with the outreach programs at the Dunlap Observatory since its opening in 1935.

Since assuming stewardship of the facility in 2009, the Toronto Centre has ensured that the David Dunlap Observatory in Richmond Hill, Ontario, continues to function—indeed, to thrive—despite all odds. The group has welcomed more than 25,000 visitors to the observatory, offering a rich variety of public outreach and education programs to school groups, and Scouts and Guides, as well as to the general public. Members focus on delighting visitors with views of the night sky, increasing their understanding of astronomy, and encouraging young people to pursue careers in the sciences (Figure 9).

Figure 9 — Outreach efforts by members of the Toronto Centre of the RASC, under the 74-inch dome (reproduced courtesy of The David Dunlap Observatory, RASC Toronto Centre).

These programs, run entirely by volunteers, require more than 2500 person hours per season. In addition, about 1500 additional volunteer hours are dedicated to the ongoing maintenance of the Great Telescope and its precinct. This also includes re-aluminizing the 2.5-ton primary mirror. The observatory team has been trained in all the operations and maintenance processes by 40-year observatory veteran, Archie de Ridder.

The Toronto Centre now offers Family Nights that are tailored to the needs and interests of parents with young children. A "Space Crafts" room has been set up in one of the classrooms of the Administration Building, where, with arts-and-crafts supplies, creative Toronto Centre volunteers encourage youngsters to create their own constellations, build an alien (or become one), and learn about space through hands-on activities.

The "Skylab" was created out of a large, somewhat battered office space. Members painted the walls "projection-screen white," installed carpeting, and sewed large pillows for lounging. They then installed a projector and audio system, to allow the projection of any space-based programming across a seven-metre expanse of wall, to create an immersive, educational experience. A team of trained presenters delivers a range of age-appropriate outreach programs.

In Ontario, high-school students are required to complete 40 hours of community service before graduation. Because of its charitable status, the Toronto Centre is able to offer a student intern program at the DDO involving several dozen York Region students each season. Several students have returned to their schools and started their own astronomy clubs. A number of the DDO's former high-school interns are now pursuing university degrees in the sciences.

We're creating a Space Science Campus within the administration building to provide daytime-school field trips and science-based after-school and weekend programs that cover astronomy, robotics, and citizen science. In addition, we're looking to create York Region's first maker space, and to include gallery exhibit space for community events. We will add a small automated telescope into one of the domes on the roof to be used for imaging requests from Ontario classrooms and students studying astronomy. The telescope will provide images of requested celestial objects and observational data, allowing students to analyze variable stars, asteroids, and exoplanets as part of their studies. It's an exciting component that allows students access to real data to study astronomy first hand. We'll also use the observatory telescopes for live webcasts as virtual observing sessions for classrooms wishing to interact with scientists, and space experts.

With its new mission in science education, the David Dunlap Observatory will continue to be a centre of excellence to inform and inspire the community to look up and wonder about the amazing universe around us for many years to come (the DDO). ✶

Contributors

Christine Clement is an Emerita Professor in the Department of Astronomy & Astrophysics at the University of Toronto. Her research specialty is variable stars in globular clusters, and other stellar systems. She was a student and a long-time professional collaborator of Helen Sawyer Hogg's.

Professor Bryan Gaensler commenced as Director of the Dunlap Institute for Astronomy & Astrophysics in January 2015. He is a radio astronomer who works on cosmic magnetism, time-domain science, and the diffuse Universe.

Paul Mortfield is the present Director of the David Dunlap Observatory. He is a member of NASA's Education Products Review team, is chair of the Solar Division of the American Association of Variable Star Observers (AAVSO), and is a noted astrophotographer.

John Percy is an Emeritus Professor at the Department of Astronomy & Astrophysics at the University of Toronto, and a Fellow of the RASC. His association with DDO began in his undergraduate days, in 1961. He is the inaugural recipient of CASCA's Qilak Award for Astronomy Communications, Public Education, and Outreach.

Dr. Mike Reid is Lecturer and Public Outreach Coordinator for the Dunlap Institute, and a radio astronomer. In 2015, he was a winner of a University of Toronto Early Career Teaching Award. He is the Chair of CASCA's Education & Public Outreach Committee.

Lee Robbins is Head Librarian of the Department of Astronomy & Astrophysics of the University of Toronto, and is the former librarian of the DDO. Before taking up her present appointment she was a librarian at Fermilab. She has an interest in the historical artifacts of the physical sciences, on which she has published.

R.A. Rosenfeld is the Archivist of the RASC. He has published on astronomical artifacts and the people who produced and used them, from the Middle Ages to the modern period. He is a recipient of the RASC's Simon Newcomb Award, and, like his colleagues John Percy and Lee Robbins, serves on CASCA's Heritage Committee.

Ernie Seaquist is an Emeritus Professor and former Chair of the Department of Astronomy & Astrophysics at the University of Toronto, and a former Director of the David Dunlap Observatory. He is a radio astronomer, and still conducts research on the ISM in active star-forming galaxies. He is a recipient of CASCA's Carlyle S. Beals Award.

Acknowledgements

The authors wish to thank the Dunlap family, Marnie Gamble, Special Media Archivist, University of Toronto Archives & Records Management Services (UTARMS) for her advice and expertise, and UTARMS, the Department of Astronomy & Astrophysics University of Toronto, and the SPECVLA ASTRONOMIA MINIMA for the loan of artifacts, and Professor Peter Martin, Dr. Mike Reid, Dr. Leslie Groer, and the David Dunlap Observatory volunteers of the RASC Toronto Centre.

References

Manuscripts, Books, and Articles

Anon. (1924). Leader in Church and Business Head Passes to Beyond: David Alexander Dunlap, Successful Mining Magnate, is no More. *The Globe* Oct. 30, 12

Académie des sciences (1887). *Congrès astrophotographique international tenu a l'observatoire de Paris pour le levé de la carte du ciel.* Paris: Gauthier-Villars

Anon. (1898). TAPS Memorandum of the Municipal Grant

Astronomical and Physical Society of Toronto (APST) (1898). Regular Meeting Minutes

Astronomical and Physical Society of Toronto (APST) (1898). Council Meeting Minutes

Beattie, B. (1982). The 6-inch Cooke Refractor in Toronto. *JRASC 76, 2*, 109-128

Cahill, M.J. (2009). The Stars Belong to Everyone: the Rhetorical Practices of Astronomer and Science Writer Dr. Helen Sawyer Hogg (1905–1993). Ph.D. thesis, University of Wisconsin-Milwaukee

Chinnici, I. (2008). La carte du ciel: Genèse, déroulement et issues. In J. Lamy (Ed.), La Carte du Ciel. *Histoire et actualité d'un projet scientifique international* (pp. 19-43). Paris: L'Observatoire de Paris et EDP Sciences

Clement, C. & Broughton, P. (1993). Helen Sawyer Hogg, 1905-1993. *JRASC 87, 6*, 351-356

Evans, G. 1991. *In the National Interest: a Chronicle of the National film Board of Canada from 1949 to 1989*. Toronto: University of Toronto Press

Friedland, M.L. (2013). *The University of Toronto: a History*, 2nd edition. Toronto: University of Toronto Press

Herschel, W. (1800). On the Power of Penetrating into Space. *Phil. Trans.*, 90, 49-85

James, C.R. (1977). *Film as a National Art: NFB of Canada and the Film Board Idea*. New York: Arno Press

Jones, D.B. (2005). The Canadian film Board Unit B. In A. Rosenthal & J. Corner (Eds.), *New Challenges for Documentary,* 2nd ed. (pp. 79-93). Manchester–New York: University of Manchester Press

Langdon, G.H. (2012). The Info-Immersive Modalities of Film Documentarian and Inventor Roman Kroitor. Ph.D. thesis, University of Toronto

Lindsay, T. (1898). *The People's Observatory* [prospectus]. Toronto: Astronomical and Physical Society of Toronto

MacRae, D.A. & Seaquist, E.R. (1963). Flux of Cas A and Cyg A at 320 Mc/sec. *AJ 68*, 77

McGee, R.W. (2011). An Analysis of Some Arguments. In R.W. McGee (Ed.), *The Ethics of Tax Evasion: Perspectives in Theory and Practice* (pp. 47-71). New York–Dordrecht–Heidelberg–London: Springer

McSorley, T. (2006). Roman Kroitor. In I. Aitkin (Ed.), *Encyclopedia of Documentary Film, 2* (pp. 747-748). London: Routledge

Mirwald, B. (2014). *Volkssternwarten. Verbreitung und Institutional-isierung populärer Astronomie in Deutschland 1888-1935*. Acta historica astronomiae 55. Leipzig: Akademische Verlagsanstalt

Payne, W.W. (1900). The Late Catherine Wolfe Bruce. *Popular Astronomy 8, 5*, 235-238

Rosenfeld, R.A. (2013). Lost in the Realm of the White Squirrel: Plans for the RASC's First Observatory. *JRASC 107, 6*, 264-268

Ruse, M. (2015). Klaatu Barada Nikto or Do They Really? In (Ed.) S.J. Dick, *The Impact of Discovering Life Beyond Earth* (175-188). Cambridge: Cambridge University Press

Sawyer Hogg, H. (1959). Star Clusters. In S. Flügge (Ed.), Astrophysik IV: Sternsysteme/Astrophysics IV: Stellar Systems, *Handbuch der Physik/Encyclopedia of Physics 11/53* (pp. 129-207). Berlin: J. Springer

Sawyer Hogg, H. (1965). *Harlow Shapley and Globular Clusters*. Publications of the Astronomical Society of the Pacific 77, 458, 336-346

Sawyer Hogg, H. (1981a). The Stars. *The David Dunlap Doings, 14, 1*, 13-14

Sawyer Hogg, H. (1981b). Forty Years with an Astronomy Column – Behind the Scenes View. *Cassiopeia, Vernal Equinox Issue*, 15-17

Sawyer Hogg, H. (1988). Shapley's ERA. In J.E. Grindlay & A.G.D. Philip (Eds.), The Harlow-Shapley Symposium on Globular Cluster Systems in Galaxies, *Proceedings of IAU Symposium No. 126*, 25-29 August 1986 (pp. 11-22). Dordrect: Kluwer Academic Publishers

Seaquist, E.R. (2006). Donald Alexander MacRae: a Memorial Tribute. *Cassiopeia 131 Winter Solstice*, 32-35

Shapley, H. (1930). Star Clusters, Harvard Observatory Monographs 2. New York—London: McGraw-Hill Book Company

Transactions of the Astronomical and Physical Society of Toronto for the Year 1894-1896 (TAPST) (1895-1897)

Wall, J.V., Chu, T.Y., & Yen, J.L. (1970). Measurements of Absolute Sky Brightness Temperatures at 320 and 707 MHz. *Australian Journal of Physics 23*, 45-57

Wall, J. (2009). The CMBR – How to Observe and Not See. In J.E. Peebles, L.A. Page, & R.B. Partridge (Eds.), *Finding the Big Bang* (pp. 280-288). Cambridge: Cambridge University Press

Wise, G. (2004). *Civic Astronomy: Albany's Dudley Observatory, 1852-2002*. Dordrecht: Springer

Websites

Department of Astronomy & Astrophysics, Helen Sawyer Hogg

www.astro.utoronto.ca/about/history/helen-sawyer-hogg/ *(accessed 2016 January 26)*

Dunlap Institute for Astronomy & Astrophysics, CHIME

www.dunlap.utoronto.ca/instrumentation/chime/ *(accessed 2015 November 18)*

Dunlap Institute for Astronomy & Astrophysics, Distant Radio Galaxies Reveal Hidden Structures Right Above Our Heads

www.dunlap.utoronto.ca/distant-radio-galaxies-reveal-hidden-structures-heads/ *(accessed 2015 November 18)*

Dunlap Institute for Astronomy & Astrophysics, DRAGONFLY

www.dunlap.utoronto.ca/instrumentation/dragonfly/ *(accessed 2015 November 18)*

Dunlap Institute for Astronomy & Astrophysics, Summer School

www.dunlap.utoronto.ca/training/summer-school/ *(accessed 2015 November 18)*

Dunlap Institute for Astronomy & Astrophysics, West African Summer School

www.dunlap.utoronto.ca/training/west-african-summer-school/ *(accessed 2015 November 18)*

Gemini Planet Imager Exoplanet Survey

planetimager.org/ *(accessed 2015 November 18)*

National Film Board (NFB), Universe

www.nfb.ca/film/universe/ *(accessed 2015 November 30)*

National Film Board (NFB), Colin Low, Colin Low: Recollections from a Distinguished Career—Universe

www.nfb.ca/playlists/colin-low-recollections-distinguished-career/viewing/universe *(accessed 2015 November 20)*

RASC, Eric Briggs, With the Stars

rasc.ca/with-the-stars *(accessed 2015 November 28)*

The DDO, RASC Toronto Centre

www.theddo.ca/ *(accessed 2015 December 8)*

Endnotes

1 The largest is the University of British Columbia's 6-metre liquid-mirror telescope, the Large Zenith Telescope, located in UBC's Malcolm Knapp Research Forest (first light 2003), and the third largest is the Dominion Observatory's 72-inch (1.83-m) telescope, at Saanich, B.C. (first light 1918).

2 The bulk of the items on display were drawn from the holdings of the Department of Astronomy & Astrophysics of the University of Toronto, with the remaining items coming from the collections of the Archives and Records Management Services (UTARMS) unit within the Department of Rare Books and Special Collections of the University of Toronto. Other artifacts from the University of Toronto era of the DDO were donated to the Canada Science and Technology Museum (CSTM) in 2008.

3 I owe this possibility to a suggestion of Dr. Dale Armstrong and colleagues of the London Centre of the RASC.

4 Her sense of rapprochement was shared with her mentor, Harlow Shapley.

A Brief History of Lunar Exploration: Part II

by Klaus Brasch
krbrasch@earthlink.net

> "*We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard.*"
>
> —John F. Kennedy, 1962 September 12

Introduction

The first part of this concise history of lunar exploration spans the pre-telescopic era to the early 19th century and the beginnings of scientific selenography (Brasch, 2015). It's important to appreciate that lunar observing, as well as most other facets of observational astronomy, was done primarily by amateurs at that time; often brilliant individuals, some of independent means, who literally dabbled in what was widely termed Natural Philosophy or *philosophia naturalis*. Some, like Cassini, Huygens, and the Herschels, had royalty or wealthy patrons for support, much like most musicians and artists at the time, and were in fact closest to what we consider professional practitioners today. The concept of Natural Science, based on observational, experimental, and verifiable evidence, emerged only gradually during the late 18th and early 19th centuries. By then, science had been formally subdivided into the life and physical branches and was practiced primarily at universities and other professional institutions (en.wikipedia, 2015a).

Selenology Matures

Thanks to Johann Schrőter's broad impact on so many aspects of observational astronomy, particularly in continental Europe, coupled with what was likely the 18th-century prime example of "aperture fever," he no doubt inspired many of his contemporaries to take up the baton. Although much criticism has since been levelled against Schrőter, mainly for some of his strange claims and ideas about changes on the Moon and that our satellite might be inhabited by intelligent beings, as we saw above, he was not alone in those regards. As Patrick Moore attests (Moore, 1963, p.57):

"The mantle of Schrőter fell upon three of his countrymen, Lohrmann, Beer and Mädler. All were clever draughtsmen as well as being good observers, and between them they explored every square mile of the Moon's visible surface—but it must be remembered that they had Schrőter's work to use as basis. The credit for founding the science of precise lunar observation must go to the Lilienthal amateur, and to him alone."

A professional surveyor and cartographer, Wilhelm Gotthelf Lohrmann (1796–1840) (Figure 1) brought those skills to selenography as well as a superb 4.8″ Fraunhofer achromatic refractor to generate the best and most accurate lunar charts up to that time (Figure 1). His resultant 1878 book titled *Topographie der sichtbaren Mondoberfläche* (Topography of the visible lunar surface), contained accurate descriptions of the methods used and results obtained, and can be regarded as the first modern dissertation on selenography (Kopal and Carder, 1974, p.29). Although Lohrmann had intended to produce a true topographic map using micrometric readings of some 79 selected surface features, he was plagued by poor health and sadly could not finish his planned large Moon map, which was not published until 1878, 38 years after his death by Johann Schmidt (1825–1884). Unlike Gruithuisen before him, Lohrmann was cautious and not subject to over-interpretation of what he saw. With regard to Gruithuisen, speculations that *Wallwerk*, in the Sinus Aestuum series of lunar rilles, might be the work of intelligent beings, Lohrmann stated "One must with great circumspection, under every condition of lighting, attend to this region if one hopes to depict it accurately" (Sheehan and Dobbins, 2001, p. 97).

Undoubtedly the title of most prominent 19th-century lunar cartographers rightfully belongs to the duo of Wilhelm Beer (1797–1850) and Johann Heinrich von Mädler (1794–1874) (Figure 1). Mädler, an excellent young student who enrolled at age 12 in the Friedrich-Werdersche Gymnasium in Berlin, was set on an academic career, but after a typhus outbreak claimed both his parents, he was left responsible for four younger siblings (Sheehan and Dobbins, 2001, p. 101). While studying to become an elementary school teacher to make a

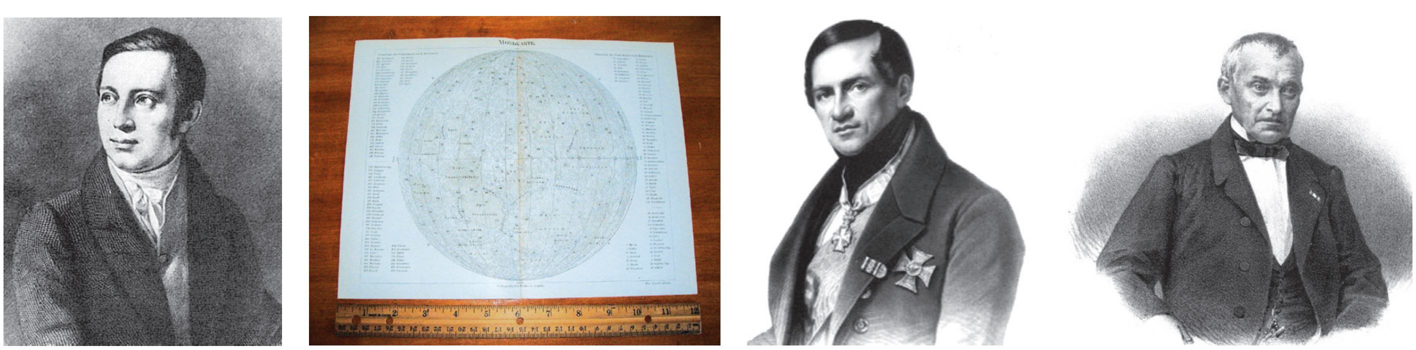


Figure 1 — W.G. Lohrmann (1796-1840); Typical Lohrmann Moon chart; W. Beer (1797-1850); J.H. von Mädler (1794-1874)

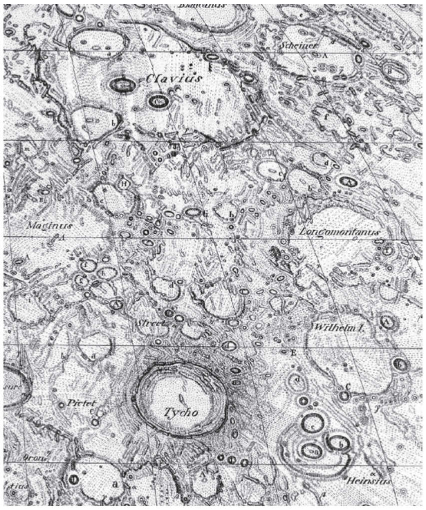


Figure 2 — An example of Beer and Mädler's superb Mappa Selenographica *(1896) (wikicommons)*

living, he also attended lectures at the University of Berlin. Beer, a wealthy Berlin banker, with the means and the interest to establish a private observatory in 1829, hired Mädler to tutor him in astronomy and work for him. Thus began a long and fruitful collaboration. Equipped with a 95-millimetre Fraunhofer refractor, both men were fully committed to mapping the Moon, although the science- and mathematics-educated Mädler was responsible for most of the actual observing and cartographic work. They set out to produce the first exacting lunar map and spent 600 nights carefully laying out a grid of surface reference points and measuring them micrometrically. The finished product (Figure 2) appeared in 1836 as Mappa Selenographica, an atlas fully one metre in diameter, which included 140 new feature names beyond those assigned by Hevelius, Riccioli, and Schrőter (Hockey, 1986). In 1837, Der Mond, a detailed description of the entire lunar surface was published, and both works remained unsurpassed in wealth of information for several decades (Kopal and Carder, 1974).

In addition to lunar work, Beer and Mädler also made detailed observations of Mars, making quite accurate determinations of its rotation period and selecting what is now known as Sinus Meridianis as the planet's prime meridian. In 1836, Mädler was appointed observer at the Berlin Observatory under Johann Encke, and in 1840 became director of Dorpat Observatory in Tartu, Estonia, home of the Great Fraunhofer refractor where he studied the planets, double stars, and the proper motions of stars (en.wikipedia, 2015c).

A staunch critic of Schrőter and his methodology, as well as Herschel and Gruithuisen's assumptions that our satellite was in any way similar to the Earth, Mädler maintained that the Moon was essentially airless, lacked any evidence of water and was most likely changeless (Moore, 1963). Thus, despite some erroneous conclusion of his own, including that the phases of the Moon and sunspots might influence our weather and that the centre of the galaxy was in the direction of the Pleiades, Mädler was one of the 19th-century's most eminent astronomers, as acknowledged by craters on both the Moon and Mars named in his honour. Beer, too, was honoured by a small lunar crater bearing his name.

With Beer and Mädler's seemingly definitive map of the Moon, coupled with the daunting realization that our satellite was probably a dead, airless, and lifeless desert, selenography went into temporary eclipse and was no longer considered fashionable astronomical work. As pointed out by Sheehan and Dobbins (2001) in a chapter entitled *Depression and Paralysis*, the latter half of the 19th century was a period of great change in both theoretical and observational science. Advances were being made on many fronts: astronomy, biology, and geology, and it was becoming increasingly difficult to rationalize biblically derived timelines for the origins and evolution of the Solar System, the Earth, and life itself.

The Rise of Evolutionary Thinking

Beginning with the Solar System, the first rational attempts at explaining its origin began in 1644 with French philosopher René Descartes's (1506–1650) (Figure 3) proposal that the Sun and planets formed through a force of vortices thought to permeate the Universe. As this idea preceded Isaac Newton, the laws of gravity were not widely understood. Almost a century later, in 1734, Swedish theologian and scientist, Emanuel Swedenborg proposed the so-called Nebular Hypothesis. This hypothesis was further developed in 1755 by the great German philosopher, Immanuel Kant (1724–1804) (Figure 3), wherein gaseous clouds or nebulae slowly rotate and collapse under gravity, eventually forming stars and planets.

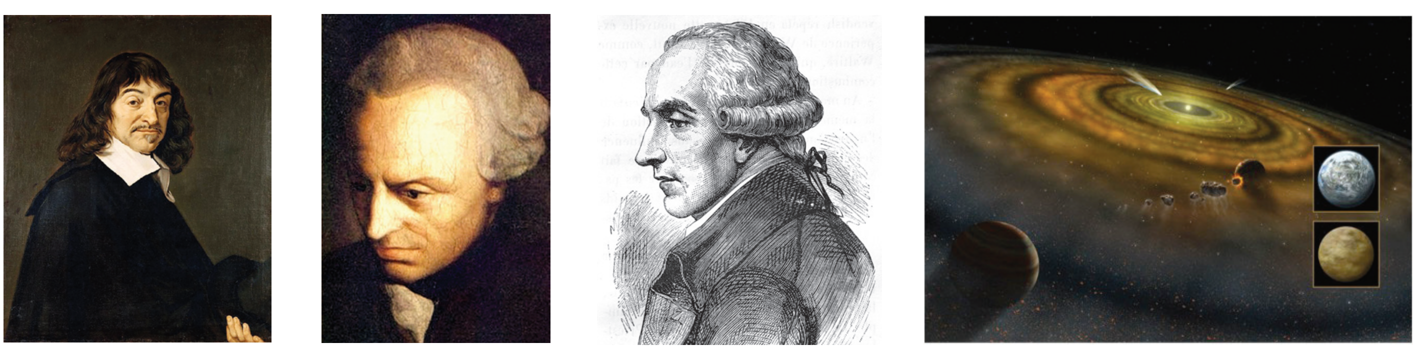


Figure 3 — René Descartes; Immanuel Kant; Pierre-Simon Laplace; Artistic impression of planetary formation (NASA)

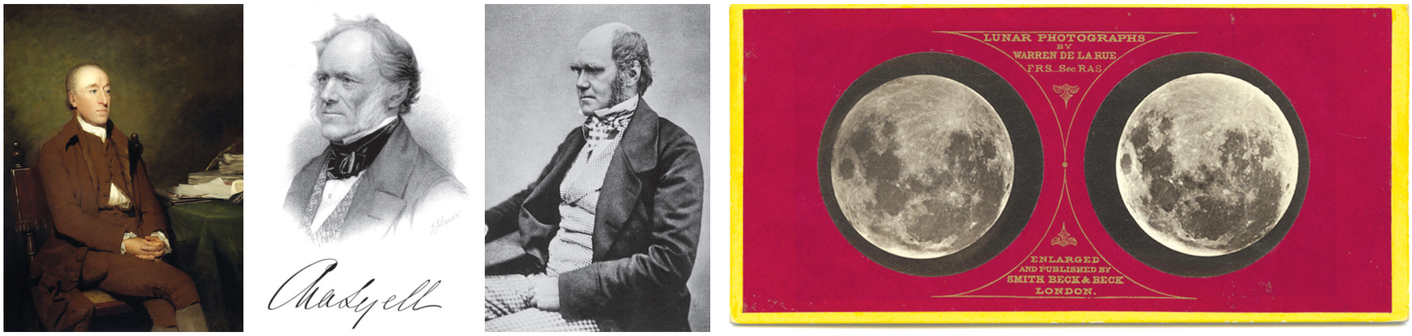


Figure 4 — James Hutton; Charles Lyell; Charles Darwin; Warren de la Rue's 1862 stereoscopic images of the full Moon

In 1796, French astronomer and mathematician Pierre-Simon Laplace (1749–1827) (Figure 3) took this a step further and proposed a protosolar cloud, which cooled and contracted, thereby spinning more rapidly and spinning off rings of gaseous material, which eventually condensed into the planets (en.wikipedia, 2015b). Though dominant until the beginning of the 20th century, this theory could not adequately account for the distribution of angular momentum between the Sun and planets and was largely abandoned. Finally, after considerable additional theoretical work, the birth of modern planetary formation theory emerged in the 1970s with Soviet astronomer Victor Safronov's solar-nebular-disk model or SNDM, and other modifications of the nebula hypothesis (Williams, 2010) (Figure 3).

Parallelling 17th- and 18th-century efforts for a scientific explanation of the origin of the Solar System, questions about the age and evolution of the Earth were also raised. Against a backdrop of flawed historic Aristotelian notions about the natural world and Bishop James Ussher's biblically based chronology that the Earth and humans were created in 4004 BC, Scottish physician James Hutton (1726–1797) (Figure 4) published a remarkable book, *Theory of the Earth* in 1795 (Tarbuck and Lutgens, 2011). This work established geology as a proper science and laid the fundamental principle of uniformitarianism as its foundation. Through careful observation and reasoned arguments, he showed that the Earth was shaped by the same physical, chemical, and biological forces that we see today. In short, erosion, sedimentation, weathering, mountain building, and related processes have worked gradually and over extremely long periods of time to shape our planet as it exists now. Hutton's work and later, Charles Lyell's *Principles of Geology* in 1830 (Figure 4) made it obvious to scientists that the Earth was extremely old by any measure, but they had no way of determining its true age. That had to await the discovery of radioactivity and radiometric dating at the turn of the 20th century.

Lyell's book, in turn, had a strong influence on Charles Darwin (1809–1882) (Figure 4) and the development of the theory of evolution, since it made clear that our planet is indeed very old, so old in fact that the gradual process of natural selection affecting all organisms clearly takes place against the background of an evolving planet as well. When published in 1859, Darwin's great book, *On the Origin of Species*, laid a solid scientific and unifying foundation for the life sciences, both in the context that all species have over time evolved from common ancestors in parallel with our ever-evolving planet. Thus, as the 20th century approached, major paradigm shifts were taking place in the natural sciences, pointing away from the heretofore orderly and divinely driven concept of the cosmos to one ruled by the impartial laws of physics and clearly random evolutionary forces.

The Impact of Photography

Another powerful development in the mid-1800s was the invention of photography (Ré 2014). As early as 1839, Louis Daguerre in France endeavoured to photograph the Moon, but the image was blurred. Though slow in initial development, lunar photography soon reached a point where it was no longer a mere curiosity. This was emphatically demonstrated by work like that of British astronomer Warren de la Rue's stereoscopic images in 1862 that exposed surface detail never before revealed (Figure 4). After the establishment of Lick Observatory in 1888 with its outstanding 36-inch refractor, director Edward S. Holden (1846–1914) undertook an extensive program of lunar photography. This resulted in publication of the *Lick Observatory Atlas of the Moon*, followed shortly after by publication in 1903 of the *Atlas Photographique de la Lune* by Maurice Leowy and Pierre Puisseux at Paris Observatory. This magnificent tour de force would remain a major reference for lunar studies until 1960 with publication by Kuiper et al. in 1960 of the *Photographic Lunar Atlas* (Hughes, 2013). Loewy and Puiseux used the unusual 23.6-inch *f*/30 Coudé refractor at Paris Observatory, specifically designed for lunar photography (Figure 5). To quote blogger Wayne Ford (2013) "What the French pair set out to accomplish was to map a larger extent of the moon's surface in astronomical detail than had been accomplished before; an achievement that would not be equaled for almost 60 years" (Figure 6). These attainments made it clear that henceforth photography would form the basis of objective and accurate lunar cartography, as it was free of individual bias, artistic license, and subjective interpretation.

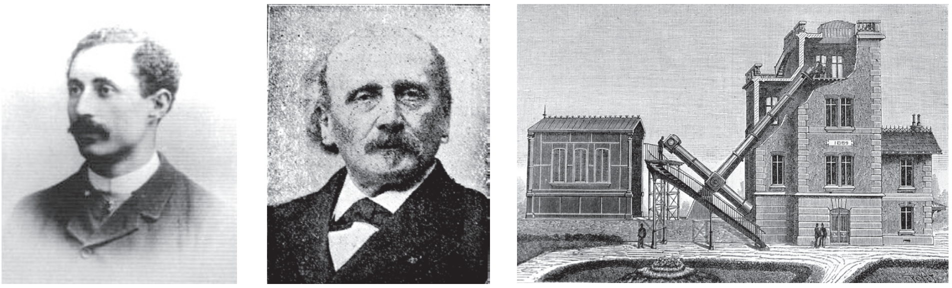


Figure 5 — Pierre Puiseux (1855-1928); Maurice Loewy (1833-1907); The 23.6-inch Coudé refractor at Paris Observatory ca. 1882 (from A. Fraissinet, La Nature, vol. 19, 1891)

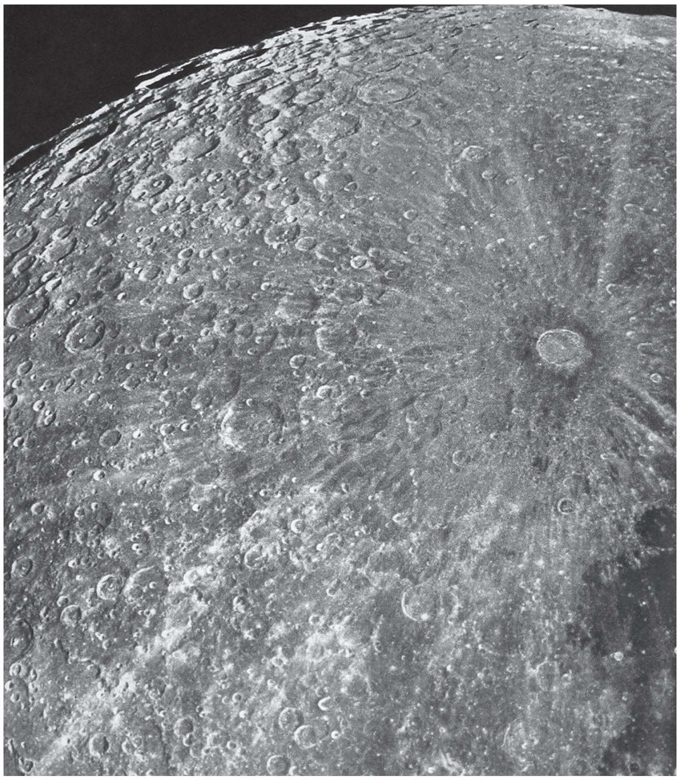


Figure 6 — Example of the outstanding images in the Atlas Photographique de la Lune by Loewy and Puiseux, published in 1899 at Paris Observatory. (public domain)

Selenography in the 20th Century

A number of observers undertook photographic and visual cartography of the Moon at the very turn of the century. Among them was Ladislav Weinek (1848–1913) at Prague Observatory, who used Lick and Paris plates as bases, to generate visual transcripts of selected lunar areas. At Harvard College Observatory, W.H. Pickering published his *Photographic Atlas of the Moon* in 1903, and in 1910 Walter Goodacre, who headed the Lunar Section of British Astronomical Association (BAA), published a Moon map nearly 2 m in diameter. Although laudable, most of these efforts either added little new detail or were not widely circulated because of high production costs, which made them unaffordable to many (Kopal and Carder, 1974). In short, the detail and definition of the *Atlas Photographique de la Lune* and the *Lick Observatory Atlas of the Moon* remained largely unequalled for decades to come.

In spite of great advances in photography at the start of the 20th century, visual observations and mapping of lunar features continued, since they could reveal finer detail than was possible with the grainy photographic emulsions of the day. It also meant that visual observers could rely on photographs for positional accuracy and to add finer detail not resolved on film. Moreover, the bulk of such work was undertaken by amateurs, who were not only eager to fill in details not evident on film, but also because many lunar features exhibit unusual and intriguing shapes and outlines under differing angles of illumination. In addition, many were intrigued by reports of so-called transient lunar phenomena (TLP), potential evidence

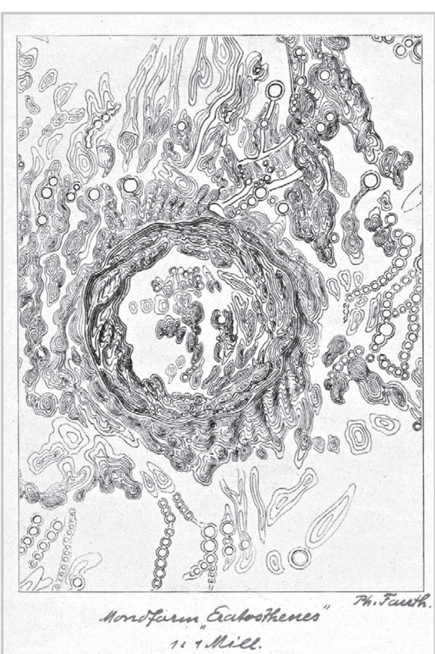


Figure 7 — Eratosthenes ; J. Krieger; P. Fauth; Gassendi

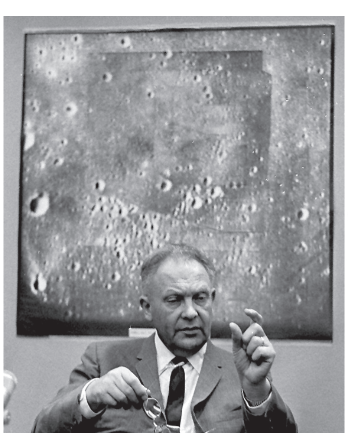
Figure 8 — H.P. Wilkins; Sir Patrick Moore; section of the 300-inch Wilkins Moon map showing crater Longomontanus at bottom left

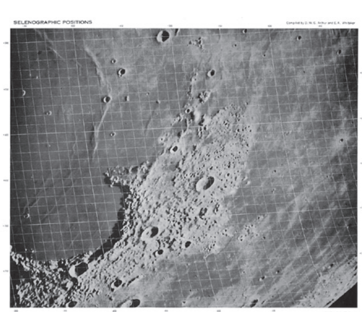
of latent volcanism, impacts by asteroids and meteors, or simply venting of subsurface volatiles, efforts that continue to this day, (see below: Does Anything Ever Happen on the Moon?) and e.g. (Haas, 1942; Wood, 2012; O'Connell and Cook, 2013).

Among leading early 20th-century selenographers were two German observers, Johann Krieger(1865–1902) and Philipp Fauth (1867–1941). Krieger (Figure 7) was a gifted visual observer and draftsman determined to produce a definitive map of the Moon. Using a fine 270-millimetre refractor and some of the best high-resolution lunar photographs from Paris and Lick Observatories as base, he would add fine visual detail with ink and graphite, resulting in some splendid and very artistic depictions of major craters and other features (Kopal and Carder, 1974). Sadly, due to frailty and failing health, he never finished his stated goal, but 28 of his finest images were later published as a *Mond-Atlas* in 1912. Like Kreiger, Fauth was also a gifted and meticulous draftsman who used photographs as a basis for adding details detected visually (Figure 7). He too intended to produce a definitive map of the Moon to a scale of 1:1,000,000, larger than any up to that point in time. In part because of Fauth's abrasive nature, his adherence to the bizarre theory advanced by Hanns Hörbiger of "glacial cosmogony," the rise of Nazi Germany and World War II, his dream of a lunar map never materialized. The map was finally finished; however, in 1964 by his son Hermann (Sheehan and Dobbins, 2001).

Among the most productive and successful mid-20th-century observational selenographers were British amateurs H.P. Wilkins (1896–1960) and Sir Patrick Moore (1923–2012) (en.wikipedia (2015d). Wilkins produced a 300-inch map of the Moon in 1951 (Figure 8) and a joint work with Moore in 1955, *The Moon; A Complete Description of the Surface of the Moon: containing the 300-inch Wilkins Map* (Wilkins and Moore, 1955). Though revised in 1961, the work was criticized for its cluttered and frequently erroneous depiction of several lunar features (Kopal and Carder, 1974, Wikipedia (2015h). By that time as well, advances in lunar photography and publication in 1960 by Kuiper et al., of the *Photographic Lunar Atlas* (Kuiper, et al, 1960), rendered it largely obsolete.

The *Photographic Lunar Atlas*, a milestone in pre-space age efforts at lunar mapping, was initiated by renowned Dutch-American astronomer Gerard P. Kuiper (Figure 9), also of Kuiper Belt fame, among many other honours. The atlas was based on enlargements of the best available photographs from Lick, Mt. Wilson, McDonald, Pic du Midi, and Yerkes observatories; and combined the work of numerous astronomers. It contained some 281 illustrations, many under different conditions of illumination and on a scale of 1:370,000. This atlas was subsequently overlaid with accurate lunar co-ordinates (Figure 9) and published as the *Orthographic Atlas of the Moon* (Arthur and Whitaker (1962), and later as the *Rectified Lunar Atlas* (Whitaker et al. 1963) projected unto a sphere (Figure 9). Among many other revelations, this technique pioneered by Kuiper's student, William K. Hartmann (Figure 9) provided the first unequivocal evidence of the huge lunar impact basin, Mare Orientale. With arrival of the space age, therefore, professional interests in lunar cartography and geology were rekindled.





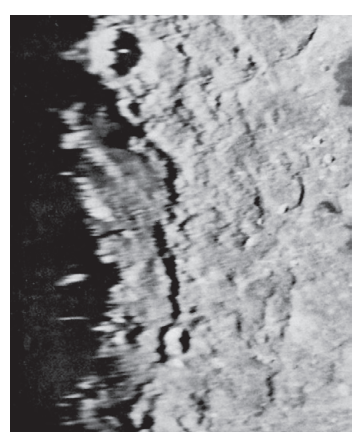


Figure 9 — G.P. Kuiper and a typical orthographic atlas image; W.K. Hartmann compiling the rectified lunar atlas in 1961 showing the edge (Right) of Mare Orientale before the far side of the Moon was seen. (W.K. Hartmann)

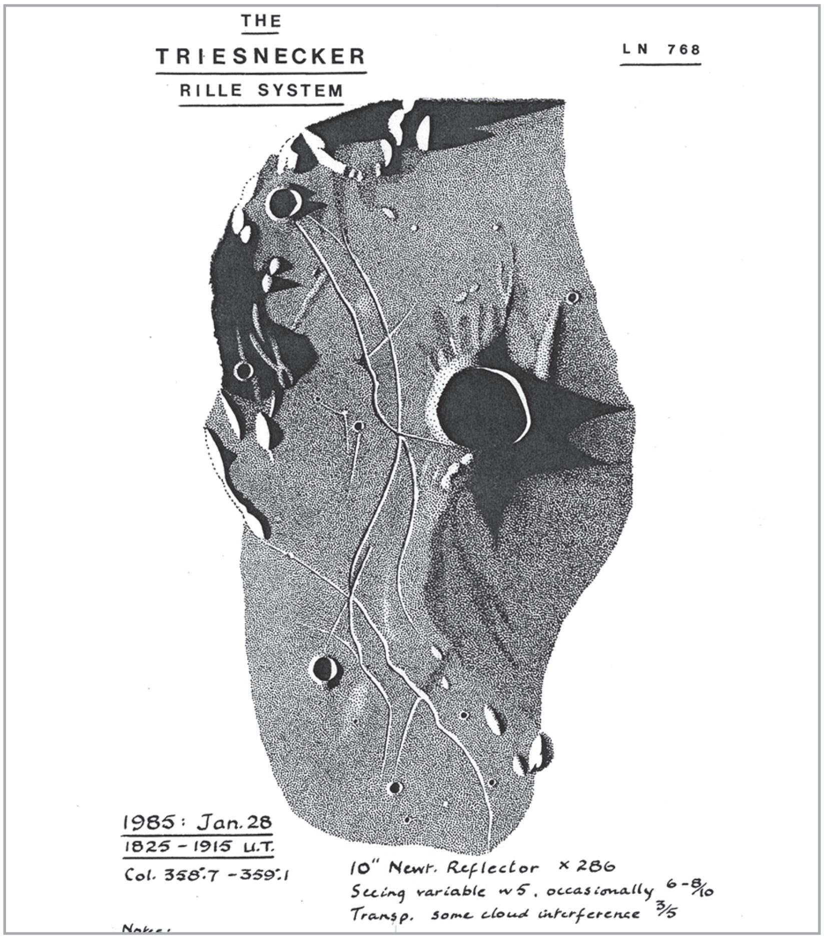
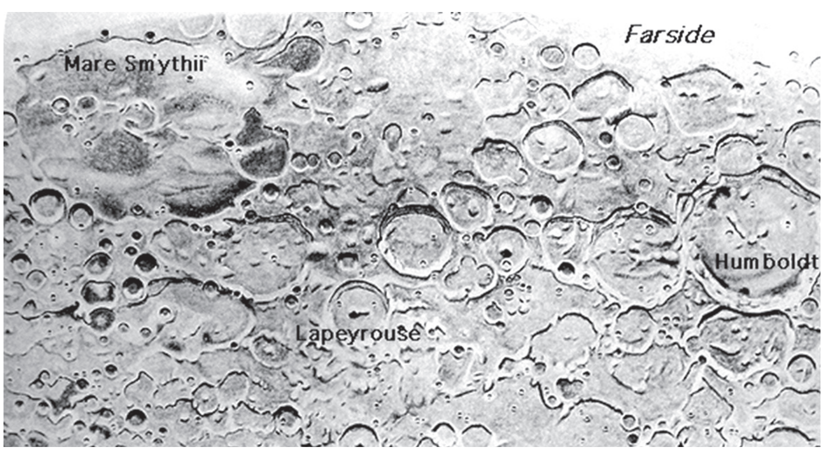


Figure 10 — Above left: Harold Hill in his observatory (ca 1990) and (top) one of his superb lunar sketches (courtesy R. Baum): Above right: Alika Herring and (below) one of his realistic renditions of the lunar surface (ca 1965)



At least two other noteworthy 20th-century visual lunar cartographers were British amateur Harold Hill (1920–2005) and American Alika K. Herring (1913–1997). While relatively unknown today (Strach and Baum (2006)), Hill combined great artistry with photographic accuracy in his cartographic work (Figure 10), culminating in his *Portfolio of Lunar Drawings* (Hill, 1991). A meticulous observer, he developed a unique, stippling-enhanced drawing style, that elegantly combined accuracy and artistry.

Talented telescope-maker for the renowned firm of Cave Optical in California, Alika Herring was an exceptional amateur lunar observer and a prominent member of the association of Lunar and Planetary Observers (Figure 10). His compelling lunar drawings graced many issues of *Sky & Telescope* magazine in the 1950s and '60s, and, because he was so good at his craft, he was hired in 1960 by the recently founded Lunar and Planetary Laboratory in Tucson, Arizona, to help produce charts for the newly announced Apollo mission.

In the half-century or so before the space program, studies of the Moon and planets were largely abandoned by professional astronomers in favour of galactic astronomy and astrophysics. Although amateurs partially filled that vacuum, and a handful of professional observatories, notably Lowell, Pic du Midi, and Yerkes, maintained lunar and planetary programs, huge knowledge gaps remained (Brasch, 2016). All that changed, however, with the advent of the space program. In addition to establishment of the Lunar and Planetary Lab, the recently formed National Aeronautics and Space Administration (NASA) and U.S. Air Force funded the International Planetary Patrol Program at Lowell Observatory, the USAF Aeronautical Chart and Information Center (ACIC), and US Army Map Services (AMS) funded a massive effort to produce a series of high-resolution Lunar Aeronautical Charts (LAC) (Kopal and Carder, 1974; The Moon (2011)).

Initiated in 1959, the LAC effort was headed by ACIC cartographer Howard Holmes, and the Lowell Observatory office was established in 1961. The latter encompassed a team of cartographers, observers, and airbrush specialists, including William Cannell, James Greenacre, Patricia Bridges, Ewen Whitaker, Fred Duncan, Jay Inge, and Edward Barr (Kopal and Carder, 1974). The

Continued on page 72

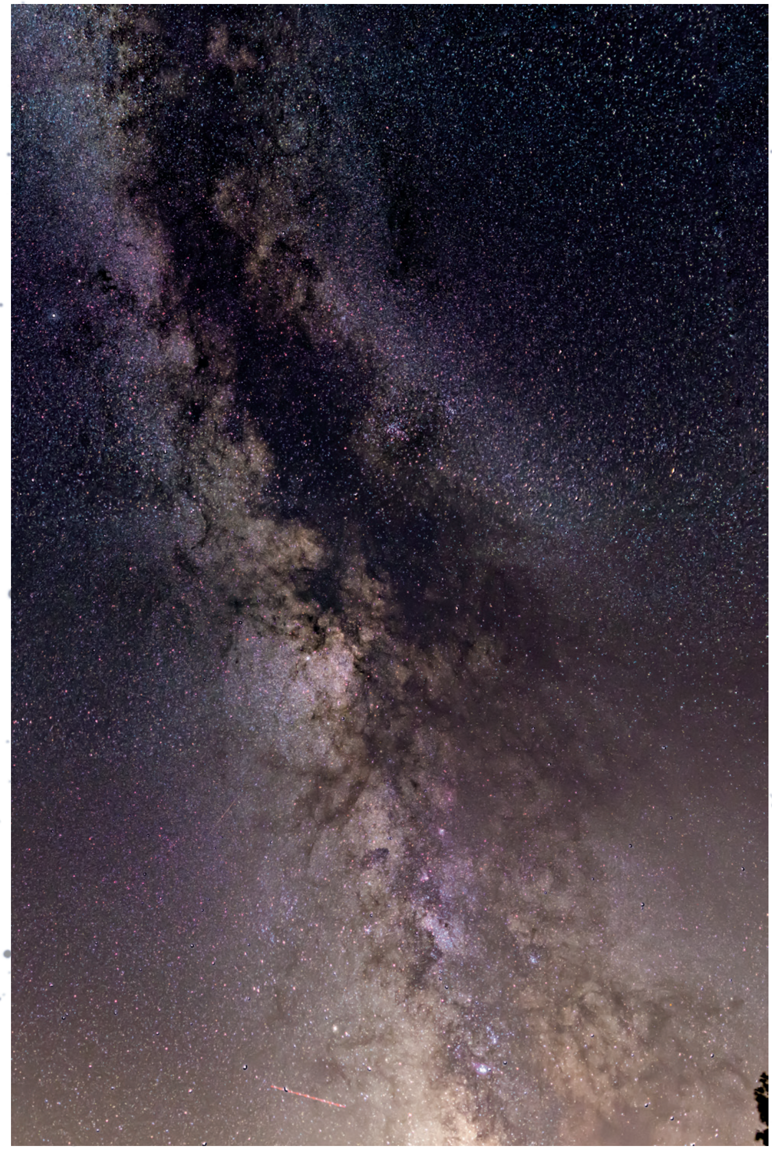


Figure 1 — Joe Gilker originally shot this image in August 2014 at the Lennox and Addington Dark Sky Viewing Area in Erinsville, Ontario. It was one of his earliest attempts at photographing the Milky Way and he recently revisited the data he collected using his accumulated processing skills since then. Gilker used a Nikon D7000 with a Nikkor 35-mm lens at ƒ/1.8 and an iOptron SkyTracker. The image is a cropped panorama of 6 × 30-second exposures shot at ISO 2000.

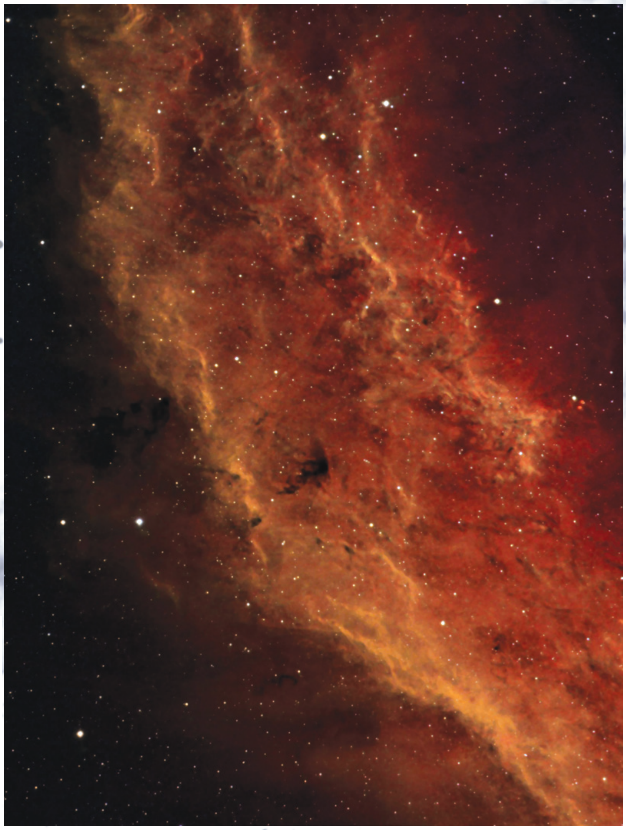


Figure 2 — The beautiful California Nebula (NGC 1499) was imaged by Dan Meek in November 2015 in Calgary. Meek used a Tele Vue NP127 telescope and a QSI583wsg CCD camera for a total of 5 hours.

Figure 3 — Accomplished astrophotographer Ron Brecher imaged one of his favourite targets, globular cluster M5 from his SkyShed in Guelph, Ontario. Brecher used an SBIG STL-11000M camera, Baader LRGB filters, 10″ ƒ/6.8 ASA astrograph, MI-250 mount, and guided with STL-11000's internal guider.

Figure 4 — François Thériault imaged the Monkey Head Nebula in narrowband from the Genesis Observatory, Moncton, New Brunswick, early this year. He used an AstroTech AT72ED with an SBIG ST8300M and a Starshoot autoguider.

Continued from page 69.

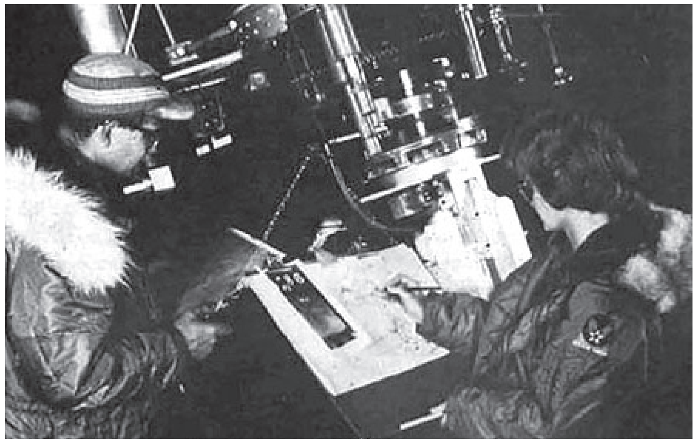
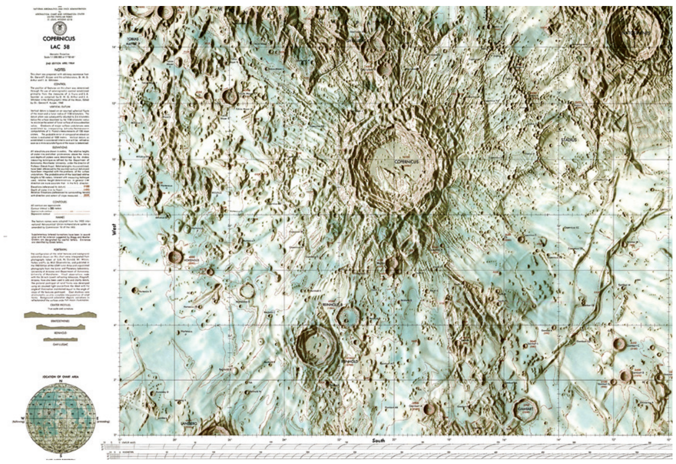


Figure 11 — Left, 24-inch Clark today (Lowell Observatory); Cannell and Bridges at the Clark ca 1960,(Kopal and Carder); bottom left: LAC-58 (Copernicus) 1964 (USGS)



final Lunar Aeronautical Charts were based on over 12,000 of the best lunar photographs and film images obtained at various institutions, and supplemented by visual observations with the 24-inch Clark refractor (Figure 11). Thanks to these visual additions, many of the charts included surface detail as small as 200 metres (St. Clair et al., 1979).

Does Anything Ever Happen on the Moon?

In 1942, a young American amateur astronomer, Walter Haas (1917-2015), the future founder of the Association of Lunar and Planetary Observers (ALPO), pondered the foregoing question in an extensive review article (Haas, 1942). He was not the first student of our Moon to pose this question, of course, but did it at a time when reports of extensive, visible changes on the lunar surface were relatively frequent.

I well recall as a newly minted teenage astronomy enthusiast joining the Montreal Centre of the RASC in 1958, and being immediately contacted by Geoffrey Gaherty, who asked me if I wanted to join the Centre's Lunar Meteor Section. Despite having absolutely no idea what that was, I agreed, and Geoff and I remain friends to this day. The idea at the time was that, since the Moon is most likely bombarded by meteors just like the Earth, perhaps it was possible to spot such events by examining the very new and old Moon telescopically when its bright crescent is thin and earthshine most prominent. Moreover, only multiple observers seeing such an event simultaneously would have any credence. We were fully aware even then, that our satellite had no measurable atmosphere and only a truly major meteoric event might be spotted from Earth with small telescopes. Still we persisted for several years, often under frigid winters and mosquito-ridden Montreal summers, ultimately to no avail of course.

Our enthusiasm for such transient lunar phenomena (TLPs) or lunar transient phenomena (LTPs), was fueled by a sensational 1958 November 2 report by Russian astronomer, Nikolai Kozyrev, that he had observed an apparent eruption on the central peak of the prominent crater Alphonsus (en.wikipedia, 2015e; Wood, 2012). Using a 122-centimetre reflector, he also obtained spectra during the half-hour event, and reported a marked brightening of the central peak. He also claimed observing bright gaseous emission lines in the spectra due to C2 and C3 molecules. Although largely discredited since, this report nonetheless drew renewed attention to the possibility that things might indeed happen on the Moon.

A far more credible TLP report followed a few years later on 1963 October 19 (O'Connell and Cook, 2013). James Greenacre and Edward Barr, two of the AICI cartographers observing with the 24″ refractor at Lowell Observatory, reported distinct red colouration inside the crater Aristarchus and along Schrőter's Valley. Although this event has been attributed by some to atmospheric dispersion and probably accentuated in an achromatic refractor (Sheehan and Dobbins, 2001), it did arouse major new interest in TLPs. Sporadic TLP reports by several professional and amateur astronomers followed, and seem to fall into the following classes: outgassing, impact events, electrostatic phenomena, and illusory factors caused by bad seeing conditions and atmospheric effects (en.wikipedia, 2015e, Wood, 2012). Clearly what is needed at this point to tackle this issue are systematic and coordinated observing programs, using not just visual methods but also now commonly available webcam and CCD technologies. Fortunately, organizations like the Association of Lunar and Planetary Observers and the British Astronomical Association are doing just that. ✶

Note: The author is grateful to Richard Baum and William K. Hartmann for providing photographs, images, and special insight for this article.

Klaus Brasch is a retired bio-scientist and a public program volunteer at Lowell Observatory. He first joined the RASC in 1957 and has been an avid amateur astronomer ever since. A frequent contributor to JRASC, SkyNews *and* Sky & Telescope, *he enjoys astrophotography from his observatory in Flagstaff, Arizona.*

References

Arthur, D.W.G. and Whitaker, E.A. (1962) *Orthographic Atlas of the Moon-Supplement Number One to the Photographic Lunar Atlas*.

Baum, R. (2010) Harold Hill and the South Polar Region of the Moon. *J. Br. Astron. Assoc. 120, 2,* 86-97.

Brasch, K. (2015) A Brief History of Lunar Exploration: Part I, *JRASC 109*, 251-260.

Brasch, K. (2016) The Dawn of Global Planet Watches, *Sky & Telescope, 131, 3*, 52-54.

en.wikipedia (2015a) https://en.wikipedia.org/wiki/Natural_science

en.wikipedia (2015b) http://en.wikipedia.org/wiki/Nebular_hypothesis

en.wikipedia.org/wiki/Johann_Heinrich_von_Mädler

en.wikipedia (2015d) https://en.wikipedia.org/wiki/Hugh_Percy_Wilkins

en.wikipedia (2015e) http://en.wikipedia.org/wiki/Transient-lunar-phenomenon

Fisher, C. (1943) *The Story of the Moon*, The American Museum of Natural History Series, Doubleday, Doran and Company, Inc., Garden City, NY, USA.

Ford, W. (2013) http://wayneford.tumblr.com/post/45762409460/atlas-photographique-de-la-lune-loewy-and

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

Hill, H. (1991) *A Portfolio of Lunar Drawings*, Cambridge University Press, Cambridge, UK.

Hughes, S. (2013) *Catchers of the Light: A History of Astrophotography* www.catchersofthelight.com/

Kopal, Z. and Crader, R.W. (1974) *Mapping of the Moon, Past and Present*, R. Reidel Publishing Company, Dordrecht, Holland.

Kuiper, G.P., Arthur, D.W.G., Moore, E., Tapscott, J.W., and Whitaker, E.A. (1960) *Photographic Lunar Atlas Based on Photographs Taken at the Mount Wilson, Lick, Pic du Midi, McDonald and Yerkes Observatories*.

Moore, P. (1963) *Survey of the Moon*, Eyre & Spottiswoode, Ltd., London, UK.

O'Connell, R. and Cook, A. (2013) Revisiting the 1963 'Aristarchus events,' *J. Brit. Astron. Assoc. 123, 4*, 197-208.

Ré, P. (2014) First Lunar Maps http://astrosurf.com/re

Sheehan, W. and Baum, R. (1995) Observation and inference: Johann Hieronimous Schroeter, 1745–1816, *J. Brit. Astron. Assoc. 105, 4*, 171-175.

Sheehan, W. and Brasch, K. (2013) The "Loch Ness" of Venus, *SkyNews, 19*, 36-37.

Sheehan, W.P. and Dobbins, T.A. (2001) *Epic Moon*, Willmann-Bell, Inc., Richmond, VA.

Strach, E.H. and Baum, R.M. (2006) Harold Hill (1920–2005) *J. Br. Astron. Assoc. 116, 4*, 203–204.

St. Clair, J.H., Carder, R.W., and Schimmerman, L.A. (1979) United States lunar mapping - A basis for and result of project Apollo. *Moon and Planets, vol. 20*, Apr. 1979, p. 127-148.

Tarbuck, E.J. & Lutgens, F.K. (2011) *Earth: an introduction to physical geology*, Prentice Hall, New Jersey, USA.

The Moon (2011) https://the-moon.wikispaces.com/History+of+the+LAC+maps

Whitaker, E.A., Kuiper, G.P., Hartmann, W.K., and Spradley, L.H. (1963) *Rectified Lunar Atlas*, University of Arizona Press, Tucson, AZ.

Whitaker, E.A. (1989) Selenography in the seventeenth century, chapter 8 in: *The General History of Astronomy*, vol. 2, Planetary astronomy from the Renaissance to the rise of astrophysics, René Taton and Curtis Wilson eds., Cambridge University Press, UK.

Williams, M. (2010) www.universetoday.com/77525/nebular-theory/

Wood, C.A. (2012) Transient lunar phenomena and the modern understanding of the Moon in: *The Moon, Vol. 2*, 36–42, BAA Lunar Sectio.

Astronomy Outreach (and Observing) in Cuba: Trip Five

by David M.F. Chapman, Halifax Centre
(dave.chapman@ns.sympatico.ca)

Preamble

For my wife and me, no two trips to Cuba have been alike, and the November 2015 trip was different again. The history of our previous Cuba trips with outreach components has been completely documented in the *Journal* (Chapman 2010, Chapman 2011, Chapman 2012, Chapman 2014). In 2015, we headed to a new region for us: Santiago de Cuba province, far to the southeast, a few tens of kilometres west of the infamous Guantanamo Bay [US] Naval Base. The purpose of this trip was almost entirely vacation, but I did a little observing, a little astrophotography, and a little outreach, enough to warrant a report.

Observing

There is nothing like going to the Caribbean for some heat and Sun in the cool, grey, damp weather offered by the month of November in the Maritimes. October is lovely at home, and December has its charms, but November is a month to travel south! The thought of viewing the late autumn and early winter sky in shorts and a T-shirt is compelling, although Caribbean nights can be humid and hazy at sea level. Nevertheless, I did manage a couple of nights of observing and photography under the dark night sky. Observing from latitude 20º N reveals a wealth of objects we would never see from Canada, including (if you go in the right season) Crux, the Southern Cross (for which November is NOT the right season).

For the first week, we chose a modest all-inclusive resort, Club Amigo Carisol Los Corales, which is essentially within *Parque Nacional la Baconao*, where there is very little development, and the skies are intrinsically dark, apart from the local glare of resort lighting. This is the bugaboo of going to resorts: the light trespass and glare is usually awful (even in so-called eco-resorts). At this resort, though, I was able to drag a lounge chair down the beach and find a spot with vegetative screening, good enough to observe and photograph the southern sky unhampered. I mention the name of the resort only because it is a handy trip from cities such as Montréal and Toronto, just a short direct flight to Santiago de Cuba, followed by about an hour on a bus (not so handy from Halifax).

Figure 1 — My observing site in Santiago de Cuba province: Club Amigo Carisol Los Corales.

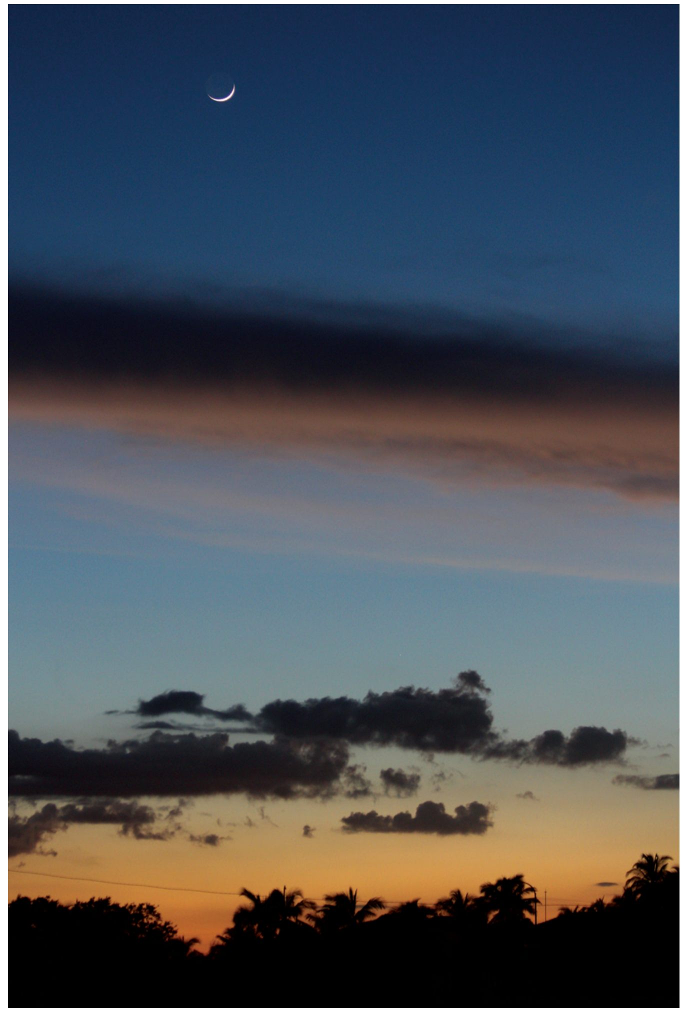


Figure 2 — The 2-day-old crescent Moon, 2015 November 13 (Saturn is just above the dark clouds at the bottom, but it may not reproduce).

I did not take a telescope, but carried an inexpensive pair of 15×70 binoculars, the kind that frequently go on sale for about $50 at a well-known home and auto store. Part of my plan was to leave them behind in Cuba, but we'll come to that. I also took my 12×36 image-stabilized binoculars that I always carry with my camera gear—I did NOT leave those behind! Before the trip, my friend and veteran observer Chris Beckett (Regina) sent me a list of 18 binocular objects I might enjoy from that latitude in November, based largely on Alan Dyer's "The Messier Catalogue" and "The Finest NGC Objects" from the *Observer's Handbook 2016*, and Chris's own "Wide-Field

Figure 3 — Orion and Sirius rising, with Sirius reflected in the sea (foreground illumination courtesy of resort light trespass).

Figure 5 — Outreach at the Natural History Museum, Santiago de Cuba. L–R: Isabel Nuñez, Eduardo Matos, the author, two unidentified staff members. The binoculars and Handbook are gifts from the RASC.

Wonders" list. I included a few objects from Alan Whitman's "Southern Hemisphere Splendours," and I spent the flight to Cuba gathering these into a personalized observing list in *SkySafari* on my iPad (this allows one to highlight the object on the display, easily record the date and time of observation, and make observing notes).

Figure 4 — Dark skies above, distant thunderclouds below.

The first clear night, I actually did some photography with my Canon Digital Rebel SL1, first capturing the young crescent Moon with my zoom telephoto in the twilight, then shooting some nightscapes with a borrowed 24-mm *f*/2.8 wide-angle lens. I got a few shots of Orion and Sirius rising, that sort of thing, just using my camera on a tripod at high ISO and 10-30-second exposures. True confession: I took my MusicBox EQ mount for tracking, but forgot the ball-head mount. Then I went to bed, and rose in the wee hours to see the southern "winter" Milky Way and the morning planets. There were some distant thunderclouds over the ocean, with frequent lightening flashes, but the sky overhead was clear and dark.

The following night, I left my camera behind and just observed. I slept until 2 a.m., and then I went out. With both sets of binoculars, a judiciously placed lounge chair, my iPad in red-screen mode, and a towel (to drape over my head), I was all set to go! First up was the constellation of Orion, on the meridian with its lovely nebulae and star fields, then down to Lepus, Canis Major, Puppis, and eventually to Vela, with globular clusters and open clusters galore. No Crux at this time of year, but I did spy the "False Cross" in Vela, a 4-star asterism that many mistake for the real thing. I must confess that I do not have the stamina to observe for a long time from home in winter, so being able to relax in comfort on a beach chair and gaze in "summer" clothes was quite a treat. I did not find all the objects on my observing list, but most of them, and I "discovered" a few that I added to my observing list as the night proceeded (I am happy to share this *SkySafari* list with anyone who asks me).

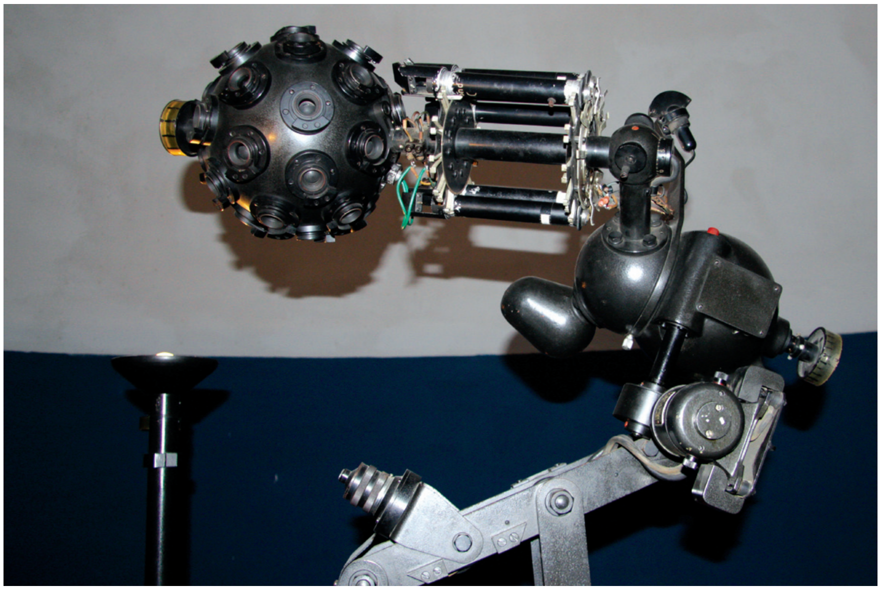


Figure 6 — The Carl Zeiss (Jena) planetarium projector (possibly model ZKP 1) in the Natural History Museum, Santiago de Cuba.

Figure 7 — Young Cuban amateur astronomers David and Marcos Mesa, observing the Sun in Havana.

I'd like to share an interesting story about a beautiful binocular double star in Vela, *Suhail al Muhlif* (γ Velorum), the 33rd-brightest star in the night sky. The star has multiple components, the brightest two having magnitude 1.8 and magnitude 4.3, separated by 41″. Confusingly, it is the brightest star in Vela, but (sadly) not observable from Canada, at declination –47º. From the *SkySafari* notes on that star: "Gamma Velorum also has the more modern popular name Regor, which is 'Roger' spelled backwards, and honors the Apollo astronaut Roger Chaffee. It was originally inserted onto NASA navigational star charts by fellow astronaut Gus Grissom as a practical joke, but has since endured as a memorial to both astronauts, who died in the 1967 Apollo 1 fire."

Outreach

During the second week of our vacation, we stayed in the city of Santiago de Cuba, at a nice 5-star hotel. We spent the mornings exploring the city and environs for a few hours, and the afternoons by and in the pool. Evenings we would go out for dinner, and a couple of times we went to some music venues (several members of the Cuban group *Buena Vista Social Club* came from there). Santiago de Cuba is the second-largest city in Cuba, and somewhat of a rival city to Havana: their baseball teams compete, and the inhabitants try to outdo each other in some ways. We decided to take home some duty-free Cuban rum (but we just bought it in the local shop, as there is no discount at the duty-free store). I had picked out some Santiago de Cuba rum, and was reaching for the Havana Club, when the shop assistant shook her head, and insisted I should only take the local rum!

As for the outreach component of this trip, it was brief, but (I believe) influential. My *Habanero* friend Alejandro (who we did not see this trip, owing to the distance) put me in touch with another Cuban amateur astronomer named Eduardo Matos, who works at the Natural History Museum in Santiago de Cuba. The museum was easy to find, so we dropped in one day to ask for Eduardo. Suspecting that the receptionist would not speak English, and knowing that my Spanish is almost nonexistent, Alejandro coached me to ask for Eduardo by name, and if that did not work, to ask for "*el hombre con telescopio*," the man with the telescope. I wrote that on the back of my RASC business card, and it worked! Eduardo had spent some time in the US, and he had pretty good English, so we got on well. That first day, we did not stay long, but we arranged to come back two days later, taking away (on loan) the observing logbooks of two young Cuban boys who were working through *Exploridad el Universo*, the Spanish-language, Cuban version of the RASC observing program, Explore the Universe.

On the second visit, I brought the 15x70 binoculars to leave behind, and two copies of the *Observer's Handbook 2016*, hot off the press (one for Alejandro). We also had a demonstration of the small, working planetarium, where our meeting was held in air-conditioned comfort. We met a few other staff, including the international relations specialist Isabel Lora Nuñez—as usual, I had totally ignored protocol by contacting Eduardo directly! I returned the boys' logbooks, which were very thorough and profusely illustrated, and we had a discus-

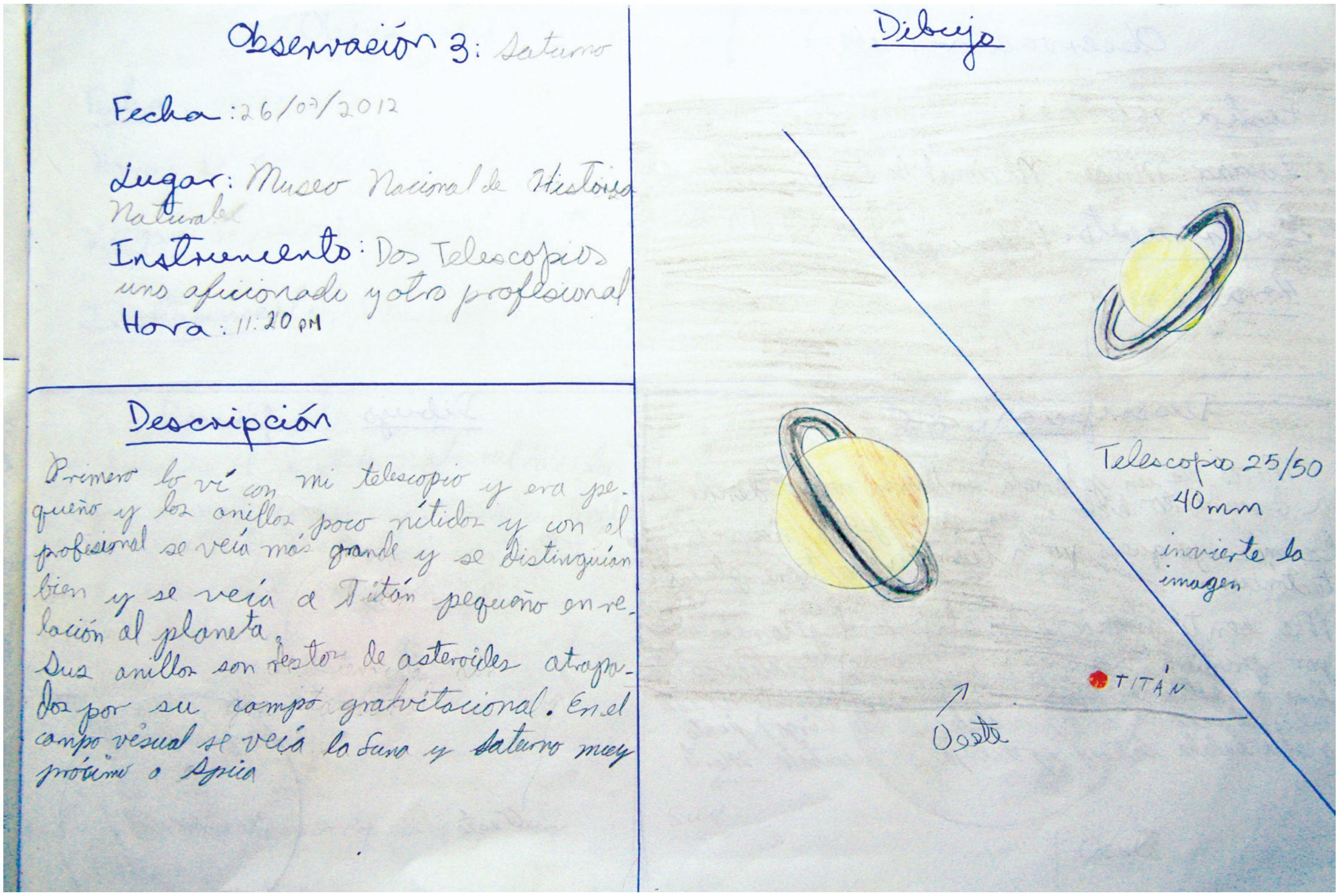


Figure 8 — A page from David Mesa's logbook for the observing certificate Exploridad el Universo*, the Spanish-language version of the RASC Explore the Universe observing program.*

sion about promoting the program locally. When the staff heard that *Exploridad el Universo* was popular in and around Havana, they became quite interested in the program, fueled in part (no doubt) by the previously mentioned inter-city rivalry. At this point, I made a bit of a show of presenting the binoculars and Handbook to the Museum to aid in the endeavour. Although I did not have high expectations for my meeting with Eduardo, I feel the outcome was more than satisfactory. I am certain that we'll see more Cuban names on the RASC EtU webpage in the future!

The Future

Speaking of the future, it is hard to foresee. Relations are warming between Cuba and the U.S., and one sees increasing numbers of U.S. citizens visiting Cuba. As a result of my visits there and my reports to this *Journal*, at least one U.S. amateur astronomer has been inspired to travel there to conduct telescope-making workshops. Also, restrictions on foreign travel by Cubans have eased somewhat, to the extent that about half of the Cuban amateur astronomers I met are now living in the U.S., although I do not know how permanent those arrangements are. I hope to continue my visits to Cuba and maintain my friendships there, but the political and social climate is changing rapidly. I believe the RASC is highly regarded by the Cuban amateurs and will continue to be so. My dream is to help the Cubans set up a Dark-Sky Preserve one day. ✶

References

Chapman, David M.F., 2010. Astronomy Outreach in Cuba: My Adventure. *JRASC, 104*, p. 232–235, December.

Chapman, David M.F., 2011. Astronomy Outreach in Cuba: Trip Two. *JRASC, 105*, p. 195–196, October.

Chapman, David M.F., 2012. Astronomy Outreach in Cuba: Trip Three. *JRASC, 106*, p. 99–103, June.

Chapman, David M.F., 2014. Astronomy Outreach in Cuba: Trip Four. *JRASC, 108*, p. 6–8, February.

Help the One Organization Dedicated to Protecting Dark Skies

Bob Gent, Past President, International Dark-Sky Association
Past President, The Astronomical League

Do you enjoy a beautiful night sky? Well of course you do, or you wouldn't be receiving a copy of this magazine. Have you ever spent money on our hobby? I am guessing the answer is yes. In my case, I have built an observatory, and I have bought a lot of telescopes and other astronomical equipment. The point is that many of us spend a lot on astronomy.

If we are spending money on astronomy, then shouldn't we also be helping the one organization that protects our night sky? There is only one organization totally dedicated to night-sky protection: the International Dark-Sky Association.

Of the many thousands of people who are amateur astronomers, how many are members of the International Dark-Sky Association? This is the really shocking answer: very few, perhaps less than a few hundred. Do you find this distressing? Well, I for one find it unbelievable and profoundly disappointing.

We are all facing a global emergency. It's the explosion of bad LED lighting. These are high glare and overly bright street lights, parking lot lights, and a rapid installation of thousands of new LED signs and billboards. Many do not comply with IDA's newly updated Fixture Seal of Approval program. Thank goodness, IDA is leading the charge to help us.

When it was time to update our light-pollution codes to fight these newly emerging threats in Sierra Vista and Cochise County, Arizona, we turned to IDA. They have developed vast amounts of reference materials, such as their Practical Guide series, and so much more. Without the groundwork completed by IDA, we would have had to start at ground zero. Thanks to IDA, defending our night skies is possible.

If we don't care enough to join IDA, who will? Sometimes it's tough to quantify what one gets for joining a nonprofit organization like IDA. As the only organization dedicated to preserving the beauty of our night skies through improved outdoor-lighting practices, IDA provides simple, low-cost solutions to the problems of energy waste, glare, light trespass, wildlife disorientation, and destruction of the night skies.

IDA is making a huge difference. Much has been accomplished, and the word is getting out. Better lighting is appearing in many locations. Better lighting fixtures are being developed and these will improve as time goes on. In addition, IDA has forged new alliances with groups like the Illuminating Engineering Society (IES). They set de facto lighting standards with their recommended practices. Several of the IDA board members are IES members.

The United States National Park Service greatly appreciates the work of IDA. They now recognize that poorly designed outdoor lighting is a serious threat to the nighttime environment at parks. They understand that the beauty of a magnificent, star-filled sky is a precious treasure that should be protected.

None of this is cheap. Running an office, paying staff members (IDA now has four full-time employees), covering utilities, supplies, insurance, rent, printing, postage, and many other expenses is quite costly. This is why your membership is critical. You are helping us help everyone in the battle to save our night skies. In addition, there is strength in numbers, and IDA leverages your support around the globe.

How much is it worth to preserve the beauty of our night skies? To conserve energy? To promote quality outdoor lighting to reduce glare and light trespass? Never before has there been such a good solution to a difficult problem. To me, membership in IDA is priceless, but it only costs $35 per year. Please help IDA by joining now. You would be doing a great service to all. Go to darksky.org/newmember and click join. ✶

Detecting Flyovers

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

I tried a couple of mobile applications to monitor flyovers of the *International Space Station* as well as other satellites. I even used the one by the developer of the Heavens Above website. The app I like the best for the Android platform is *ISS Detector* by Runar Skaret. The version reviewed is 2.01.62.

ISS Detector offers three panels that can be viewed by swiping left or right.

The left-most pane (see Figure 1) contains a filtered list of upcoming events on a day-by-day basis. Beside each date heading the sunrise and sunset times are conveniently noted.

For each flyover event, the following data are shown: magnitude, time (Iridium flare) or times (start and end of satellite pass), maximum elevation, along with an eyeball icon. It seems that the bigger the eyeball the more easily seen the pass. It is very interesting to note a weather icon beside each event—the app is pulling local weather to help you decide to get off the couch or not! A thin green or orange bar may appear beside an event alluding to the quality. More on that later.

Figure 1 — List of upcoming satellite passes. At 6:29 p.m. on February 1 it is going to be cloudy.

At the top left of this panel the next event based on your current or the configured location is noted. T-minus, counting down!

The middle pane shows a radar-like screen assuming you're looking down. The arc on the compass (blue for the ISS, orange for Iridiums) shows the predicted path of the satellite with the middle bullet indicating where the object culminates. For the ISS, a bright bullet is where to start from; the dark bullet is where it will disappear.

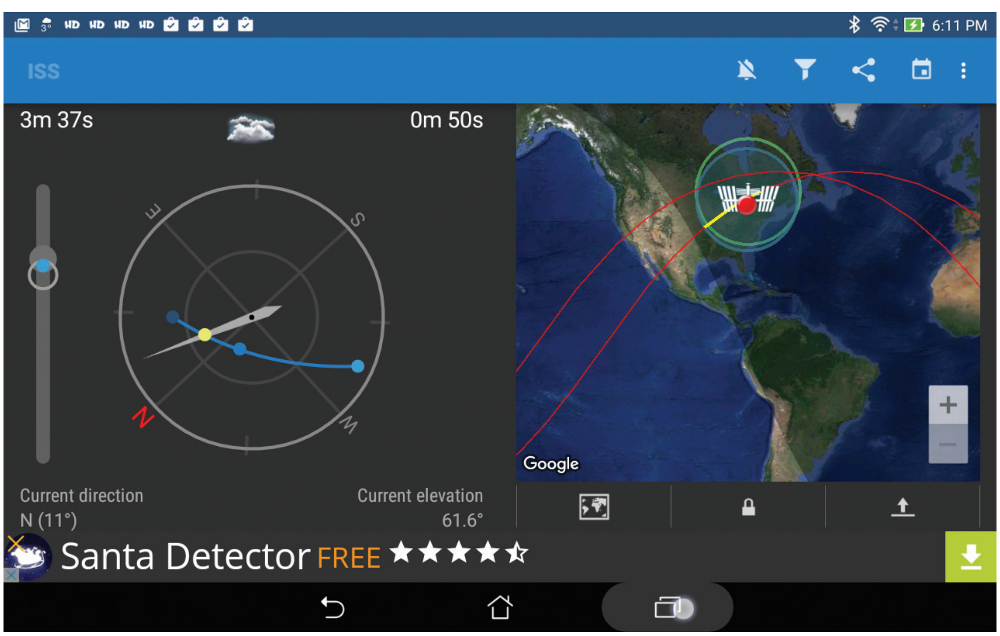


Figure 2 — Flyover in progress. Compass shows it is in the NNE.

Before the satellite event (see Figure 1), the needle shows where it will appear; whereas, during the event (see Figures 2 and 3), the pointer needle follows the object. A timer at the top-left corner counts down to the beginning of the event. The time value at the top right is the duration of the event. This turns into a timer that will run down once the event has started. Here again the weather infographic appears.

The final pane is obvious with a zoomable world map (which can be shown in a bright or dark mode). It shows the path of the satellite (see Figures 2 and 3) and where it is now. Your location is marked with a red dot. A circle surrounds your location indicating your visibility range with a similar circle drawn around the satellite. The sunlight terminator is shown as well.

By default, the map remains centred on the object in question but you can turn off the lock, and then pan anywhere in the world.

If you collapse the map (see figure 4), additional details appear, including the distance to the object, its speed, elevation (i.e. angle), height above the ground, etc.

Tap on any event and the compass panel will update and the map will briefly animate, then show where the satellite is at that very moment.

When the app is open and running on the phablet, a tone will sound for five seconds when the object is coming into view. Perfect for those fleeting flares from the Iridium communication satellites.

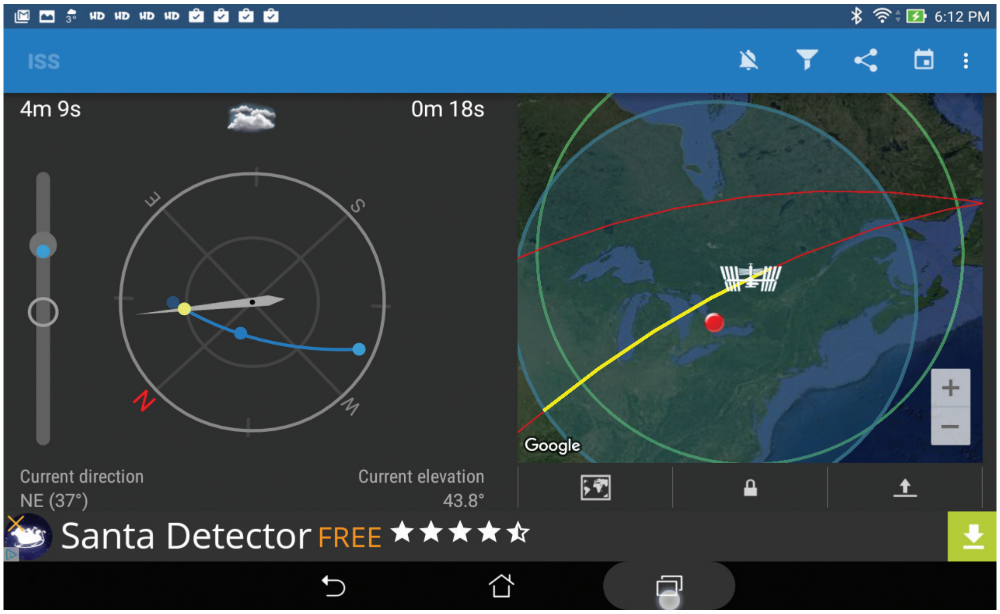


Figure 3 — 18 seconds left. The ISS is heading over Québec.

In the Filters screen (see Figure 5), one can configure parameters for the displayed objects, including if the class of object should show. One can indicate if the alarm should be sounded or not, the minimum elevation, the threshold magnitude, and the quality. By default, the visible passes filter is applied.

The app supports notifications and comes with an informative widget.

There is a "quality" system in *ISS Detector* that rates events. Bright flyovers in excellent weather conditions will be given a good rating (green), while dimmer objects in less-favourable conditions will be given a medium rating (orange).

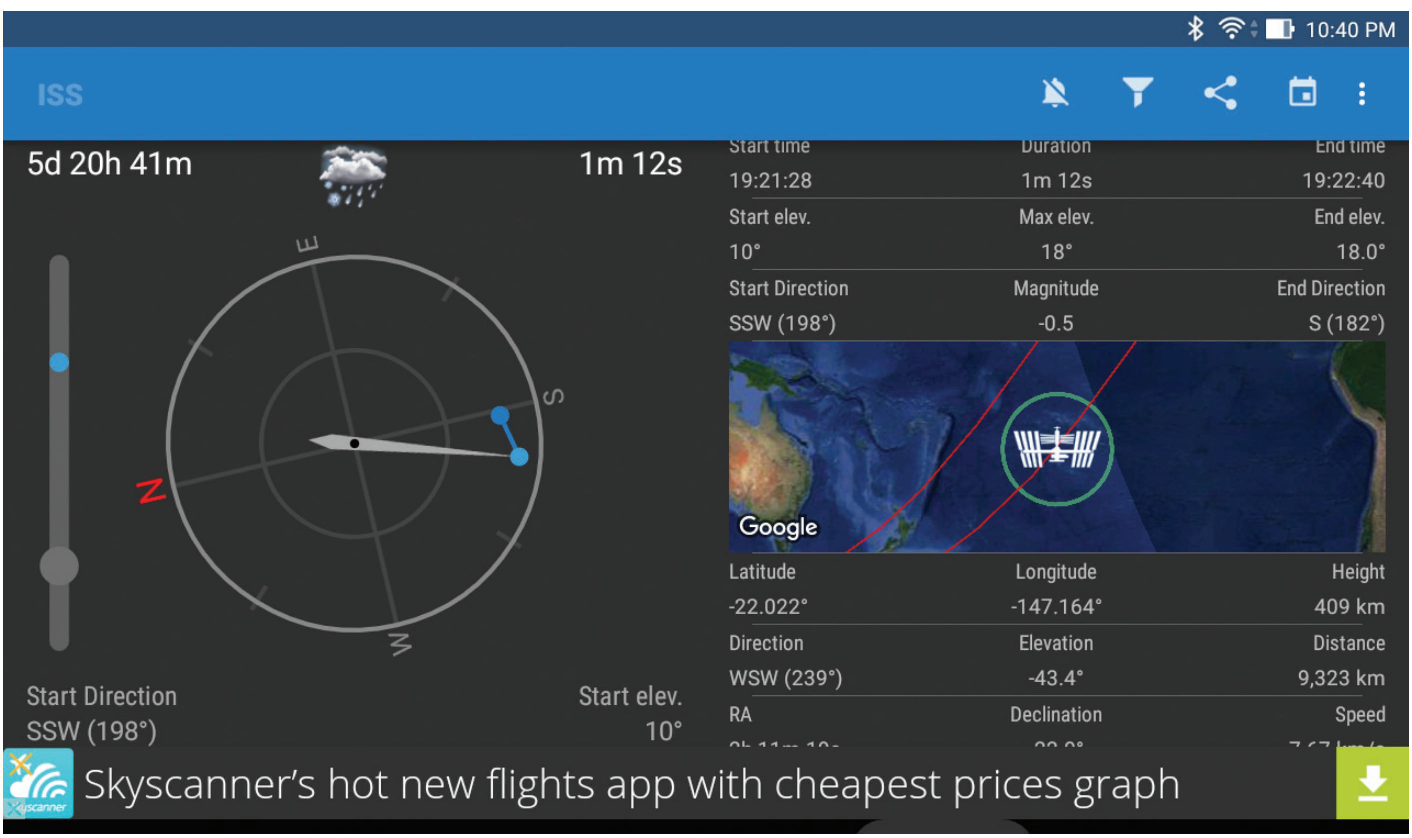


Figure 4 — Map collapsed revealing details of the space station location.

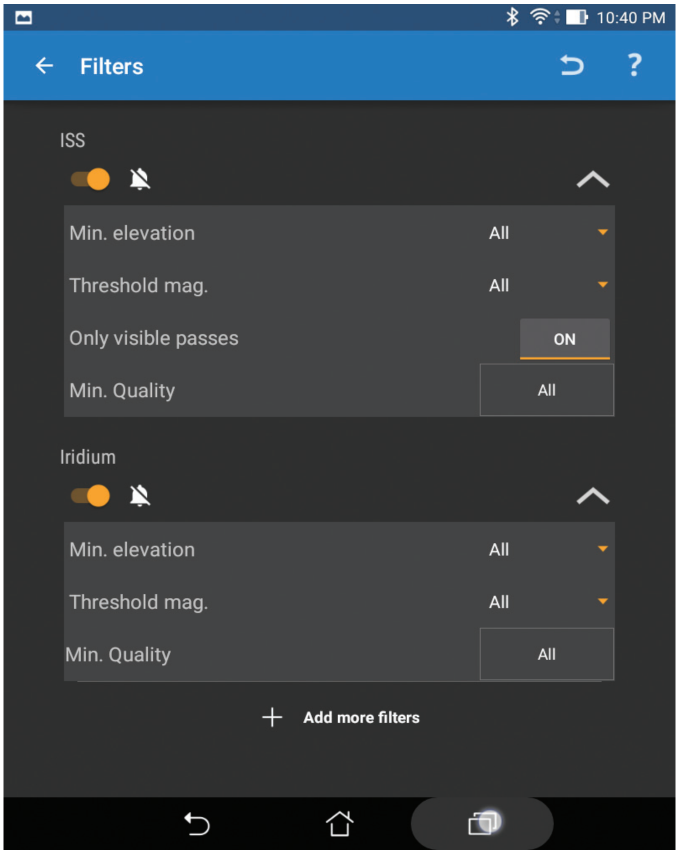


Figure 5 — Set the filter options for the ISS and Iridium satellites.

This can be used as your filter criteria. Thin green and orange indicators will show in the left edge of the list panel.

Another very nice feature of the app is the ability to transfer an event to one's calendar. It will transfer the time details and creates an appropriate title. That's pretty slick. You can also share things! It's easy to send an email or a tweet to a friend about an upcoming event.

The app works without an Internet connection. That is, the immediate upcoming events will be listed. Handy when you're in the field, or a field far away from a mobile-phone tower. For far-future events, you'll need to get on-line at some point so the app can retrieve more data. I also like that you can make the app be silent during a certain period. When you really need to sleep. Crazy hobby!

I could not find any documentation on the Web save a couple of brief videos. I spent some time figuring out a couple of the more mysterious things on my own. Later however I stumbled across the on-board help, which proved quite thorough.

For example, I had no idea what the ball-and-stick meter meant in the middle pane. It had something to do with the tilt or angle of the tablet and the maximum elevation of the satellite. The Help described it as the Inclination Indicator running from 0 to 90 degrees. Put the moving ball in the centre of the larger grey disk, like a spirit level, and the angle of your phone or tablet shows the maximum altitude of the target. During the flyover, a circle moves along the stick reflecting the elevation.

The developer was quick and helpful with my questions. I asked about a version for iOS and learned it is not in the cards. I asked about the calibration of the compass and learned it is taken care of automatically, as needed. And later I saw this to be true when prompted to recalibrate.

The panels seem an odd size on my ASUS Memo Pad 7, like they are designed for a smaller device. Still the app works well. For me, it is visually more attractive in landscape mode. The free version of the *ISS Detector* app is supported by banner and pop-up ads, most of which are for the add-ins. I was able to close the banner bar in some cases! The free version is quite useable.

Various in-app purchases can be made for adding more elements and features such as comets, Ham radio satellites, other orbiting objects like the *Hubble* or the *X-37B*, planets, and red-light mode. There's a bundle, for less than $3, which includes all the features. I might go for that. These purchases also remove the ads.

Again, there are lots of ISS prediction apps out there, but I like *ISS Detector*. It is neat that it shows the weather conditions. And I like the little things, too. I can answer questions when out and about, like, "Exactly where is the space station right now?" The rendered terminator reminds me somehow of the rare Geochron World Clock. And I've always been intrigued knowing the rapidly changing actual distance for the ISS.

Visit www.issdetector.com for more information.

In the next issue we'll take a look at a good ISS detection app for the iOS platform.

Update Bits

This new section will note updates and changes in software applications reviewed (as software is constantly being revised, of course) and any interesting notes regarding the companies and developers. For example:

The Stellarium team announced a new release of their software, version 0.14.2, recently. The version reviewed in the Feb 2015 *Journal* was 0.13.1. A number of bug fixes were applied, as is usual. I like the illumination layer in custom landscapes and the new DSO catalogue references for searching. Visit http://stellarium.org for more information. ✶

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 EPO, co-manages the Carr Astronomical Observatory, and is a councillor for the Toronto Centre. In daylight, Blake works in the IT industry.

CFHT Chronicles

2015 Science Discoveries

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

While 2016 is in full swing, let us take a look back at some of the scientific discoveries announced in 2015 using Canada-France-Hawaii Telescope (CFHT) data. Astronomers from Canada, France, the University of Hawaii, China, and Taiwan all have access to CFHT. Last year over 150 papers were published using CFHT data. In an increasing number of papers, astronomers used CFHT archival data. The discoveries selected for this article all had accompanying press releases and were featured on the CFHT website's News section.

Dwarf Galaxies in Virgo

In May, Jonathan Grossauer and James Taylor at the University of Waterloo announced the discovery of hundreds of new galaxies in the Virgo Cluster, the nearest large cluster of galaxies to our home in the Milky Way. Most of the galaxies are extremely faint dwarf galaxies. Dwarf galaxies are hundreds of thousands of times smaller than our own Milky Way Galaxy. Many of these are among the faintest galaxies known in the Universe.

The discovery was announced by the "Next Generation Virgo Cluster Survey" (NGVS) team and is based on data collected at CFHT over the course of 6 years using Megacam, CFHT's 340 Megapixel camera. NGVS observed the entire Virgo cluster, covering an area of the sky equivalent to over 400 full Moons. Astronomers created a mosaic of the image, almost 40 billion pixels in size, making NGVS the deepest, widest, continuous field imaged in such detail.

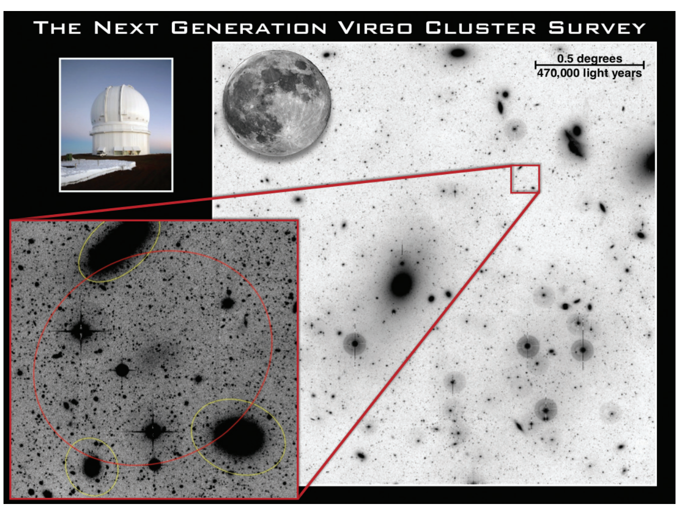


Figure 1 — Very faint dwarf galaxies in the Virgo cluster field. The inset is a zoomed in picture of the red box on the field

To utilize the full power of the data, Laura Ferrarese, Lauren McArthur, and Patrick Côté of the National Research Council of Canada developed a sophisticated data analysis technique that allowed them to discover many times more galaxies than were known previously, including some of the faintest and most diffuse objects ever detected.

The sheer number of dwarf galaxies discovered intrigued astronomers. Studying galaxy formation is complicated. Unlike watching plants grow or the life cycles of fruit flies in biology, astronomers do not have the opportunity to watch one galaxy from start to finish. Instead they observe many galaxies across the Universe at different stages of development and try to fill in the gaps. Galaxy clusters are ideal to study because they contain galaxies of varying sizes and shapes. Some are huge spiral galaxies like our own Milky Way, while others are smaller faint dwarfs. Astronomers study these clusters and create computer simulations to try to understand how galaxies form.

These computer models predict that hundreds or thousands of faint dwarf galaxies should have formed within our Local Group, the galaxy cluster containing the Milky Way and our large neighbour, the Andromeda Galaxy. However, astronomers have discovered fewer than 100. Compare this with the new results from NGVS, and a disconnect emerges between what we see in our Local Group and what astronomers observed in the Virgo Cluster and predicted with their models. The models also show a relationship in the Virgo Cluster between dark-matter mass and the brightness of galaxies. This relationship is missing in our Local Group. Why are the Virgo Cluster and the Local Group so different? Astronomers aren't sure. The answer to that question requires a follow-up study with higher-resolution simulations to explore how the galaxies are distributed within the Virgo cluster.

New Horizons at CFHT

Launched in 2006 January 19, the *New Horizons* spacecraft passed Pluto on Tuesday, 2015 July 14. The flyby marked the first human encounter with the Plutonian world, and astronomers have learned a tremendous amount about the icy world as a result of the data collected. New images of Pluto show widespread water ice, fascinating ice cliffs, and the flyby generated enough data to keep astronomers busy for years to come. A less-well-known part of the *New Horizons* story is that the spacecraft arrived at Pluto by relying on CFHT data.

New Horizons is roughly 2.5 metres across, weighing approximately 480 kilograms (about half a ton)—when first fuelled. It travels at the tremendous Earth-relative speed of about 16.26 kilometres per second (58,536 km/h). At this speed however, *New Horizons* was only able to make a flyby close to Pluto and did not enter orbit. Entering orbit would mean that operators would have had to reduce the craft speed by over 90%, a move requiring more than 1000 times the fuel that *New Horizons* can carry.

Figure 2 — Pluto superimposed over the field imaged by Megacam and used for New Horizons *navigation*

Nevertheless, mission control executed a series of maneuvers for a collisionless approach to Pluto. Such maneuvers require accurate mapping of the objects close to or in the Plutonian system. In order to achieve this, the *New Horizons* team performed several images scans for smaller objects, for both intrinsic scientific interest, and as potential collision hazards. However, in order to enable the hazard search, *New Horizons* required a high-precision flux/position reference system.

CFHT discretionary time awarded to J.J. Kavelaars at the CADC in 2014 turned out to be the best dataset to do just that. During the 2014A semester, Kavelaars and collaborators used MegaCam to refine Pluto's astrometric system, improving our knowledge of Pluto's orbit and aiding the *New Horizons* pre-encounter hazard search team. The catalogue resulting from these observations allows more precise calibration than any other wide-field imager currently in operation, due to the decade-long use of MegaPrime on CFHT and the precise calibration system developed for this camera by Stephen Gwyn at the CADC. CFHT/MegaPrime astrometric reference catalogue was fed directly into the navigation process for guiding *New Horizons* into its final encounter with the Pluto system.

Mysterious, Massive, Magnetic Stars

In September, Matt Schultz, announced the discovery of a unique object—two massive stars with magnetic fields in a binary system. Mr. Shultz, a graduate student at Queen's University in Ontario, Canada, found the system—Epsilon Lupi—and published the new result in Monthly Notices of the Royal Astronomical Society.

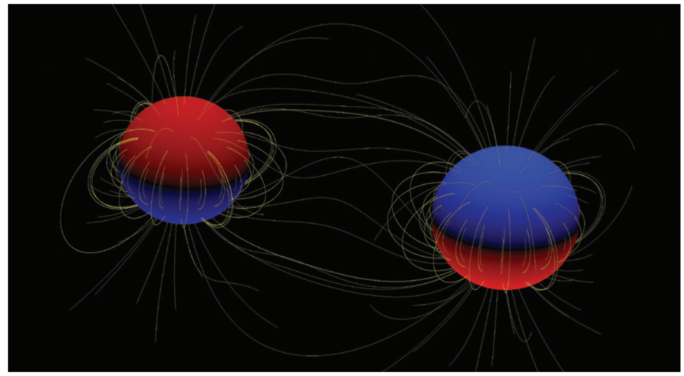


Figure 3 — The polarity of the star's surface magnetic field, north or south, is indicated by red and blue respectively. Yellow lines indicate the magnetic field lines running from the stellar surface. Credit: Visualization courtesy of Volkmar Holzwarth, KIS, Freiberg.

Around one-third of stars in our Galaxy are thought to be in binary systems, where two or more stars orbit around a common centre. They are invaluable for astronomers, as watching how they behave lets astronomers measure the stars' mass and connect this with their brightness—a key way in which we understand how stars evolve.

Mr. Shultz is a member of the Binarity and Magnetic Interactions in various classes of Stars—BinaMIcS—consortium led by Dr. Evelyne Alecian of the University of Grenoble in France. The collaboration studies the magnetic properties of close binary stars using ESPaDOnS and is one of CFHT's Large Programs. Large Programs at CFHT can request anywhere from 100–429 nights of CFHT time to study a specific topic in great depth—like the binarity and magnetic interactions of various classes of stars. Several of the discoveries highlighted in this article, including this one, originate from our Large Program.

The star system studied by Shultz, Epsilon Lupi, is the fourth-brightest star system in the southern constellation of Lupus. The pair of stars is about 500 light-years away from the Earth, are both blue in colour, each have 7 to 8 times the mass of the Sun, and, combined together, the pair is around 6000 times as luminous as the Sun. Astronomers have known for many years that Epsilon Lupi is a binary system, but prior to the announcement of this discovery had no idea that the two giant stars had magnetic fields.

Shultz comments: "The origin of magnetism amongst massive stars is something of a mystery and this discovery may help to shed some light on the question of why any of these stars have magnetic fields."

In "cool" stars, such as the Sun, magnetic fields are generated by "dynamos" powered by strong convection in the outer layers of the star, where hot material rises, cools, and falls back. These dynamos, combined with rotation of the Sun, cause formation of the star's magnetic field. A similar process occurs in the Earth where the rising, cooling, and falling of molten material in our mantel, combined with Earth's rotation, form its magnetic field. But there is essentially no convection in the envelopes of massive stars, thus there is no support for a magnetic dynamo. Nevertheless, approximately 10 percent of massive stars have strong magnetic fields.

Two explanations have been proposed for their origin, both variants on the idea of a so-called "fossil" magnetic field, a field generated at some point in the star's past and then locked into the star's surface. The first hypothesis is that the magnetic field is generated during the star's formation; a second is that the magnetic field originates in dynamos driven by the violent mixing of material when two already-formed stars in a close binary merge.

"This discovery allows us to rule out the binary merger scenario," said Mr. Shultz, "However, it doesn't change the basic finding of the BinaMIcS collaboration: fewer than two percent of massive stars in close binaries have magnetic fields, and we still don't know why that is."

The research shows the strengths of the magnetic fields are similar in the two stars, however their magnetic axes are anti-aligned; the south magnetic pole of one star points in approximately the same direction as the north pole of the other. It may even be that the two stars share a single magnetic field.

"We're not sure why yet, but it probably points to something significant about how the stars are interacting with one another," adds Shultz.

The stars are close enough that their magnetospheres are likely to be interacting during the whole of their orbit around each other. This means that their magnetic fields may act as a giant brake, slowing down the stars. As a result, in the long term, the two stars could even be spiraling in toward each other.

First discovery of a magnetic Delta Scuti Star

Coralie Neiner from the Laboratory for Space Studies and Astrophysics Instrumentation, LESIA (CNRS / Observatoire de Paris / UPMC / Université Paris Diderot) and Patricia Lampens (Royal Observatory of Belgium) discovered the first magnetic Delta Scuti star, through spectropolarimetric observations with ESPaDOnS at CFHT. Delta Scuti stars are a class of pulsating stars. Two types of pulsating stars exist among stars with a mass between 1.5 and 2.5 solar masses: the Delta Scuti stars and the GDor stars. Theory tells us that stars with a temperature between 6900 and 7400 Kelvin may pulse with characteristics similar to both types of stars—referred to by astronomers as "hybrid stars." However, NASA's *Kepler Space Telescope* has detected a large number of hybrids stars at colder or warmer temperatures. The existence of these hybrid stars on a larger temperature range is very controversial as it challenges our understanding of pulsating Delta Scuti and Gamma Dor stars.

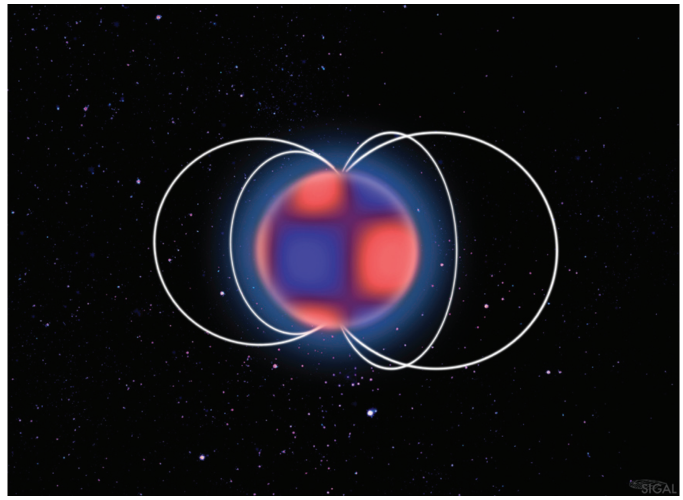


Figure 4 — Illustration of a magnetic Delta Scuti star. Copyright: Sylvain Cnudde LESIA/Observatorie de Paris

The team sought to determine which physical phenomena could mimic the signatures of Gamma Dor pulsations in Delta Scuti stars, causing astronomers to incorrectly categorize them as hybrids. One explanation is the presence of a magnetic field that produces spots on the surface of the star: when the star rotates, the passage of the spot in front of the observer mimics the signature of Gamma Dor type of pulsations. Confirmation of this hypothesis requires detection of a Delta Scuti star with a magnetic field.

Using ESPaDOnS, they looked for the presence of a magnetic field in a hybrid *Kepler* star, HD188774. They discovered that this star is actually a magnetic Delta Scuti star and that the signature of this magnetic field is confused with the signature of Gamma Dor type pulsations. HD188774 is thus not a true hybrid, but the first known magnetic Delta Scuti star. It is likely that many other stars thought to be hybrids among *Kepler* stars are actually magnetic Delta Scuti stars, which would resolve the controversy between the theoretical predictions and the *Kepler* observations. This discovery brings new light to the interpretation of the *Kepler* observations.

Galaxy Cluster with a Vibrant Heart

Astronomers discovered a rare galaxy cluster whose heart is bursting with new stars. The unexpected find, made with NASA's *Spitzer* and *Hubble* space telescopes, MOSFIRE on Keck Observatory, and MegaCam on CFHT, suggests that behemoth galaxies at the cores of these massive clusters can grow significantly by feeding off gas stolen from another galaxy.

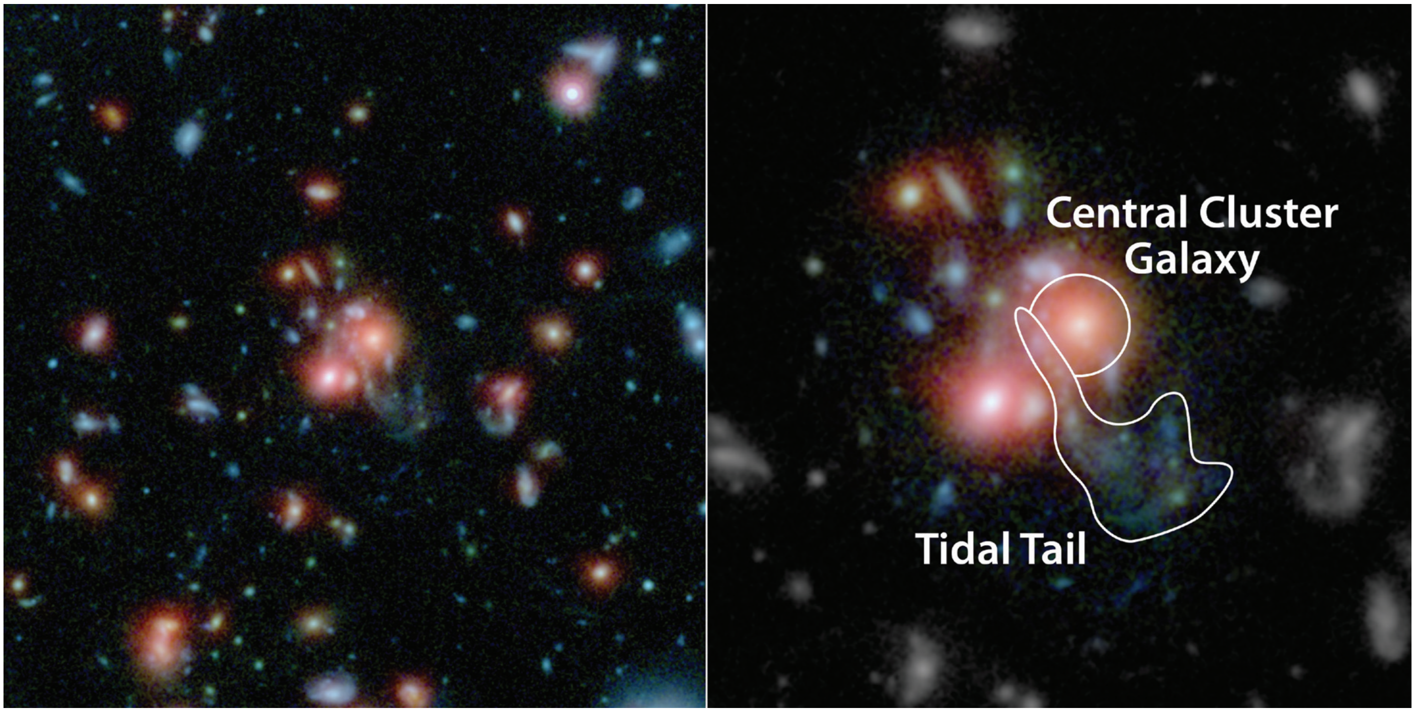


Figure 5 — Massive galaxy cluster, SpARCS1049+56, can be seen in this multi-wavelength view. Image credit: NASA/STScI/ESA/JPL-Caltech/McGill

"Usually, the stars at the centres of galaxies clusters are old and dead, essentially fossils," said Tracy Webb of McGill University, lead author of the paper on the findings. "But we think the giant galaxy at the centre of this cluster is furiously making new stars after merging with a smaller galaxy."

Galaxy clusters are vast families of galaxies bound by the ties of gravity. Our own Milky Way resides in a small galaxy group, called the Local Group, which itself is on the periphery of the vast Laniakea supercluster of 100,000 galaxies (Laniakea is Hawaiian for "immeasurable heaven").

The cluster in the new study, referred to by astronomers as SpARCS1049+56, has at least 27 galaxy members, probably more, and a combined mass equal to nearly 400 trillion Suns. It is located 4 billion light-years away in the Ursa Major constellation. The object was initially discovered using *Spitzer* and the Canada-France-Hawaii Telescope and confirmed using MOSFIRE on Keck Observatory.

What makes this cluster unique is its luminous heart of new stars. At the core of most massive galaxy clusters lies one hulking galaxy. The galaxy dominating the cluster SpARCS1049+56 is rapidly spitting out an enormous number of stars—about 860 new ones a year. For reference, our Milky Way makes only about one to two stars per year.

Follow-up studies with *Hubble* in visible light helped confirm the source of the fuel, or gas, for the new stars. A smaller galaxy seems to have recently merged with the monster galaxy in the middle of the cluster, lending its gas to the larger galaxy and igniting a fury of new stars.

"*Hubble* found a train wreck of a merger at the centre of this galaxy," said Webb. *Hubble* specifically detected features called beads on a string, which are pockets of gas that condense where new stars are forming. Beads on a string are telltale signs of collisions between gas-rich galaxies, a phenomenon known to astronomers as wet mergers, where "wet" refers to the presence of gas. In these smash-ups, the gas is quickly converted to new stars. Dry mergers, by contrast, occur when galaxies with little gas collide and no new stars are formed.

Typically, galaxy clusters grow in mass either through dry mergers at their core, or by siphoning gas into their centres, as is the case with the megatropolis of a galaxy cluster known as the Phoenix cluster.

The new discovery is one of the first known cases of a wet merger at the core of a distant galaxy cluster. The researchers are planning more studies to find out how common galaxy clusters like SpARCS1049+56 are. The cluster may be an outlier—or it may represent an early time in our Universe when gobbling up gas-rich galaxies was the norm.

Last issue's column featured a discovery using ESPaDOnS whereby a potential hot Jupiter was found around a very young star, so add that to the list of exciting discoveries from 2015. 2016 is off to an awesome start and we hope to see some SITELLE discoveries this year. ✶

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

Dish on the Cosmos

Seeing the Sounds of the Universe

by Erik Rosolowsky, Department of Physics, University of Alberta

The Dominion Radio Astrophysical Observatory (DRAO) lies nestled in the hills above the Okanagan Valley of British Columbia. Few of the tourists sampling wines up and down the valley realize they are in the heart of a Radio Quiet Zone, where certain types of radio transmitters are prohibited since they would ruin the astronomical observations. Much of Canada's rich history in radio astronomy has been written here, and Canadian astronomers and engineers are coming to DRAO to author the next chapter in this legacy. In the last column, I wrote of the Square Kilometre Array (SKA) that would transform our view on the Universe. The SKA lies far off in an uncertain future. Other astronomers working at DRAO are frantically building a new telescope now, taking advantage of the radio quiet that covers the valley. While the SKA would answer a broad swath of science questions, the Canadian Hydrogen Intensity Mapper (CHIME) will make a single, world-leading measurement of how the Universe itself is expanding (Figure 1).

The study of this expansion is a major question in astronomy because it tells us the overall recipe that guides the Universe's evolution. We have known the Universe was expanding since Edwin Hubble's observations of galaxies in the 1920s. He found that distant galaxies appeared to be moving directly away from Earth; and critically, the more distant a galaxy was, the faster it was moving away. When viewed in the context of Einstein's theory of relativity, this result indicated that the space itself was expanding out from a Big Bang.

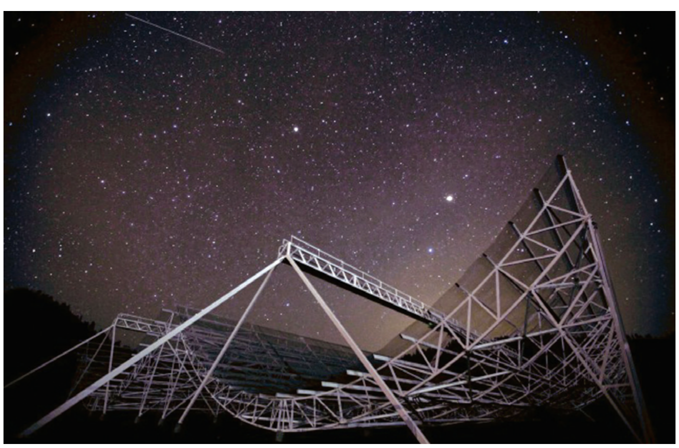


Figure 1 — The CHIME radio telescope at night. This picture shows the innovative design of the CHIME telescope, which will enable Canadian astronomers to make a definitive measurement of ancient cosmic expansion. This careful measurement will give new clues into the nature of the dark energy that pervades the cosmos. Photo credit: Keith Vanderlinde (Dunlap Institute; University of Toronto).

The rate of this expansion and how it changes as the cosmos evolves tells us what the Universe is made of and consequently its evolution. My favourite analogy to draw is considering a ball thrown straight up. If we observed the ball as we observed the Hubble Law, we could find out the speed of the ball and how far it had travelled since being thrown. If there were no gravity, the speed of the ball would never change and we could figure out how long ago the ball had been thrown. A similar measurement of the Hubble Law would give a naive estimate for the age of the Universe. Of course, there is gravity and the ball will slow down continuously as soon as it is thrown. With a little physics, you can use the rate of slowing to infer how much gravitational force is pulling on the ball, and this gravity measurement tells you something about the mass and size of the planet you are on. In the case of galaxies, you are making a measurement of the amount of gravitating matter in the Universe and thus its composition. You can also revise your age of the Universe to take account of the slowing due to gravity, leading to better understanding about its evolution.

One of the major discoveries about the Universe in the past two decades was the discovery of dark energy. The discovery was made by looking at distant supernova explosions during earlier times in the Universe. In the ball analogy, this would be like measuring the speed and distance at earlier times in its travel. Under the effects of gravity alone, we would expect the ball to be travelling faster earlier in its rise since it must always be slowing down. Disturbingly, the Universe did not show this continuous slowing, giving a clear sign of additional components in our cosmic mix. This unexpected extra ingredient pushes space apart and has been given the simple name dark energy. However, naming something does not mean that we understand it, and the origins and nature of this effect are almost completely unknown. Attempts to explain the effects using other aspects of physics can end up comically wrong, and we are left seeking more information to guide us about the nature of this dark energy.

This quest for more information about dark energy guides the CHIME project. The key to CHIME's strategy lies in measuring the signature of "baryon acoustic oscillations" (BAO) in the patterns of matter in the Universe. This BAO signature arises from the physics in the expanding early Universe well before the formation of stars and galaxies. At that time, all the matter was a smooth, hot plasma (i.e. an ionized gas where hydrogen atoms are split into electrons and protons). As gravity starts to pull matter together into the early seeds of galaxy clusters, the rising pressure in the compressing plasma causes it to bounce back creating a sound-wave front moving out of the forming cluster. Since the Universe was both cooling and expanding through this early phase, the plasma undergoes a rapid change becoming a neutral gas. This sharp change from a gas of free protons and electrons into atoms of hydrogen means that the light in the early Universe was free to travel, unimpeded by matter. The sound waves are a combination of pressure from radiation and gas. These waves suddenly stall when this transition happens, leaving an enhancement in the density of matter on a specific size scale. We can now understand why BAO is an obvious name to physicists: baryon just means ordinary matter like protons; acoustic indicates the importance of pressure forces; and oscillation is used to show the wave-like nature of the effect.

The timing of the change from plasma to neutral matter means that the BAO signature has a fixed scale in the structure of the Universe. If you look at the distances between pairs of galaxies and galaxy clusters at a specific age of the Universe, you find that galaxies are randomly spread through the sky, but there is a slightly better than random chance of finding extra galaxies on the BAO scale. Note that this scale changes over the course of the Universe because of the nature of the expansion. By measuring the scale of the BAO signature at different ages of the Universe, astronomers can reverse the line of reasoning and thereby directly measure the expansion. Unfortunately, measuring this signature using galaxies in the early Universe is hard, because these galaxies are far away and therefore faint. It is difficult to measure enough galaxies to detect the signature.

CHIME neatly sidesteps this problem by measuring the radio signal from the atoms of hydrogen that are part of galaxies as well that material that has yet to fall into galaxies and be made into stars. CHIME is also an interferometer, like ALMA and the SKA discussed in this column previously. Interferometers operate by measuring the differences between signals arising from two different directions. These differences are precisely how the BAO signal appears in data, so CHIME is perfectly designed to make this measurement. Unlike studies of BAO using hundreds of thousands of individual galaxies, the hydrogen signature will be attained by looking across all the sky and adding up the signal. CHIME will measure the signal over the entire sky visible from Penticton.

CHIME can survey the BAO signature at many different ages of the Universe by looking at different frequencies. The expansion of the Universe stretches out the 21-cm wavelength of hydrogen emission to longer wavelengths. The CHIME team will measure the shifted hydrogen emission emitted when the Universe was one-quarter to one-half of its current age. These results will tell us about the nature of the Universe's expansion and therefore the subtle role of dark energy in the era when it starts to dominate the evolution of the Universe (now, we are firmly into the dark-energy era).

This is an exciting measurement since it should give a vital clue to the nature of dark energy. CHIME is also leading the race to be the first instrument that will make this study, and it is doing so at surprisingly low cost. By taking advantage of advances in computer gaming, CHIME uses off-the-shelf video cards for high-efficiency data processing. The reflecting surface of the telescope itself is little more than wire mesh bolted to U-shaped frames. With ingenuity and dedicated efforts, Canadian astronomers are poised to make the definitive measurement of how a dark Universe expands. CHIME is starting to collect data now and should complete its basic objectives in two or three years. If you are in the Okanagan, you can come visit CHIME and the other telescopes at DRAO and see the history of Canadian radio astronomy as well as its future.

CHIME is a partnership between the University of British Columbia, McGill University, the University of Toronto, and the Dominion Radio Astrophysical Observatory. You can read more about CHIME at http://chime.phas.ubc.ca/ ✶

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

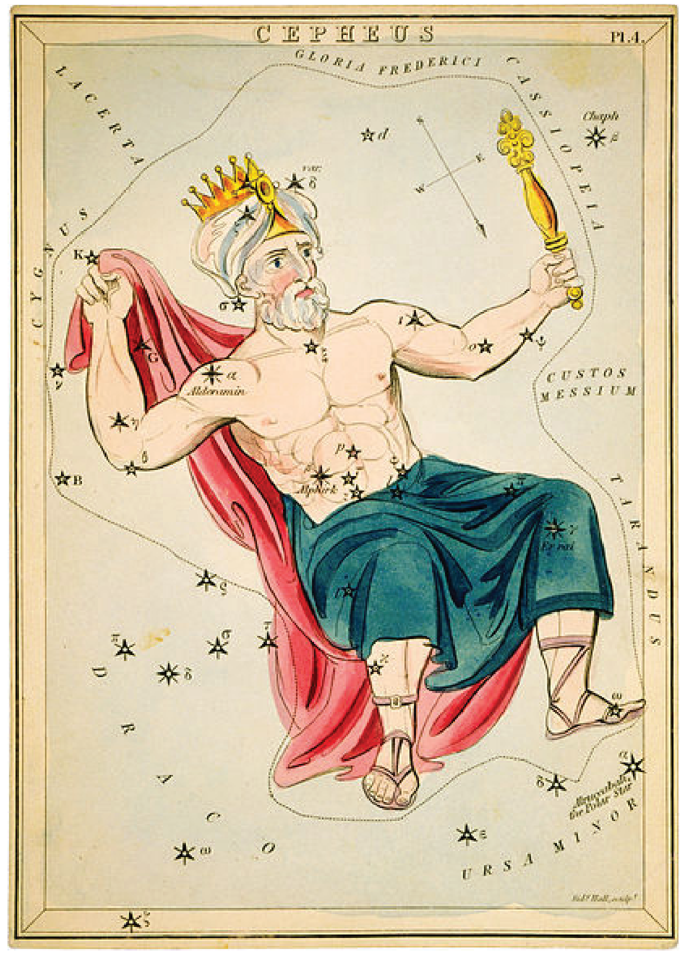
Beta Cephei Stars—The Brightest Class of Stars that You Have Probably Never Heard of

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

Hands up, those who think astronomers know everything about the brightest stars! Unfortunately not.

In my previous column, I revisited J. Miller Barr (1856–1911), a remarkable but enigmatic Canadian amateur astronomer from a century ago. In the present column, I revisit an equally remarkable but enigmatic group of bright variable stars, dating from Barr's era, and closely related to Barr's work on spectroscopic binaries and variable stars.

Exactly half a century ago, I began my doctoral research project on "the nature of the Beta Cephei Stars," and subsequently published a review paper on the topic in this *Journal* (Percy 1967). In a nutshell: they are hot B0.5-2 III-IV stars, typically about ten times larger and more massive than the Sun, near the main sequence on the Hertzsprung-Russell diagram (luminosity versus temperature), pulsating with periods of a few hours. They seem to be normal objects and, because of their brightness, should be useful tools for understanding stellar structure and evolution. Now my colleague Hilding Neilson (Neilson and Ignace 2015) has reminded me that they continue to perplex astronomers.



The constellation Cepheus, from **Urania's Mirror** *(1824), a set of celestial cards, created by Reverend Richard Rouse Bloxam, and engraved by Sidney Hall. Beta Cephei (Alphirk) is on Cepheus's belly. From Wikipedia, public domain.*

History

In 1902, Edwin B. Frost (1902) discovered β Cep (Alfirk or Alphirk) to be a "spectroscopic binary" with a very short period, which he soon refined to 0.19 day (4.57 hours). In 1909, William W. Campbell (1909) listed β CMa (Mirzam) as a radial-velocity variable, also with a short period. Eventually, astronomers came to realize that these short-period variables were actually pulsating stars, not spectroscopic binary stars. (A fraction of them are also spectroscopic binaries, with "normal" periods of days or weeks.) Most of the first-discovered Beta Cephei stars were slow rotators, but that was mostly a "selection effect"; slow rotators have sharp spectral lines, and velocity variations are easier to detect and study in this case. Slow rotators may also have larger pulsation amplitudes.

By 1950, β CMa was also shown to demonstrate a "beat effect"—a pulsation amplitude that rose and fell with a period of 49 days. The beat effect is now known to be caused by the presence of one or more non-radial[1] periods, which interfere with the main radial period. Many Beta Cephei stars have multiple radial and non-radial periods, and these can be used to probe the internal structure of the stars in a process called *asteroseismology*.

Because β Cep did not show a beat effect, many astronomers preferred to use the name Beta Canis Majoris for these stars. That also avoids a problem: there was already a well-known class of pulsating variable stars known as Delta Cephei stars, or Cepheids, which are rather different beasts. Unlike Cepheids, which vary in brightness by up to a magnitude, the Beta Cephei stars vary in brightness only subtly, by a few hundredths of a magnitude. It required photoelectric photometry to discover and study them as brightness-variable stars. The most vigorous member of this class is BW Vul, with a period of 0.2 day, an in-and-out velocity of 200 kilometres a second—imagine!—but a visual-light amplitude of only 0.2 magnitude. If your eyes were sensitive to ultraviolet light, though, you would observe a much larger amplitude.

Most of the "classical" Beta Cephei stars—those listed in my 1967 review, for instance are—naked-eye stars. Those listed in Wikipedia have the following distribution of number with apparent magnitude: 0 (2), 1 (3), 2 (8), 3 (8), 4 (8), 5 (4), and 6 (1), though many fainter candidate stars have since been found in post-1980 surveys. The brightest member is β Cen. Other bright members include: ∊ Cen, δ Cet, β Cru, δ Cru, α Lup, α Mus, γ Peg, and ϰ Sco.

The Astrophysical Zoo Gets Crowded

By the late 20th century, astronomers began to find other variable stars resembling Beta Cephei stars, but that had distinct differences as well. In addition, there were other types of variable stars that could have similar physical and variability properties, and could be confused with them. These included hot, short-period eclipsing stars, and ellipsoidal variable stars that are stars distorted into football shapes by a binary companion, and therefore vary slightly in brightness as they simultaneously orbit and rotate. There were rapidly spinning hot stars with strong magnetic fields, which produce large bright or dark patches on the surface of the stars, which, in turn, cause small light variations when the star rotates ("rotating variables").

Then, using a new generation of spectrographs, astronomers discovered spectral "line-profile variable" stars, which turned out to be pulsating non-radially (example: ∊ Per). Photometrists discovered "slowly-pulsating B stars" (example: τ Her), which were also pulsating non-radially, but in slower modes—typically with periods of a day or two. The emission-line B stars or Be stars (example: λ Eri)—rapidly rotating B stars that excrete discs of gas from their equators—turned out to vary in brightness on time scales of 0.5 to 2 days, almost certainly due to non-radial pulsation (though a few die-hards held out for other explanations). For many years, Be stars were my main area of research.

Partly because of this confusing menagerie, and partly because of the stars' complexity and small amplitudes, there are large numbers of stars that have been rejected as Beta Cephei candidates. In Wikipedia, the list of these is as long as the list of confirmed stars, and this is true in many other such lists. There is even a famous bright star—Spica—which was a radially pulsating Beta Cephei star, but has now turned into a pure non-radial pulsator.

Why Do They Pulsate?

For decades, this was the fundamental problem of the Beta Cephei stars. Cepheids pulsate because the ionization and recombination of the abundant hydrogen and helium atoms in their outer layers can absorb and store radiant energy, and release it at just the right stage of the pulsation cycle to drive the pulsation. Beta Cephei stars are so hot that the hydrogen and helium are almost all ionized, and cannot drive the pulsation.

I tried, unsuccessfully, to solve this problem as part of my thesis research. By the 1980s, theorists could list a dozen or more possible driving mechanisms. None of them worked. The problem—and simultaneously several others in stellar pulsation—was finally solved in 1987 with the release of new calculations of the opacity of gases in stars. These calculations came from the U.S. Lawrence Livermore National Laboratory (and previous calculations had come from Los Alamos National Laboratory); opacity calculations are an important tool for research on nuclear explosions, and conditions in these explosions are not unlike conditions in stars. The new calculations showed that the opacity of iron atoms at temperatures of 100,000–200,000 K was much higher than previously believed, and was high enough to drive the pulsations of Beta Cephei stars—even though iron is a relatively rare element in the stars. The problem was solved. Incidentally, Norman Simon (1982) had anticipated this solution, several years earlier.

Other Mysteries Remain

Stellar evolution can be observed directly, in a pulsating star, by measuring the rate at which the pulsation period is changing (see Percy [2014] for an application to Polaris). Many years ago, Peter Eggleton and I (1973) compared the observed period changes in Beta Cephei stars with those predicted by our evolutionary models, and found general agreement. Now, Neilson and Ignace (2015) compare the observations with new improved models, and no longer find agreement; they suggest that "the evolution of Beta Cephei stars, and their pulsation properties are more complex than expected." In science, every time old problems are solved, new problems arise.

Current research on Beta Cephei stars is also going on in several other exciting areas, as a quick search of the SAO/NASA Astrophysical Data System shows. One area is asteroseismology: with ground-based and space observations, it's possible to identify many pulsation modes in these stars, and to compare these with theoretical models to determine the interior properties of these stars. We are also still not sure what determines the pulsation amplitude in these stars, and what determines which pulsation modes will be present. Perhaps it is the speed of rotation. Secondly, do they all have significant magnetic fields and, if so, how do magnetic fields affect their behaviour? The local expert in this field is Gregg Wade, at the Royal Military College, in Kingston, Ontario. There are many new possibilities for doctoral theses on these stars, half a century after mine.

Next time you are hosting a star party, or just looking at the sky for yourself, remember that these bright "performing stars" have intrigued astronomers for more than a century, and continue to do so. ✶

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

Endnotes

1 In radial pulsation, the whole star expands and contracts in unison. In non-radial pulsation, this is not the case; the poles can be moving inward while the equator is moving outward, for instance.

References

Campbell, W.W. 1909, Eleven stars having variable radial velocities, *Astrophys. J.*, 29, 224.

Eggleton, P.P. and Percy, J.R. 1973, Period changes in beta Cephei stars: comparison of observations and theory, *Mon. Not. Roy. Astron. Soc.*, 161, 421.

Frost, E.B. 1902, The spectroscopic binary beta Cephei, *Astrophys. J.*, 15, 340.

Neilson, H.R. and Ignace, R. 2015, Period change and stellar evolution of β Cephei stars, 2015arXiv 1509.05433

Percy, J.R. 1967, The Beta Cephei Stars, *JRASC, 61*, 117.

Percy, J.R. 2014, Polaris: More than just the North/Pole star, *JRASC, 108*, 172.

Simon, N. 1982, A plea for reexamining heavy element opacities in stars, *Astrophys. J., 260*, 87.

Imager's Corner

Equipment Review

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

In this edition we will take a look at an interesting noise-reduction filter that is extremely easy to use. I came up with this one while writing my last column comparing the Canon 7D MII and the Nikon 810a to my trusty Canon 60Da.

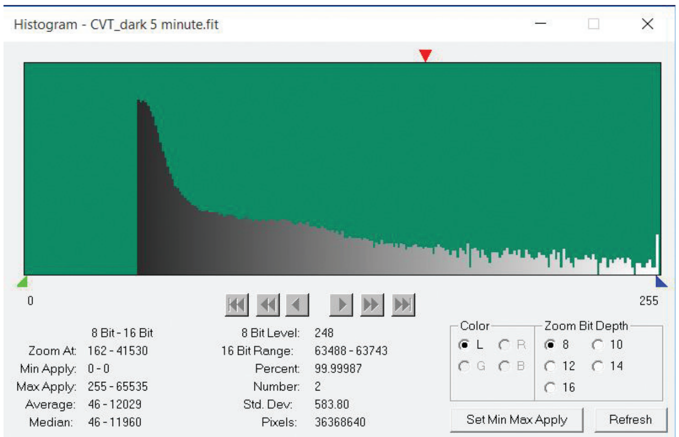


Figure 1 — Nikon 810A histogram

If you remember the last edition, the Nikon was showing some weirdness in its histogram as shown in Figure 1.

This is the histogram of a Nikon dark frame and it shows distinct clipping of the low end of the histogram. The other thing to note about the Nikon images is that there is a very slight blur compared to the Canon cameras. This is evidence of some form of filtering being applied to the raw data in the camera. The catch is what kind of filter can account for the very slight blur and the histogram clipping?

Figure 3 — Full-resolution central crop

Figure 2 — Stretched M8

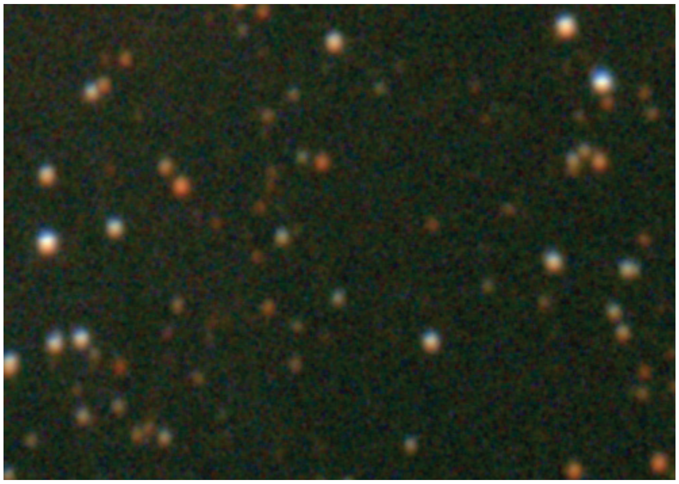


Figure 4 — Lower right corner

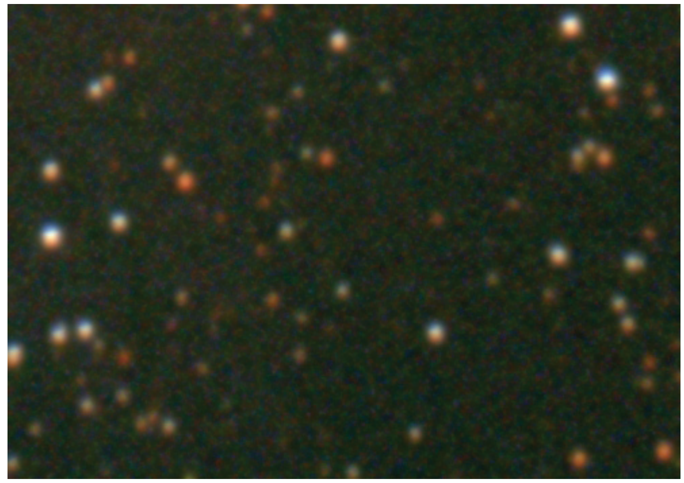


Figure 5 — Filtered lower right portion of the image

It turns out that there is a class of statistical filter that can account for the weird histogram and the slight blur. Starting with the image of M8 shown in Figure 2 let's take a look at a couple of areas up close to see what the image really looks like.

First examine the full resolution crop of the central area of the image.

Looking carefully at the bright central area you can see that the SNR is very high and although it could use a little sharpening, focus is reasonably crisp. Now let's take a look at the lower right corner of the image.

Here we see the noise that shows up in the dim areas. Normally, to handle the noise in the dim areas and avoid blurring the bright centre, an inverse luminance mask is be applied to the noise-reduction operation. This imposes some limitations to the processing, as it means that the mask needs to be very dark around the stars to avoid blurring them and it needs to be bright in the dim areas to allow the noise reduction to show through.

The beauty of the statistical filter is that it automatically adjusts to the varying brightness in the image, applying just the right amount of noise reduction to each area in the image. The way the filter works is to duplicate the image on another layer and apply a small kernel box filter, say five to nine pixels, to the upper layer. The box filter replaces the value of a pixel with the average value of all the pixels under the filter kernel, that's the statistical part of the filter. Next set the blend mode of the filtered upper layer to lighten, and presto, just the right amount of noise reduction across the entire image. Take a look at the filtered lower-right-hand portion of the image.

The filter replaces the darker spots with the average under the filter kernel accounting for the slight brightening of the background. No mask has been applied to the filter: note that even the faintest stars have not been adversely affected.

Figure 6 — Central portion of the filtered image

Now look at the filtered bright central portion of the image.

There is a very slight blur applied to the bright areas that is just barely noticeable. Since no mask is needed, the filter can even be applied before stretching the image. Since the filter has very little effect on the brighter elements of the image, you can apply it after each stretch, making for a nice clean final image.

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.

Second Light

A Fast Radio Burst Localized

by Leslie J. Sage
(l.sage@us.nature.com)

The first "fast radio burst" was discovered back in 2007. It was a pulse of radio energy lasting about a millisecond, and because it was bright (as these things go) the signal could have entered the telescope beam across a moderately large area of the sky. No transients at any other wavelength were discovered, and there was no obviously strange source in that part of the sky. After several years, it was concluded by some that it was a one-off event likely originating in Earth's atmosphere or magnetosphere. There are, after all, small bursts of gamma rays generated in events that are like lightning. Then a few more fast radio bursts were found, and the nature of the source was revisited. Astronomers started to think that they perhaps originated in galaxies at cosmological distances. But the problem of localization remained, and until that was solved, nothing conclusive could be said. Evan Keane of the Square Kilometre Array Organization in Manchester, UK, and his collaborators put together a network of telescopes around the globe to spring into action when a burst was found, and on 2015 April 18 they hit pay dirt, and were able to trace the burst to a host galaxy at a redshift of 0.49 (see the February 25 issue of *Nature*).

I am going to have to get a little technical for a moment, because a particular term used in radio astronomy is an important part of the story. Very sharp pulses of photons interact with charged particles (electrons and protons) in between the source and the observer. These interactions are frequency dependent, so that the lower-frequency photons are delayed by the interaction a little more than the higher-frequency ones. In radio astronomy, only the electrons are important. This slight spreading out of the photons is called the "dispersion measure," and it is directly related to the number of electrons along the path that the photons have taken. The dispersion measures of the other fast radio bursts seen before Keane's had values consistent with the sources being in distant galaxies. The action of the electrons on the photons can also cause other changes in the observed properties of the radio signal, causing it to become polarized. Most of us are familiar with polarization through the use of sunglasses. Normally, sunglasses filter out the light that is scattered from the ground/beach/ocean, because that scattered light is polarized in the direction of the ground. In December 2015, Kiyoshi Masui of the University of British Columbia and his collaborators reported measuring the linear polarization of a fast radio burst (see the December 24 issue of *Nature*) for the first time, and found the signature of a very dense plasma, which had to be closely associated with the source, which they estimated was at a maximum redshift of 0.5. They concluded that this fast burst was likely associated with a magnetar, which is a neutron star with a very intense magnetic field (at least 100 trillion times Earth's magnetic field). We will come back to this later.

Two hours after the discovery of Keane's burst, the Australia Telescope Compact Array was observing the region of the sky from which the burst came, and found a fading radio transient source. Armed with the position of that source, Keane and his team used the Subaru 8.2-metre telescope on Mauna Kea to find a small elliptical galaxy at the source position. A subsequent observation measured the redshift of the galaxy to be 0.492.

The properties of the galaxy are such that it is unlikely to have had recent star-formation activity, which argues against a magnetar source, as magnetars are exclusively associated with regions of quite recent star formation. Keane concedes that there could be some residual star formation in an otherwise "red and dead" galaxy (as astronomers call them). But most elliptical galaxies at that redshift are red and dead. So he favours an explanation involving the collision between two compact objects, like white dwarfs or neutron stars. Merging neutron stars have been argued as the best explanation for the short gamma-ray bursts, and merging white dwarfs have become the favoured explanation for most type Ia supernovae. As Keane saw the radio burst fade over a period of about six days, that does argue for some kind of heated ejecta that generates the radio waves. But it's relatively hard to make a cosmic explosion that is seen only at radio wavelengths. There have, however, been radio transients associated with four short gamma-ray bursts.

Gamma-ray bursts (both short and long) are generally thought to be quite highly beamed—we can only see the bursts that are pointed directly at Earth. Astronomers have been puzzled for about 18 years—the time I have been writing this column—about the so-called "orphan bursts." These are fading optical transients with no gamma-ray burst. There should be lots of them, but none have been seen. Perhaps the fast radio bursts are the orphan bursts.

Coming back to the Masui et al. result, it seems clear that Keane and Masui are seeing radio bursts from rather different sources, meaning that there are at least two classes. I suspect that we have not heard the last about fast radio bursts.

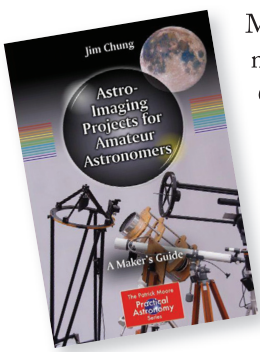
Keane was able to do some interesting cosmology with this burst. We know from the *WMAP* and *Planck* missions that normal matter makes up about five percent of the total matter-energy density of the Universe. One problem has been, though, that if one counts up all the matter that can be seen—all the gas and stars radiating at any wavelength—one finds that it adds up to just about one percent. It has long been thought that the rest of the matter is very diffuse and spread through intergalactic space. Keane used the observed dispersion measure and inverted it to ask how many electrons there are along the line of sight. As there has to be change balance, this gives the number of protons and—presto!—it adds up to five percent of the mass-energy density.

There has been a lot of buzz in astronomy over the past decade about the coming age of "time domain astronomy"—where we are able to track transients in the sky in real time. The Large Synoptic Survey Telescope will do this in the optical when it begins science operations in about 2021. But in the radio, that age has already begun. ✶

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.*

Reviews / Critiques

Astro-Imaging Projects for Amateur Astronomers: A Maker's Guide, by Jim Chung, Forward by Dan Friedman, and Introduction by the author, pages 246 + xii, 15.5 cm × 23.5 cm, Springer International Publishing, Switzerland, 2015. Price $34.95 USD softcover (ISBN: 978-3-319-18454-3).



My favourite section of *Sky & Telescope* magazine through the years was always *Gleanings for Amateur Telescope Makers* (ATMs), a column that is sadly no longer published. *Gleanings* outlined a variety of great projects, both large and small, that could keep an avid amateur telescope maker busy, particularly when regular observing was impossible. Today, with the imaging segment of the hobby growing in popularity, the focus of many telescope makers has leaned more toward electronics and smaller projects than mirror grinding and lenses.

Astro-Imaging Projects for Amateur Astronomers is the replacement for *Gleanings for ATMs* to the new generation of tinkerers. Jim Chung begins the reader's journey by discussing digital single-lens reflex cameras (DSLRs) and the new Micro 4/3 four-thirds system cameras, and then progresses from building cooled, monochrome cameras through construction of observatory piers, mounts, and telescopes. There is a project for just about any mid-level to advanced tinkerer possessing a suitable shop and budget.

Jim Chung is a dentistry graduate from the Western University, who maintains a private practice in Toronto and is active in dental charity missions. He developed mechanical skills while restoring vintage motorcycles, and applies those skills to various projects in astronomical imaging that should interest budget-conscious amateurs. He has a regular column in JRASC describing such interests.

One of several major projects in the book describes the construction of a cooled, monochrome camera. By utilizing a used DSLR, a readily available monochrome CCD sensor, and some parts from a drink cooler available at Canadian Tire, Chung "MacGyvered" (crudely created) a quite usable astro-camera suitable for Luminance, Red, Green, and Blue (LRGB) or narrow-band imaging. It is a truly marvellous project that taught me quite a few things about what is possible with readily available items.

The title of the book is somewhat misleading. Although the projects are, for the most part, targeted at people interested in imaging, Chung does describe a few projects that would be of interest to visual observers. Even so, there is no reason to avoid the book if astroimaging does not interest you. Some of the smaller projects could easily be first-time projects for someone who has never built anything before, or who is "all thumbs" when handling instruments.

The only discouraging aspects of *Astro-Imaging Projects for Amateur Astronomers* are some overlooked copyediting needs. Chung's writing style makes the text easy to follow, his instructions are fairly clearly described, and the imagery and graphics of the book nicely complement the description of different projects. Yet I would have preferred a slightly different title and a rearrangement of some chapters to give them greater focus. Better copy editing would also have caught the grammatical errors that crop up through the text.

Astro-Imaging Projects for Amateur Astronomers is one book that should be in every telescope-maker's library. While some of the projects may not be of interest to all, they provide great insight into how different projects can and should be tackled. I found myself re-reading chapters several times for information about projects that I am now thinking of tackling. *Astro-Imaging Projects for Amateur Astronomers* is definitely a keeper, and I look forward to additional works by Chung.

Rick Saunders

Rick Saunders is a DSLR astrophotographer and inveterate tinkerer from London, Ontario, where he designs and builds small electronic parts in an attempt to make the hobby simpler.

LETTER

On Galileo and the Moon

For many years astronomers have been puzzled about the identity of the over-sized crater that Galileo depicts on the lunar terminator in his *Sidereus nuncius* (1610). In 1974 I proposed that it was the crater Albategnius, a suggestion that has been widely adopted. In his interesting article on lunar history in the December issue of the JRASC, Klaus Brasch writes, "It took but one glance at the first-quarter Moon through the 20-power telescope to solve the mystery of the large crater; it was most likely the great walled plain, Albategnius..."

We were both wrong.

As it works out, this mystery cannot be solved by looking at the sky. Instead, the answer lies in Galileo's working draft of his book, preserved in the national library in Florence, and reproduced in facsimile in volume 3 part 1 of the so-called Favaro edition of his works. In studying this draft it becomes clear that the lunar images in the *Sidereus nuncius* are not intended as maps but as pictures that Galileo manipulated to illustrate the Earth-like features of the lunar surface. Originally he planned to use an additional pair of illustrations, numbered 6 and 7, to show two aspects of illumination for an arbitrary crater. (His original drawings, also in the Florentine library, show no giant crater at all, so they are clearly additions in the *Sidereus nuncius*.) Eventually, however, he placed these details as typical insets onto his pair of quarter-Moon images.

Galileo must have soon regretted this change of plans, because in the process of finishing his book (a rush job!) he thought of a neat way to determine the height of a mountain on the Moon. This method used the illuminated tip of a mountain lying in the dark area beyond the terminator. Unfortunately, he had positioned the giant crater inset precisely over the place where the illuminated mountain peak lay, so he lost the chance to show the observational basis for his measurement.

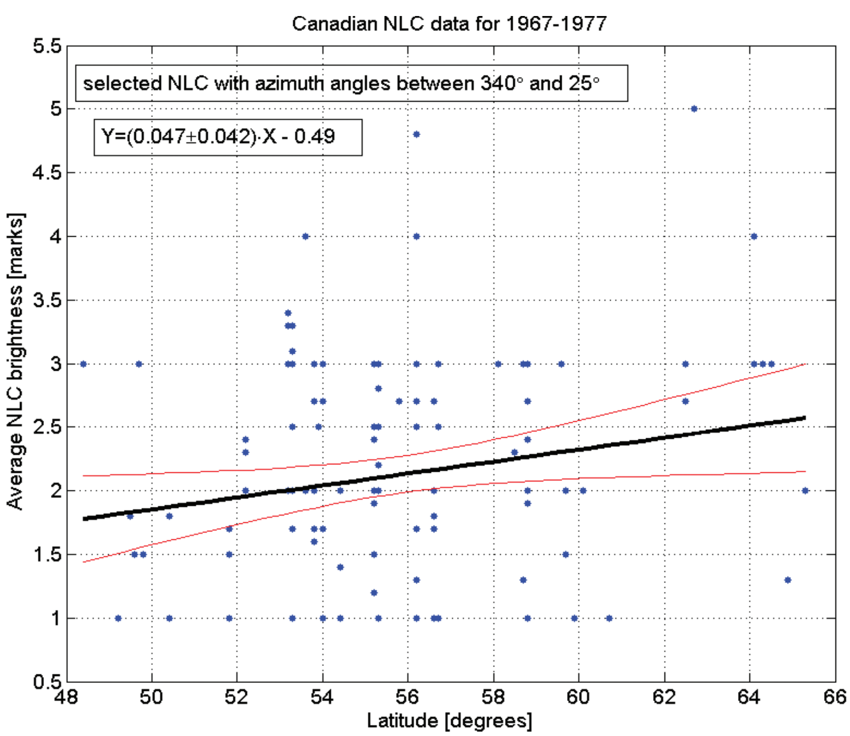
My extensive analysis of Galileo's manipulation of the lunar images is found in "The Mystery of the Missing 2" in the 2012 annual issue of the *Journal of Galilean Studies*, *Galilaeana* 9, 91-101, 2012.

Owen Gingerich
Harvard-Smithsonian Center for Astrophysics
Cambridge, MA, USA

ERRATUM

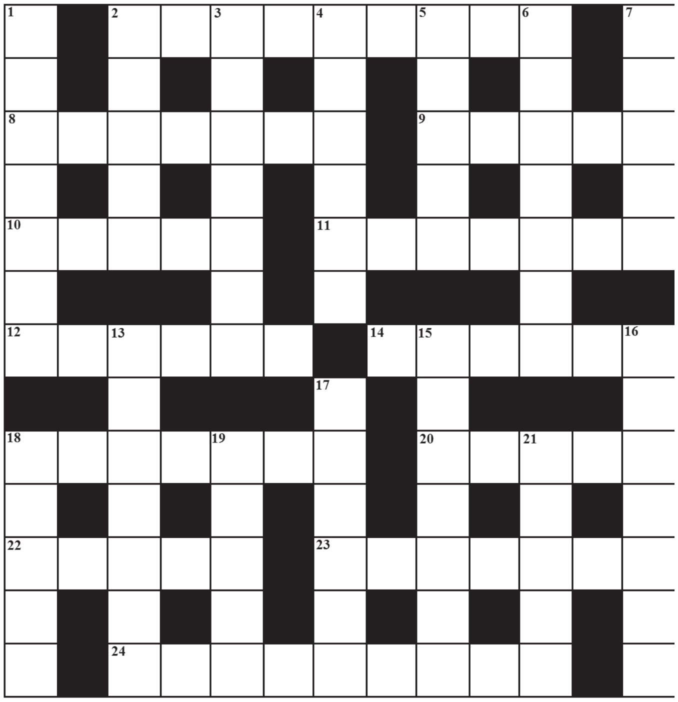
In the February issue of the *Journal* (research article "North American Noctilucent Cloud Observations in 1964-77 and 1988-2014: Analysis and Comparisons"), the image presented in Figure 7 on page 13 is incorrect. The correct image has been provided here. As well, the electronic web version for the February issue has been corrected and updated online.

We deeply regret the error.



Astrocryptic

by Curt Nason



ACROSS

2. Mom liked a spin on a possible galactic merger (9)
8. Unwary about a star expelled from the galaxy (7)
9. Mike sketches in disheveled toga around early Tuesday (5)
10. Courtyards highlighted by the peak of a triangle (5)
11. Planet doesn't start rotating in Draco's eye (7)
12. Segre's turn to observe Io's shadow leave Jupiter (6)
14. Look at star twinkling in cloud layers (6)
18. Colourful stars of Lear bio revision (7)
20. Wolf first looks up to us (5)
22. Set of dishes described in Bujold's Barrayar (5)
23. Altair's neighbour has lain around for years (7)
24. Our passion for an unusual stray moon (9)

DOWN

1. Browse the Web to get 100% on a test of galactic brightness (7)
2. Planet that isn't round nor trails half a mile (5)
3. Sam returns in slow rotation of stars with non-convective cores (3,4)
4. Babe with sex chromosome and incomplete gene seen in big stars (6)
5. Soundly consumed a number of planets (5)
6. Neat recycling used to detect pulsar signals (7)
7. Dwarf star he helped make a dwarf planet (5)
13. Rare bot developed by casual first neurologist in space (7)
15. Outer moon may settle uneasily by October 1st (7)
16. Supergiant product dizzies Americans after morning dropout (7)
17. Swordfish spears our ED between two parties (6)
18. Mad as hell in a ring around Neptune (5)
19. French astronomer emitted photon at an alien (5)
21. Ptolemy's ends are turning inside an extremely northern crater (5)

Answers to February's Astrocryptic

ACROSS

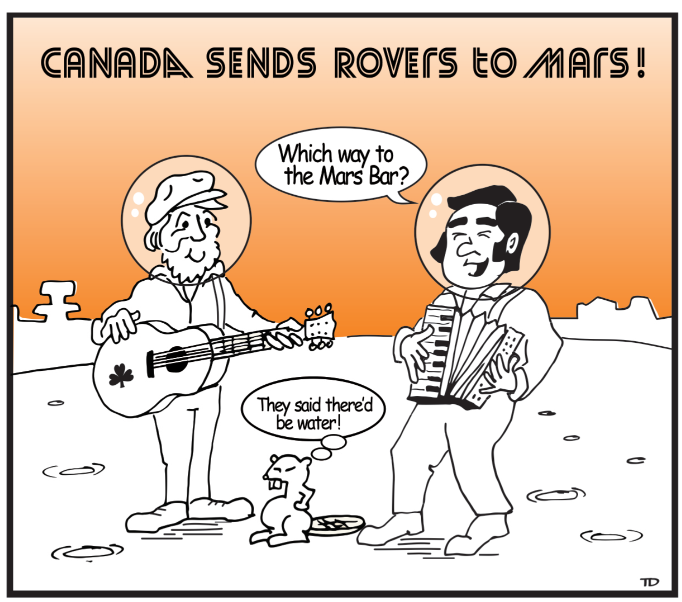
1 MIRACH (anag); **4** SHAULA (an(AU)ag); **9** MOTTLES (mot(TL)es); **10** EMBER (an(M)ag); **11** STRIP (St.+ RIP); **12** RAINING (hidden); **13** ORION NEBULA (anag); **18** PISCIUM (pi + anag); **20** LIGHT (see 17D); **22** LYDIA (anag); **23** RADIATE (an(rev)ag); **24** OBERON (anag, I=Be); **25** ASPECT (anag + T)

DOWN

1 MIMOSA (M + anag); **2** ROTOR (anag + r); **3** CALYPSO (anag); **5** HAEDI (h + rev); **6** UMBRIEL (anag); **7** AURIGA (Au + Riga); **8** ASTRONOMERS (anag); **14** RESIDUE (an(U)ag); **15** BOLIDES (Bo(LI)des); **16** APOLLO (2 def); **17** STREET (LIGHT) (s(anag)ight); **19** IMAGO) (I + MAGO); **21** GRAZE (homonym)

It's Not All Sirius

by Ted Dunphy



THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

Great Images

by Daniel Posey

Daniel Posey imaged the Bubble Nebula from the Victoria Centre Observatory on the grounds of the Dominion Astrophysical Observatory. The monochrome image consists of 3 hours and 40 minutes of 21 sub frames with a QSI583c using a 3-nm-wide hydrogen-alpha filter. The frames were captured at a cooled temperature of -30 °C and shot through a Tele Vue 127is (660 mm focal length) He calibrated the image with dark and bias frames and stacked/processed the image in PixInsight.

Journal

Great Images

Sheila Wiwchar says she was determined to get this particular shot. Braving the -38 °C windchill, Wiwchar headed about 15 km out of Winnipeg hoping clouds would clear, and it was well worth the gamble. She set up and managed to get comet C/2013 US10 (Catalina) while it made its closest approach to Earth and as it appeared close to M101.