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Journal

Le Journal de la Société royale d'astronomie du Canada

PROMOTING ASTRONOMY IN CANADA

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Volume/volume 110
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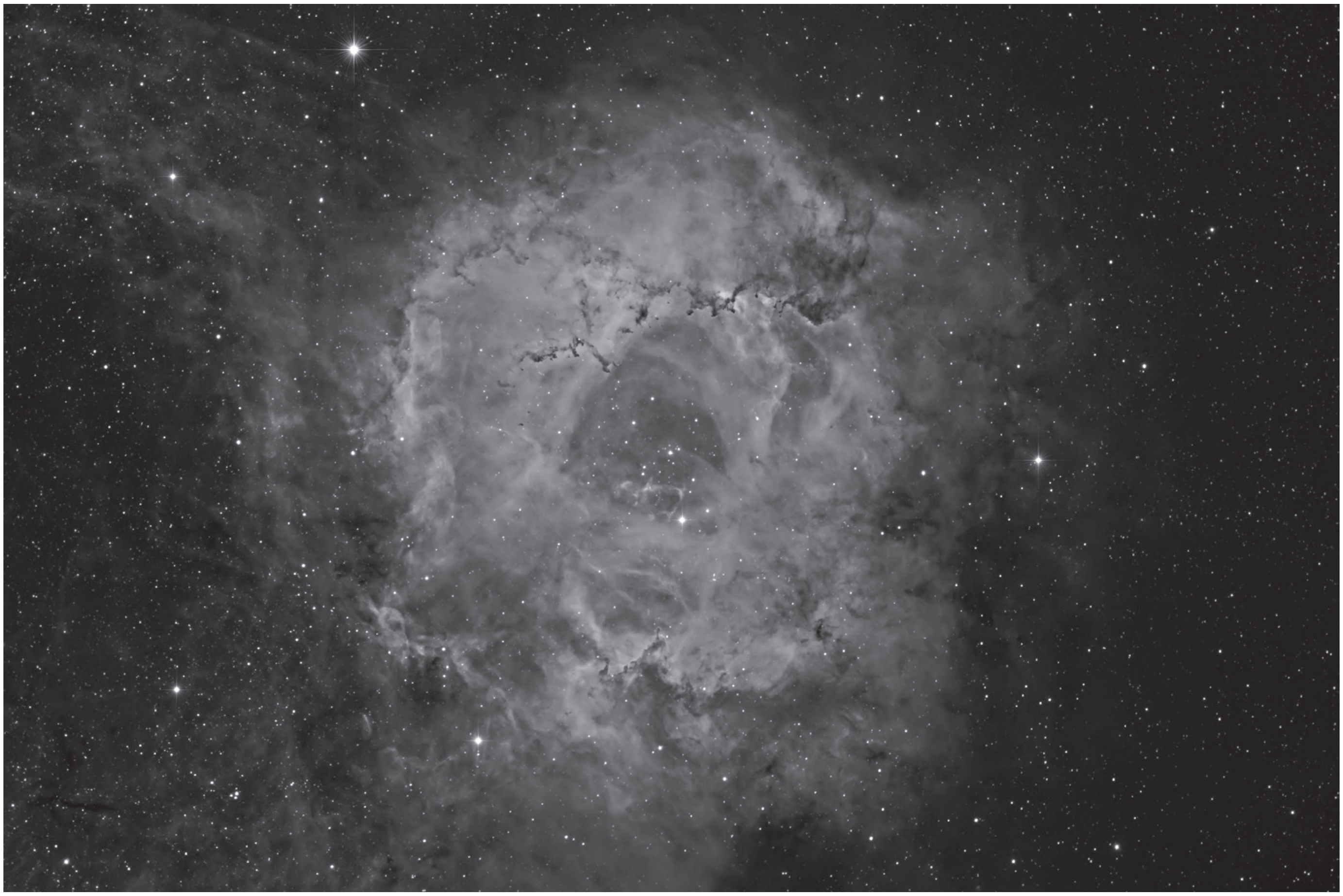
Inside this issue:

Mercury's Transit

The Best of Monochrome.

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



Joel Parkes imaged the Rosette Nebula in Hα for a total of two hours using a Takahashi 130-mm refractor ƒ/6.2, and an SBIG STL 11000M CCD with an Astrodon Gen I Hα 5-nm filter.

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

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Ian Wheelband shot this image of the Mercury transit on 2016 May 9 from the RASC's Carr Astronomical Observatory in Thornbury, Ontario. He used a Stellarvue SV80 ED F7, with HoTech field flattener and a Kendrick visual solar filter on a SkyWatcher Star Adventurer along with a Nikon D7100, 1/250th sec at ISO 100.

Journal

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

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President's Corner

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

The Yukon Astronomical Society officially became the RASC Yukon Centre on Monday evening, June 6, in Whitehorse. I was there representing the Society, having made the arrangements while I was still President. The Executive of the new Centre are President Anthony Gucciardo, his wife, Catheryne Lord, as Secretary, and Treasurer Viktor Zsohar.

I was royally treated on arrival by air on Sunday, getting the grand tour of Whitehorse, seeing some of the locations being scouted for an observatory, Bar-B-Qued burgers and pasta at the Gucciardo residence, with homemade pasta sauce (yummy!), a tour and tasting session at Yukon Brewing. And, that was just the first afternoon!

Tuesday was more of the same, beginning with coffee at a local outlet where we met Scott Acton and Elizabeth Carlisle of the James Webb Space Telescope World Bicycle Tour, then off to CBC North for a radio interview on Leonard Linklater's Midday Café, where we spoke about the importance for Whitehorse to have an RASC Centre and all that it entails. Then, it was lunchtime at the Klondike Rib & Salmon, where I was told by a friend here in Melville that I MUST eat there. Jeniffer worked there a few years ago, and I was sure given a warm welcome by the restaurant owner! Then it was time to round up the telescopes used for the opening ceremony at Yukon College and get set up. The Centre had a couple of solar scopes on hand, just in case the clouds parted enough to see the Sun. And, they did. Interestingly, there wasn't a blemish on the Sun's surface—not one sunspot!

The inauguration of the Yukon Centre went off without a hitch. Opening remarks by Anthony Gucciardo were given in French by Catheryne Lord, and I followed with a few words welcoming the new Centre into the fold of the RASC. A local sponsor, Garry Umbrich, who donated a rotating dome structure and some land at Takhini Hot Pools for the Centre's observatory, spoke of the importance for Whitehorse tourism to have such a vibrant team willing to impart their science knowledge to all.

Figure 1 — L–R: James Edgar, Anthony Gucciardo, Viktor Zsohar, Scott Acton

I then spoke in the college meeting room presenting *Synthesis of Elements in Stars*, my favourite talk. The assembled guests, members, and public were an attentive audience. Then we realized suppertime had breezed right by and we were famished. Whitehorse has a cure for hunger, and we willingly underwent immediate treatment!

The next day, Tuesday, was a true adventure, where Viktor, Anthony, and I drove to Skagway, about two hours away, to then fly by helicopter to Meade Glacier, spend some time on the glacier surface, and learn about the science of glaciology from local guides. What a memorable experience—one I won't soon forget!

Then, it was back to reality, flying to Saskatchewan on Wednesday. It's always nice to be home, but my mind is still reeling from my amazing Yukon adventure! ✶

News Notes / En Manchettes

Compiled by Jay Anderson, FRASC

Getting under Jupiter's skin

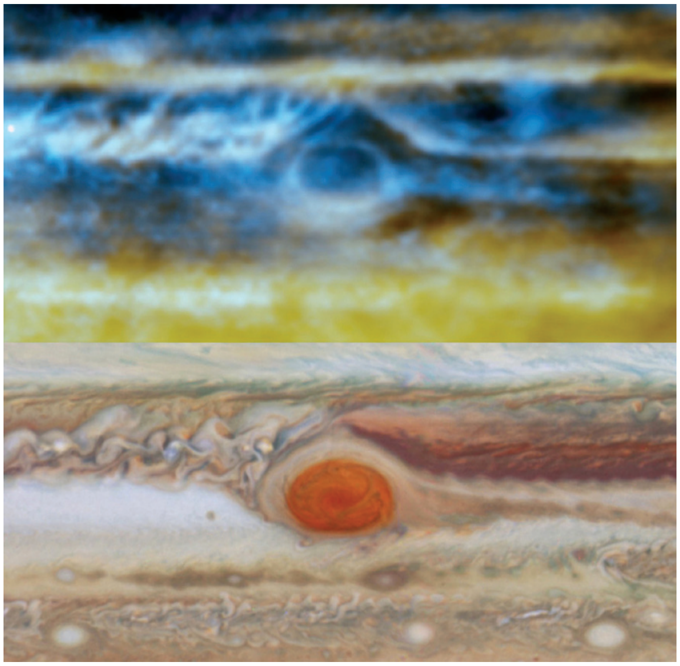


Figure 1 — The VLA radio map (top) of the region around the Great Red Spot in Jupiter's atmosphere shows complex upwellings and downwellings of ammonia gas that shape the colourful cloud layers seen in the approximately true-color Hubble Space Telescope *map (bottom). Two radio wavelengths are shown in blue (2 cm) and gold (3 cm), probing depths of 30-90 kilometres below the clouds. Radio image by Michael H. Wong, Imke de Pater (UC Berkeley), Robert J. Sault (Univ. Melbourne). Optical image by NASA, ESA, A.A. Simon (GSFC), M.H. Wong (UC Berkeley), and G.S. Orton (JPL-Caltech).*

NASA's *Juno* mission to Jupiter will have reached the giant planet before you read this article, but scientists at the University of California, Berkeley, not content to wait, have peered deep into the planet's atmosphere with the upgraded Karl G. Jansky Very Large Array (VLA) in New Mexico and have obtained new insights about the planet's weather systems. The UC Berkeley astronomers measured thermal radio emissions in the 4–18 gigahertz band, where Jupiter's clouds are transparent. At these wavelengths, the thermal emissions are partly absorbed by ammonia gas, so that the researchers could determine both the amount and depth of the absorbing gas. The observations only became possible because of recent upgrades to the VLA that increased its sensitivity by a factor of ten.

"We now see fine structure in the 12 to 18 gigahertz band, much like we see in the visible, especially near the Great Red Spot, where we see a lot of little curly features," noted Michael Wong, a member of the research team. "Those [features] trace really complex upwelling and downwelling motions there."

The radio map shows ammonia-rich gases rising into and forming the upper cloud layers: an ammonium hydrosulfide cloud at a temperature near 200 Kelvin (–73 degrees Celsius) and an ammonia-ice cloud in the approximately 160 Kelvin cold air (–113 degrees Celsius). These clouds are easily seen from Earth by optical telescopes. Conversely, the radio maps also show ammonia-poor air sinking down into the planet, opening holes in the cloud-cover similar to how descending air from upper layers dissipates clouds on Earth.

The analysis revealed an active weather system in Jupiter's upper atmosphere in which plumes of ammonia swell up in wave patterns to form bands tens of thousands of kilometres across. These bands are interspersed with vast cloudless regions, where dry air descends. "The overall dynamic picture is still correct, but now we see a lot of fine detail on that picture," explained Imke de Pater, who led the new study. The observations also resolve a puzzling discrepancy between the ammonia concentration detected by the *Galileo* probe when it plunged through the atmosphere in 1995—4.5 times the abundance observed in the Sun—and VLA measurements from before 2004, which showed much less ammonia gas than measured by the probe.

The map also shows that hotspots—so-called because they appear bright in radio and thermal infrared images—are ammonia-poor regions that encircle the planet like a belt just north of the equator. Between these hotspots are ammonia-rich upwellings that bring ammonia from deeper in the planet.

Compiled from notes provided by the University of California, Berkeley.

New *Hubble* image of Mars

Last May, Earth and Mars were closer to each other than at any time in the last ten years. The NASA/ESA *Hubble Space Telescope* exploited the opposition to catch a new image of our red neighbour, showing some of its famous surface features. On May 12, ten days before the date of closest approach, *Hubble* turned its gaze towards Mars to take an image of our rusty-hued neighbour, adding it to the collection of previous images. From this distance, the telescope could see Martian features as small as 30 kilometres across. This image supplemented previous *Hubble* observations of Mars and allows astronomers to study large-scale changes on its surface.

Using its Wide Field Camera 3 (WFC3), *Hubble* obtained a sharp, natural-colour view of Mars that revealed several prominent geological features, from smaller mountains and erosion channels to immense canyons and volcanoes.

In Figure 2, the large, dark region to the far right is Syrtis Major Planitia, one of the first features identified on the

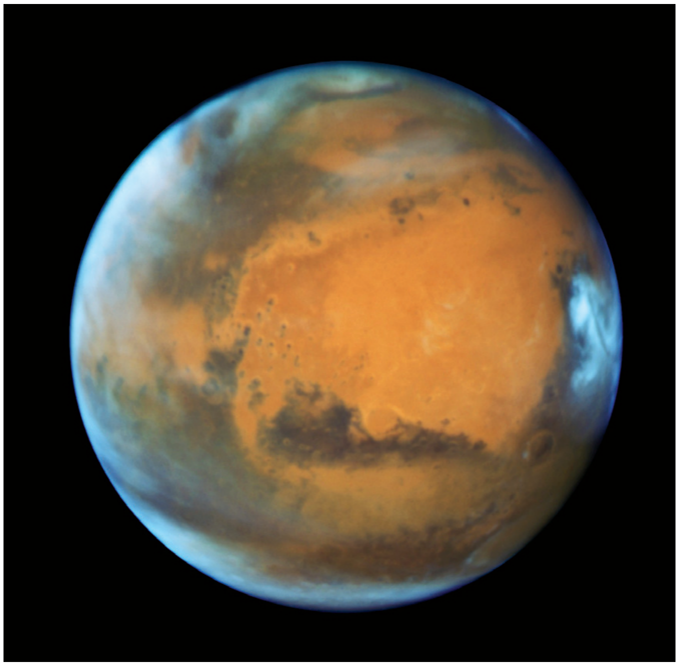


Figure 2 — During May the NASA/ESA Hubble Space Telescope *has exploited the opposition of Mars to catch a new image of our red neighbour, showing some of its famous surface features. Image: NASA*

surface of the planet by 17th-century observers. Syrtis Major is an ancient, inactive shield volcano. Late-afternoon clouds surround its summit in this view. The oval feature south of Syrtis Major is the bright Hellas Planitia basin, the largest crater on Mars. About 1,800 kilometres across and eight kilometres deep, it was formed about 3.5 billion years ago by an asteroid impact.

The orange area in the centre of the image is Arabia Terra, a vast upland region. The landscape is densely cratered and heavily eroded, indicating that it could be among the oldest features on the planet.

South of Arabia Terra, running east to west along the equator, are the long dark features known as Sinus Sabaeous (to the east) and Sinus Meridiani (to the west). These darker regions are covered by bedrock from ancient lava flows and other volcanic features.

An extended blanket of clouds can be seen over the southern polar cap. The icy northern polar cap has receded to a comparatively small size because it was late summer in the northern hemisphere.

Prepared with material provided by NASA and the ESA.

Herschel illuminates the Milky Way

The European Space Agency's (ESA) *Herschel* mission released a series of unprecedented maps of star-forming hubs in the plane of our Milky Way galaxy and a set of catalogues listing hundreds of thousands of compact sources that span all phases

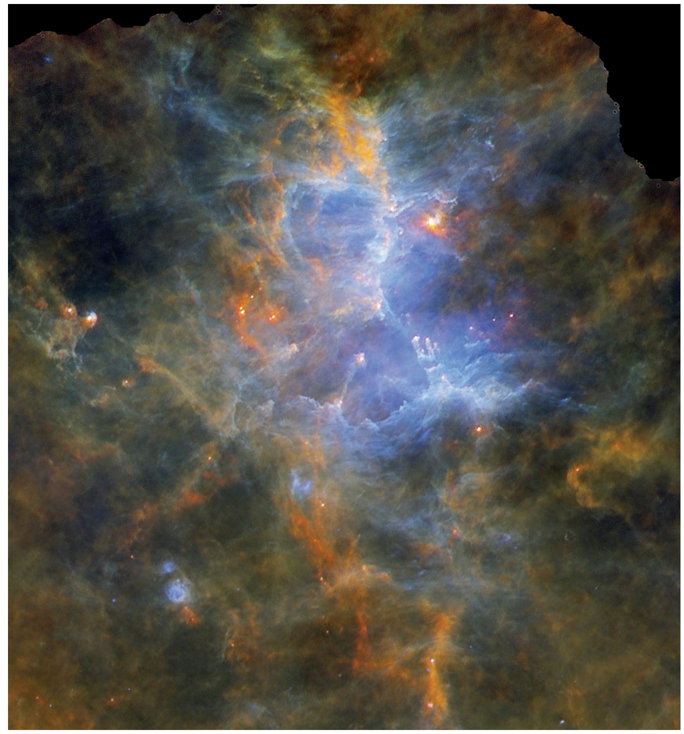


Figure 3 — The Eagle Nebula, also known as M16, seen by ESA's Herschel Space Observatory*. A group of young, bright stars, not visible at these infrared wavelengths, are located near the centre of the image. The powerful light emitted by these stars is setting the surrounding gas ablaze, causing it to shine; the stars also drive mighty winds that are carving the giant cavities in the cloud. At the borders of these cavities, the interstellar mixture of gas and dust becomes denser, eventually collapsing and giving rise to a new generation of stars. The image is a composite of the wavelengths of 70 microns (blue), 160 microns (green), and 350 microns (red). Image: ESA/Herschel/PACS, SPIRE/Hi-GAL Project. Acknowledgement: G. Li Causi, IAPS/INAF, Italy*

leading to the birth of stars in our galaxy. These maps and catalogues will be very valuable resources for astronomers, to exploit scientifically and for planning follow-up studies of particularly interesting regions in the Galactic Plane.

During four years of operations (2009–2013), the *Herschel Space Observatory* scanned the sky at far-infrared and sub-millimetre wavelengths. Observations in this portion of the electromagnetic spectrum are sensitive to some of the coldest objects in the Universe, one of which is cosmic dust, a minor but crucial component of the interstellar material from which stars are born.

The *Herschel* infrared Galactic Plane Survey (Hi-GAL) is the largest of all observing programs carried out with *Herschel*, in terms of both observing time—more than 900 hours of total observations—and sky coverage—about 800 square degrees, or two percent of the entire sky. Its aim was to map the entire disc of the Milky Way, where most of its stars form and reside, in five of *Herschel*'s wavelength channels: 70, 160, 250, 350, and 500 μm.

Over the past two years, the Hi-GAL team has processed the data to obtain a series of calibrated maps of extraordinary quality and resolution. With a dynamical range of at least two orders of magnitude, the maps provide an unprecedented view of the Galactic Plane, ranging from diffuse interstellar material to denser filamentary structures of gas and dust that fragment into clumps where star formation sets in. They include pre-stellar clumps, protostars in various evolutionary stages, and compact cores on the verge of turning into stars, as well as full-fledged stars and the bubbles carved by their highly energetic radiation.

On April 22, the team released the first part of this data set, consisting of 70 maps, each measuring 2 × 2 degrees, and provided in the five surveyed wavelengths.

"These maps are not only stunning from an aesthetic point of view, but they represent a rich data set for astronomers to investigate the different phases of star formation in our galaxy," explains Sergio Molinari from IAPS/INAF, Italy, and Principal Investigator for the Hi-GAL Project.

The maps cover the inner part of the Milky Way, toward the Galactic Centre as seen from the Sun, with galactic longitudes between +68° and -70°. A second release, with the remaining part of the survey, is foreseen for the end of this year.

"It is not straightforward to extract compact sources from far-infrared images, where pre-stellar clumps and other proto-stellar objects are embedded in the diffuse interstellar medium that also shines brightly at the same wavelengths," explains Molinari. "For this reason, we developed a special technique to extract individual sources from the maps, maximizing the contrast in order to amplify the compact objects with respect to the background."

Prepared using material provided by the ESA.

Exoplanet motion hints at unseen companions

HD 95086 is an A-type star that hosts a dusty debris disk and a hefty 4–5 Jupiter-mass planet (HD 95086b) that is extremely red in colour. Past observations at infrared wavelengths have shown that the star is likely surrounded by a three-part debris disk: a warm inner belt, a colder outer belt, and a large halo. Observations from the *Herschel Space Observatory* suggest that a large gap is present between the two belts.

Using the Gemini Planet Imager (GPI) at the 8.1-metre Gemini South telescope in Chile, a large international team led by Julien Rameau, a postdoctoral researcher at the Université de Montréal, has been able to directly monitor the orbit of the planet from 2013 until early this year. With the extended positional data, the researchers determined that the planet is orbiting nearly face-on from our perspective, at about 60 astronomical units or twice the distance between our Sun and Neptune, in a nearly circular orbit. The orbital parameters for HD 95086b allowed the research team to conclude that HD 95086b "cannot carve the entire gap inferred from the measured infrared excess…" Rameau noted, "Because of the orbital configuration of planet b, we conclude that another body, or bodies, are necessary to explain the architecture of the system." The researchers suggested that either two planets on moderately eccentric orbits, or three to four planets with inhomogeneous masses and orbital properties are possible.

The GPI is an extreme adaptive-optics imaging polarimeter and spectrometer that provides high-contrast, diffraction-limited data between 0.9 and 2.4 microns at separations of 0.2–1 arcsecond in a 1–2 hour observation. GPI's adaptive-optics technology greatly reduces the blurring effect of the Earth's atmosphere, resulting in higher-resolution images. A coronograph blocks the light of the star that would normally hide the much dimmer exoplanet. A spectrograph separates the light of the exoplanet according to wavelength, revealing the distant world's composition, temperature, age, and other characteristics.

Prepared with material provided by Gemini Observatory

Something's not right in the Universe

Astronomers using the W.M. Keck Observatory on Maunakea, Hawaii, have obtained the most precise measurement yet of how fast the Universe is expanding at the present

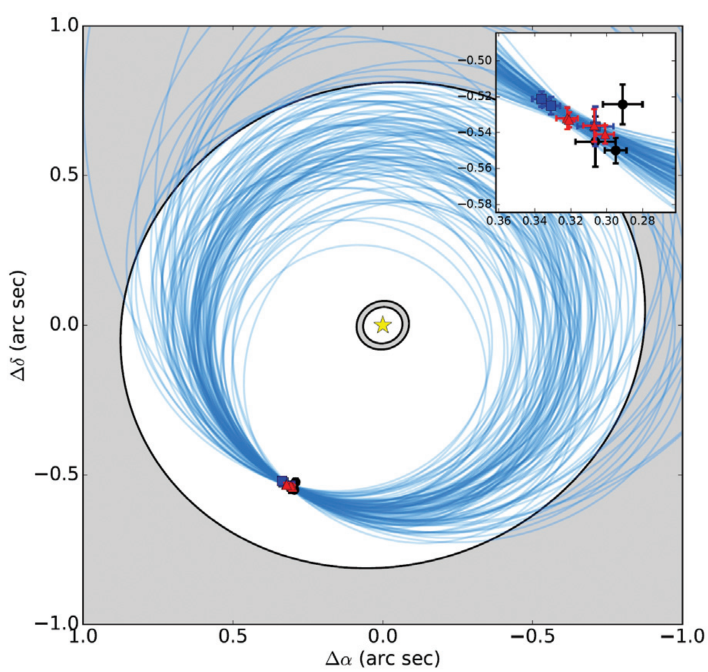


Figure 4 — Schematic diagram of the HD 95086 system in the sky plane. The positions of HD 95086b are plotted (black circles – VLT/NaCo L0, red triangles – GPI K1, blue squares – GPI H), as well as a hundred representative orbital fits randomly drawn from the analysis. The inner and outer dust rings are indicated as the gray shaded regions. The astrometric measurements are shown within an inset. Image: Gemini Observatory.

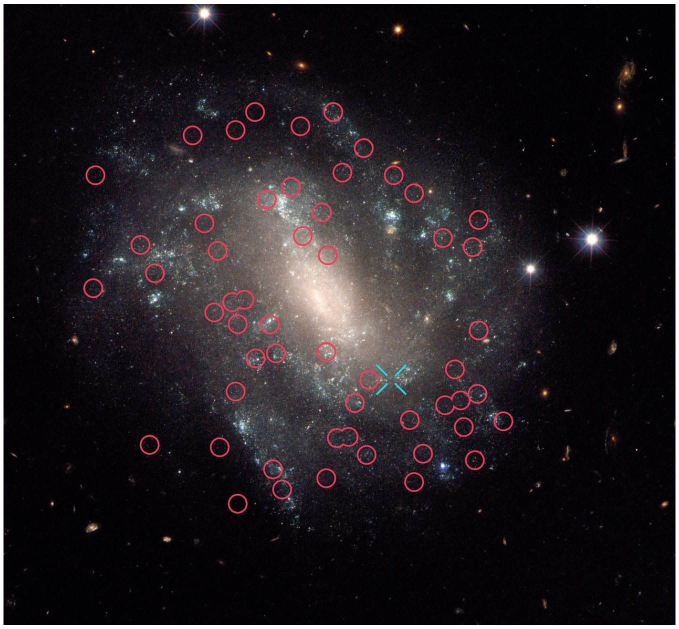


Figure 5 — An image of the galaxy UGC 9391, one of the galaxies in the new survey. UGC 9391 contains the two types of stars—Cepheid variables and a Type 1a supernova—that astronomers used to calculate a more precise Hubble Constant. The red circles mark the locations of Cepheids. The blue "X" denotes the location of supernova 2003du, a Type Ia supernova. Image: NASA, ESA, and A. Riess [STScI/JHU]

time, and it doesn't agree with predictions based on other data and our current understanding of the physics of the cosmos. The discrepancy—the Universe is now expanding nine percent faster than expected—means either that measurements of the cosmic microwave background radiation are wrong, or that some unknown physical phenomenon is speeding up the expansion of space.

"If you really believe our number—and we have shed blood, sweat, and tears to get our measurement right and to accurately understand the uncertainties—then it leads to the conclusion that there is a problem with predictions based on measurements of the cosmic microwave background radiation, the leftover glow from the Big Bang," said Alex Filippenko, a UC Berkeley professor of astronomy and co-author of the paper announcing the discovery.

Using the Keck-I 10-metre telescope, Filippenko's group measured the chemical abundances of gases near the locations of Cepheid variable stars in the nearby galaxies hosting Type Ia supernovae. This allowed them to improve the accuracy of the derived distances of these galaxies and thus to more accurately calibrate the peak luminosities of their Type Ia supernovae.

"We've done the world's best job of decreasing the uncertainty in the measured rate of universal expansion and of accurately assessing the size of this uncertainty," said Filippenko, "yet we find that our measured rate of expansion is probably incompatible with the rate expected from observations of the young Universe, suggesting that there's something important missing in our physical understanding of the Universe."

The cause could be the existence of another, unknown particle—perhaps an often-hypothesized fourth flavour of neutrino—or that the influence of dark energy has increased over the 13.8-billion-year history of the Universe. Or perhaps Einstein's general theory of relativity, the basis for the Standard Model, is slightly wrong. "This surprising finding may be an important clue to understanding those mysterious parts of the Universe that make up 95 percent of everything and don't emit light, such as dark energy, dark matter, and dark radiation," said Nobel Laureate Adam Riess, the leader of the study from the Space Telescope Science Institute and Johns Hopkins University.

A few years ago, the European Space Agency's *Planck Observatory* measured fluctuations in the cosmic background radiation to document the Universe's early history. *Planck*'s measurements, combined with the current Standard Model of physics, predicted an expansion rate today of 66.53 (±0.62) kilometres per second per megaparsec. The new direct measurements yield a rate of 73.24 (±1.74) km/sec/Mpc, an uncertainty of only 2.4 percent and clearly incompatible with the Planck predictions, Filippenko said.

The team looked for galaxies containing both Cepheid variables and Type Ia supernovae. Cepheid stars pulsate at rates that correspond to their true brightness, which can then be compared with their apparent brightness as seen from Earth to accurately determine their distance and thus the distance of the galaxy. Type Ia supernovae are exploding stars that flare with the same intrinsic brightness and are brilliant enough to be seen from much longer distances.

By measuring about 2,400 Cepheid stars in 19 nearby galaxies and comparing the apparent brightness of both types of stars, they accurately determined the true brightness of the Type Ia supernovae. They then used this calibration to calculate distances to roughly 300 Type Ia supernovae in far-flung galaxies.

Aside from an increase in the strength with which dark energy is pushing the Universe apart, and the existence of a new fundamental subatomic particle—a nearly speed-of-light particle called "dark radiation"—another possible explanation is that dark matter possesses some weird, unexpected characteristics. Dark matter is the backbone of the Universe upon which galaxies built themselves into the large-scale structures seen today. ✶

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

Editor's note

by Nicole Mortillaro

This year I attended my first General Assembly. While I wasn't sure what to expect, I certainly wasn't disappointed.

It was marvellous to listen to the talks by so many prominent and engaging speakers, as well as meeting so many people, especially those with whom I'd corresponded with over the years. But I was particularly thrilled and honoured to have met and spoken with David Levy. Though this was not our first encounter, it was definitely the most memorable, as I was able to speak one-on-one with this successful and amazingly humble astronomer.

David needs no introduction. His contributions to astronomy, particularly the discovery of comets, are well known.

I remember reading about David when I was a young. I was fascinated by his findings. I couldn't understand how one Earth-bound person could find these small pieces of space debris millions of kilometres out in space. And this was far before the advent of digital cameras and technology that facilitates these discoveries (not that I'm saying it's easy today).

And then there was Comet Shoemaker-Levy 9.

In 1994, Comet Shoemaker-Levy 9 was slated to slam into Jupiter's atmosphere. Nobody knew what to expect. It was thrilling. For me, I watched it alongside my 11-year-old sister from York University Observatory. It was all I could do to tear myself away from the eyepiece.

The discovery of Shoemaker-Levy 9 forever changed the way we looked at our home—we began to truly understand the danger asteroids and comets pose to our small planet.

But I digress.

It is with great pleasure that I announce the addition of a regular column by David Levy in the *Journal*. I am sure that you, as do I, anticipate great insight into his work, both current and past, and his ruminations on astronomy as a whole. ✶

Research Article / Article de recherche

Two Telescope Mysteries in One: Sudbury's "Vatican mirror"

by Clark Muir (K-W Centre)
cmuir10@rogers.com

Within the Sudbury Astronomy Club in Sudbury, Ontario, there has been a popular mystery involving the origins of a 20-inch f/6.5 telescopic mirror. The mirror, long cleaned of its optical coating, at 4.5-inches thick, weighs in at a hefty 45 kg. It is accompanied by a more than 20-kilogram mirror cell that was custom-made for the massive glass. It is an imposing sight.

Some of the details as to how the mirror arrived in Sudbury were known to a few, but beyond that, the particulars grow vague. It was believed to be more than 100 years old, but who owned it, who built it, and where it came from remained elusive. Conventional wisdom was that the mirror was brought to Sudbury in the 1960s by a gentleman who was a priest and who had worked for some time at the Vatican. The nickname, perhaps humorously assumed to the mirror and cell, was the "Vatican mirror."

This curiosity was not just notorious within the overactive astronomy community in Sudbury. On 2008 February 16, Lara Bradley of the *Sudbury Star* wrote a full page article "Mysteries Abound at Astronomy Club" dedicated to the affair. The article displayed a picture of the huge glass disk showing its distinct greenish hue. Two members of the Sudbury astronomy club, Robert Pothier—the president at that time—and telescope-maker Alan Ward, are posing with the glass.

The Sudbury connection to the mystery begins with Father Roger Leclair (1912–1989). Among his educational pursuits were his studies in astronomy at Harvard University and Georgetown University in Washington where he completed his Ph.D. in 1950. His fascinating career had him stationed at the Vatican Observatory in Rome (1950–1952). Later, he worked at the Canadian college of Addis Ababa in Ethiopia (1955–1957).

Leclair was an influential figure in building Sudbury's astronomy legacy. During his years at Laurentian University (LU) he helped secure a planetarium for the university and was head of the physics department through much of the 1960s. Leclair was also a Life Member of The Royal Astronomical Society of Canada.

In the late 1960s, Fr. Leclair had ordered all the parts to build a telescope around the 20-inch mirror and cell. The telescope was to be mounted on a new fifth floor observatory in the Fraser Science Building at LU in Sudbury.

Paul-Emile Legault, who joined LU in 1968, was given the task to assemble the components and create a fully working observatory. Paul-Emile is still at LU as director emeritus.

A description of this mammoth telescope comes from Steve Dodson (aka Stargazer Steve). Dodson toured the Department of Physics and Astronomy at LU in 1977.

> *"The Tube was white in colour and very generous in girth, perhaps 26–28 inches in diameter. I climbed the observer's ladder, and found I could barely reach over the top of the huge tube and touch the focuser, which faced away from my perch. The eyepiece was completely out of reach of eye or hand at the end of a nearly two-foot extension tube. The open end of the tube was only a few inches beyond the focuser axis. A heavy steel plate had been rolled to a mating half-cylinder and was bolted to the tube opposite the focuser. The telescope was not moved on its axes during our visit, but one can imagine the large sideways movement of such a large heavy system on a long declination axis would have been difficult to manage safely."*

Dodson later stated that the telescope was never able to function properly. The reason for this was that the telescope had been designed for a larger dome than was actually built. During construction a startling discovery was made by Legault. The copies of the official blueprints conflicted on the size of the dome. In actuality, the dome for the observatory was 4.9 metres in diameter. Unfortunately, the prints used by the telescope designers erroneously showed the dome as 6.1 metres in diameter!

The only solution available was to modify the design. This led to all sorts of technical problems, including the need for enormous counterweights. The many design changes eventually led to the dismantling of the telescope.

Figure 1 — "Vatican Mirror" the nickname given to the 20-inch primary mirror that has been used twice in telescopes custom built in Canada. The first was built in 1903. Photo: Alan Ward, April 2015.

Figure 2 — The large mirror during fabrication is shown on a barrel with a worker. Note the notches chiselled on the side of the glass. The mirror cell can be seen in the background leaning against a window. Photo: Scientific American, 1903 January 24.

In 1986, Fred Boyer and Greg Beach (president and vice-president of the Sudbury Astronomy Club) refitted the observatory with their 17.5-inch truss-tube telescope on a German-Equatorial Mount. The details of this project were featured in *Sky & Telescope* magazine in May 1987 (p. 554).

The Cell "Mirror of Justice"

The cell is as massive as the mirror would demand. There are eight heavy brackets on the mount that secure the mirror. Eight equally spaced notches have been chiselled out of the side of the glass to accommodate each bracket.

The cell has some interesting features that preserve clues as to the origins of the mirror. The Latin phrase "Speculum Justitia" (Mirror of Justice) has been etched on a metal plate along with a stylized "M" that symbolizes the Virgin Mary. The plate is securely fastened to the back of the cell.

Montréal 1903

A fascinating story dating back to 1903 gives the details of a 20-inch telescope built by Jesuits in Montréal.

In a *Scientific American* article from 1903 January 24, details were given about a custom telescope being built by Jesuits at the Loyola College in Montréal, Québec. Fortuitously, several high-quality photographs were included in the article. Similar details were published in the *New York Tribune* (1903 March 8, p. 14).

The article indicated that, upon completion, it would be the largest telescope in Canada. A reflector of 20 inches was housed in a huge 11-foot tube made of glued paper. The article also highlighted the method used to grind, polish, and "silver" the mirror. Upon completion, the telescope is shown in the *New York Tribune* article towering above a builder's head in its equatorial mount.

The 20-inch blank was ground to an $f/6.5$ curve (identical to the Sudbury mirror). Furthermore, in one of the photographs, the mirror cell can be seen leaning on a background window. The cell is easily identifiable as the one in Sudbury. In the same photograph, the mirror is shown with several large notches ground out on its side. This is also a feature recognized on the Sudbury 20-inch.

When individuals recently became aware of both narratives, it quickly become obvious to them that the mirror and cell in each story were one and the same. Two mysteries were solved simultaneously!

Although it cannot be confirmed, the *Scientific American* article asserts that the mirror blank was made by the Mantois firm in France. Eduard Mantois is best known for the outstanding blanks he produced for many of the greatest refractors ever built. The blanks for the Yerkes 40-inch (completed in 1897), and the great 49-inch refractor for the Paris fair "Exposition Universelle" in 1900, are just two examples of his work. Although the Sudbury glass was clearly designed for a reflecting telescope, it is intriguing to note that this may be its origin.

Figure 3 — Mirror cell with Latin inscription and Marian Symbol. Speculum Justitia. Photo: Alan Ward

After completion of the Montréal telescope in the spring of 1903, all traces of its existence disappear. Where did it go?

The 20-inch Montréal telescope's planned purpose is still unknown. Was it intended for the use of college students? Or could it have been used for a more specific purpose such as comet hunting? All indications are that the telescope was never used. An extensive search has not shed any light (pardon the pun) on its intended use. There are, however, a few small clues about a couple of the men who helped build it.

The authoritative figure in the construction of the Montréal telescope is Father Geraix S.J. (sometimes

Gerais). Fr. Geraix left Canada for Asia in 1905, well after the completion of the telescope. While there, Fr. Geraix was a witness and survivor of the deadly typhoon of September 1906 that struck Hong Kong. Fr. Geraix was on the steamer Heungshan that became shipwrecked on its way to Hong Kong from Macao. A few of the 500 or so passengers drowned while the rest waited for rescue on an uninhabited island.

The other known person probably involved was Rev. I.J. Kavanagh (also an RASC member). The RASC Archives documents reveal that Rev. Kavanagh was involved in the prominent Canadian expedition to observe the 1905 August 30 total solar eclipse from Labrador. A large contingency of Canadian astronomers and scientists including C.A. Chant and J.S. Plaskett made the voyage to observe the eclipse.

Rev. Kavanagh was stationed at the Jesuit College in Montréal during the building of the telescope. It is almost certain that Rev. Kavanagh must have been involved with the design and building of it.

Fragile, Handle with Care

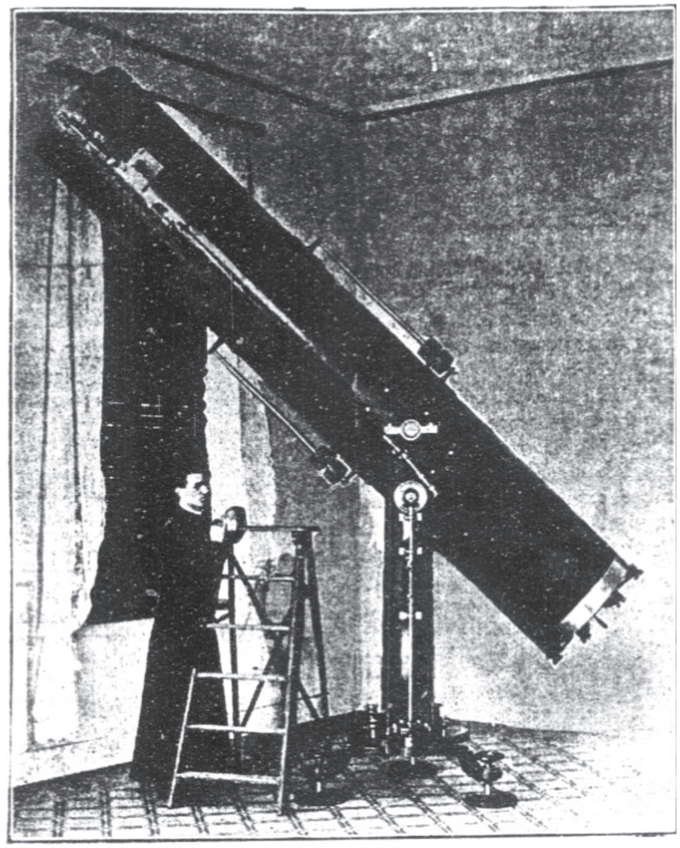
At least twice during the mirror's long history it has nearly been destroyed. Anyone who looks at the mirror will notice an enormous chip out of the back edge away from the polished surface. Alan Ward has examined the mirror and can confirm that a pressure wave was created when the mirror was dropped. When this drop occurred is not known. How close it was to being destroyed is anyone's guess.

At a much later date, a fire nearly destroyed the mirror again. The mirror had been moved only days before the fire. A heavy object would fall on the machinery in the very spot the mirror had been placed for examination.

Conclusion

It was noted earlier that the design by Jesuits in 1903 included a rolled paper tube. Although the tube weighed a hefty 250 lbs, the similarities to Sonotube that would decades later become a staple for future amateur telescope makers is apparent. It was John Dobson who later popularized this type of tube for his revolutionary design in telescopes.

The most reasonable deduction is that shortly after the completion of the Montréal 20-inch telescope, the obvious design flaws (including monstrous weight and undersized mount) made the telescope unusable. At some point, the tube, mount, etc. were dismantled and either discarded or recycled. The mirror and cell, however, were kept intact and stored somewhere, awaiting its resurrection.



THE COMPLETED TELESCOPE.

Figure 4 — Captioned "The Completed Telescope." The telescope is shown with the 3.4-metre tube towering above a builder. Photo from the New York Tribune 1903 March 8.

Miraculously, some six decades later, Fr. Leclair—doubtless through his connections within the clergy—learned of a 20-inch mirror that was available in Montréal. He transported the mirror and cell to Sudbury and helped design a new telescope around these components. As documented here, the telescope had irresolvable issues. The mirror and cell were once again put in storage.

After another five decades or so, the mirror and cell are now in the possession of Alan Ward. By today's standards, the mirror is pointlessly heavy. Unless for historical purposes, it would be unsound to build another telescope around it.

Given the remarkable journey the mirror has had, including surviving a near fatal drop, a fire, and twice stored for decades at a time, I can't help but wonder what the future holds for Sudbury's "Vatican mirror." ✶

Acknowledgements

The Author would like to thank Alan Ward, Steve Dodson, and the Sudbury Astronomy Club for their cooperation and contributions.

CHFT Chronicles: Nice Work, CFHT

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

Every three years, CFHT hosts a Users' Meeting in one of the countries in its partnership. This year's meeting was held the first week of May in Nice, France. The Users' Meeting gives CFHT staff and users the opportunity to discuss the science, instrumentation, and overall state of CFHT. For many CFHT staff members, the meeting is the first time they can meet people in person with whom they exchange regular emails. And for our constituency of astronomers, they meet the people who ensure they receive the highest quality data.

The Users' Meeting was full of exciting science and discoveries, some of which are so new that they simply cannot be shared yet. But we can provide summary of other science programs.

A Comet without a Tail and Saving the Earth

The Users' Meeting began with a press release from Dr. Karen Meech and her team at the University of Hawaii. Dr Meech and her team initially detected the comet using the Pan-STARRS on Haleakala, hence the comet's name: C/2014 S3 (PANSTARRS). Once they detected the comet, the team emailed CFHT to conduct rapid follow-up observations of the comet. Because comets contain ice, they sublimate as they move closer to the Sun in their orbit. The sublimating ice and escaping gas form the comet's characteristic tail. But there was something unusual about this comet. Upon realizing they were onto something very unique, the team observed the comet using ESO's Very Large Telescope (VLT) to obtain the comet's spectra.

The observations with CFHT and VLT show that C/2014 S3 (PANSTARRS) is the first object to be discovered with the orbit of an Oort Cloud comet, but the characteristics of an inner Solar System asteroid. The data indicated C/2014 S3's composition was typical of an S-type asteroid, which are generally found in the asteroid belt between Mars and Jupiter, not in the outer reaches of the Solar System. Furthermore, the comet looks more like a frozen asteroid and has a million times less comet activity than an active long-period comet at a similar distance. As a result, the tailless comet has been nicknamed a "Manx comet," after the tailless cat. This comet may provide important clues about how the Solar System formed. *(See figure 1.)*

In a paper published in the journal *Science Advances*, Karen Meech and her team conclude that C/2014 S3 was formed in the inner Solar System at the time that the Earth was forming, but was ejected into the Oort Cloud at a very early stage. Their observations indicate that it is an ancient rocky body, rather than a contemporary asteroid that strayed out. As such, it is one of the potential building blocks of the rocky planets, such as the Earth, that was expelled and preserved in the deep freeze of the Oort Cloud. The authors conclude that this object is probably made of fresh inner Solar System material that has been stored in the Oort Cloud and is now making its way back into the inner Solar System.

Because astronomers are unable to observe the formation of our Solar System, they use theoretical models to reproduce much of the structure we currently see. Multiple models exist and an important difference between the models relates to what they predict about the objects that make up the Oort Cloud, particularly the relative numbers of icy and rocky objects it contains. Comet C/2014 S3 is the first discovery of a rocky object from the Oort Cloud and is therefore an important test of the different predictions of the models. The team estimates that observations of 50–100 of these Manx comets are needed to distinguish between the competing current models.

Dr. Richard Wainscoat, a fellow UH astronomer with Meech and a co-author on the comet paper, presented his work on identifying near-Earth-orbiting asteroids or NEOs. Like Meech, most of Wainscoat's asteroids are first identified using Pan-STARRS. He then uses Megacam for follow-up and characterization of the asteroids. Oftentimes, his team used

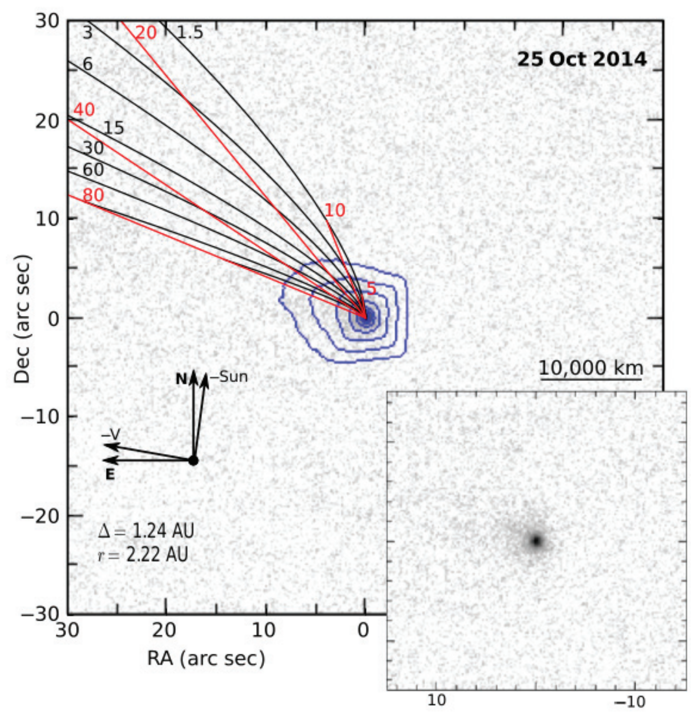


Figure 1 — CFHT image of C/2014 S3 (PANSTARRS) obtained October 25, 2014. The red and black lines map out the expected position of dusts released from the nucleus due to solar radiation. Meech and her team noticed the absence of dust along those lines- a clue to the strange nature of the comet.

Megacam's large field of view (1deg x 1deg) to follow up the most difficult objects; only about 10 percent of these "difficult" asteroids are not found by Megacam.

Wainscoat and his team not only look for asteroids, but comets as well. He estimates Pan-STARRS discovers more than half of the new comets with follow-up at CFHT. He started his talk by announcing, tongue-in-cheek, that his work at CFHT is trying to save the world—a statement that several other astronomers referred to during the course of the week. "We're not saving the world like Richard, but…"

PAndAS

From 2008 to 2010, CFHT embarked on the Pan-Andromeda Archaeological Survey (PAndAS) under the direction of Alan McConnachie at NRC Herzberg in Victoria. PAndAS mapped the Andromeda (M31) and Triangulum (M33) galaxies. The map of the Andromeda and Triangulum galaxies (see Figure 2) extends over approximately 450 square degrees of sky, centred on these two galaxies. Familiar images of Andromeda and Triangulum are superimposed, separated by approximately 15 degrees. The surrounding map shows the density of resolved red-giant-branch stars at the distance of Andromeda, as identified in over 400 pointings of CFHT/MegaCam. Red-giant-branch stars are those that have exhausted the hydrogen in their cores and have started fusion of hydrogen in a shell surrounding the core. They have luminosities of up to 3000 times our Sun, making them easier to trace than fainter stars.

The colour map refers to the mean colour (metallicity) of the giant stars, with blue indicating regions of lower mean stellar metallicity and red indicating regions of higher mean stellar metallicity. Clearly, the outskirts of Andromeda and Triangulum are much more extended than the bright central disks of these galaxies imply; a vast array of large-scale structures extending over, literally, hundreds of kiloparsecs is visible.

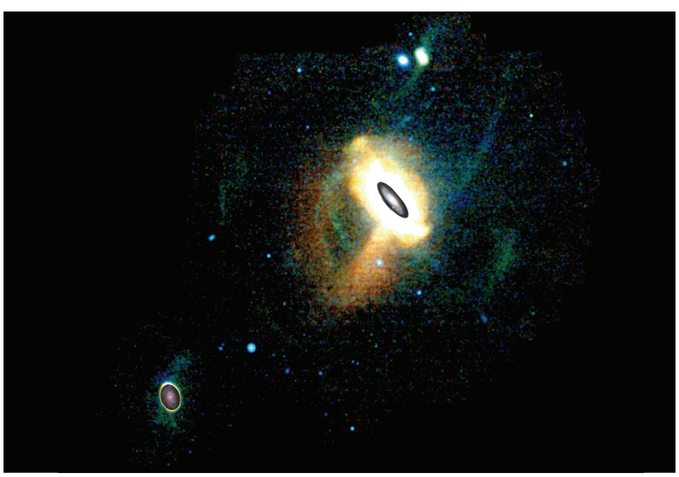


Figure 2 — PAndAs map of M31 and M33. The commonly imaged portions of both galaxies are overlaid over the deeper PAndAs images. The text describes the meaning of the colours in the images.

Triangulum exhibits a large-scale stellar disturbance in its outskirts, presumably a remnant of a past interaction between it and Andromeda. Also visible are a large contingent of dwarf-galaxy satellites. The two brightest of these are NGC 185 and NGC 147 at the top of the image, with a previously unknown stellar stream extending from NGC 147 in the shape of an "S." Many of the remaining bright-blue concentrations of stars surrounding Andromeda are metal-poor dwarf spheroidal galaxies, of which a total of 17 are new discoveries from this survey. This image is perhaps the most direct, visual confirmation of the ongoing hierarchical build-up of galaxies, as revealed by close inspection of their faint stellar outskirts.

The PAndAS survey provided astronomers with new insight into our nearest galactic neighbours. As of the Users' Meeting, 39 peer-reviewed papers, including two *Nature* articles, were written using PAndAS data. We call that a successful program!

NGVS

The Next Generation Virgo Survey (NGVS) ran at CFHT for six years with Megacam. NGVS took advantage of Megacam's wide-angle coverage, observing the Virgo cluster in its entirety—an area of the sky equivalent to over 400 full Moons. The depth and resolution of the survey significantly exceeded any other existing survey of Virgo. The resulting mosaic comprised nearly 40 billion pixels and is the deepest, widest, contiguous field ever seen in such detail. The NGVS team developed a data analysis technique that allowed them to discover many more times the number of galaxies in the field than were previously known. These discoveries included some of the faintest and most diffuse objects ever discovered.

I highlighted an NGVS discovery in our 2015 CFHT summary, a discovery of hundreds of new dwarf galaxies within the cluster. NGVS team members catalogued the globular clusters within the cluster, a whopping 67,000. Detailed studies of the globulars show differences exist between the globular clusters located in the inner part of the cluster.

The amazing thing about NGVS is that the discoveries were not limited to the Virgo system. Approximately 90 inner Oort Cloud objects were discovered in the field of view. The team studied substructures in our Milky Way Galactic Halo and measured the distance of the Sagittarius Stream—a long, complex structure made of stars that wraps around our galaxy. The stars within the stream were likely tidally stripped by the Milky Way during the galactic cannibalism of the Sagittarius Dwarf Galaxy. A graduate student at Queen's University, Nicholas Fantin, used NGVS data to look for white dwarfs within the halo of our own Milky Way. He studied the proper motion of over 900 candidates and ended up finding roughly a dozen halo white dwarfs with proper motions on the order of 50 milli-arcseconds per year. Nicholas plans to continue his work with NGVS data during his Ph.D. studies.

OSSOS

The Outer Solar System Origins Survey (OSSOS) team provided an update on their active search for icy bodies past Neptune (Trans-Neptunian Objects). OSSOS has 560 nights to create a uniquely characterized survey of our outer Solar System. They observe eight blocks, each 21 sq deg of sky in the r band; wavelength range of 566–714 nm centred around 640 nm. The fields are chosen to find and track TNOs in the outer Solar System. OSSOS aims to probe the smaller end of the size distribution.

The OSSOS team also presented their COLOSSOS (Colors of OSSOS) project. COLOSSOS is a series of ongoing, coordinated observations between CFHT and the Gemini Observatory, our neighbours on Maunakea. The team uses Gemini to obtain follow-up observations of particularly interesting OSSOS objects. They look at the light-curve variation of the objects to obtain a signature of the physical properties of the objects. It also allows for extra differentiation from dynamically excited TNOs. When COLOSSOS is observing, the observations are coordinated between CFHT and Gemini, triggered by a phone call to CFHT by a COLOSSOS observer at Gemini. Everything is ready to go ahead of time at both facilities, leading to a 90-percent success rate of requests to CFHT.

MiMeS

The Magnetism in Massive Stars (MiMeS) large program studied O and B type stars using ESPaDOnS at CFHT (594 hours), Narval (Espadon's sister instrument) at Pic du Midi in France (565 hours) and HARPSpol (278 hours). Massive stars are defined as those with initial masses on the main sequence greater than 8 M_{Sun}. While the existence of magnetic fields in massive stars was not in question, MiMeS sought to fill the void in our knowledge of the statistical properties of massive-star magnetic fields.

They observed 530 targets, 30 of which were monitored. Monitored targets are visited repeatedly, observing them at regular intervals to obtain a clearer picture of the stellar activity. Of the stars observed, 40 were magnetic, including 8 O type stars—four times the number of known magnetic O type stars prior to the survey. The MiMeS data has produced 50 papers thus far and has shown that ~10% of hot stars are magnetic.

Also on the ESPaDOnS front, the MaTYSSE team has exciting news, currently embargoed at the time of writing. An update will be provided when possible.

SITELLE

The SITELLE team provided updates from their recent science verification run and engineering. As you may recall, SITELLE is CFHT's newest instrument, a Fourier Transform Imaging Spectrograph. In layman's terms, SITELLE not only takes an image of an 11 arcmin x 11 arcmin field of view, but also generates a spectrum for each of the pixels through the magic of Fourier Transforms. This translates to ~4 million pixels per image.

The power of SITELLE lies with its ability to provide composition and kinematic information for targets. Laurent Drissen and the SITELLE team recently released the images below of M51 taken by SITELLE. Figure 3 is an H-alpha map of SITELLE that traces the star formation regions of M51. The red in the image represents the intensity of the H-alpha emission, which is caused by UV radiation from young, newly formed, hot stars.

Figure 4 is a Doppler map of M51, which traces the rotation of the gas within the galaxy. The galaxy is rotating at roughly 500 km/s. The red regions are moving away from us, while the blue/green regions are moving toward us. In reality, the entire galaxy is moving away from us due to the expansion of the Universe, but this redshift was removed from the image so Laurent's team could investigate the rotation of the galaxy relative to its centre. ✶

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.*

Figure 3 — Hydrogen alpha map from SITELLE of M51

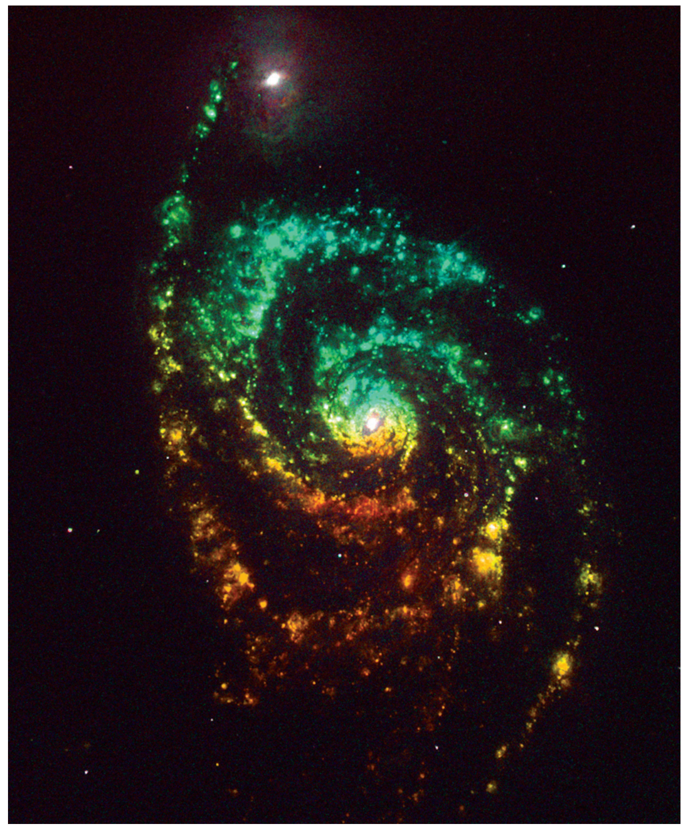


Figure 4 — Doppler mape of M51 from SITELLE

Astronomical Art & Artifact

Obstacles to Hearing Herschel

by R.A. Rosenfeld, RASC Archivist
(randall.rosenfeld@utoronto.ca)

This paper is dedicated to the memory of Dr. Geoff Gaherty (1941-2016), amateur astronomer and musician

Abstract

At this stage of the slowing Space Age it is an oddity that William Herschel's music still remains difficult of access, particularly in light of the numerous examples of diverse genres of music from many cultures available as audio files and scores. This paper describes the situation, considers the causes, and suggests a few solutions. As a small contribution toward increasing access to William Herschel's music, a transcription and arrangement according to 18th-century practices is included.

An unduly obscure facet of an otherwise famous life…

Journal readers, if asked to name a notable astronomer who was also a musician, or a notable musician who was also an astronomer, might nominate the papal astronomical consultant Jean de Murs (ca. 1290-post 1344), or the *doyen* of English 15th-century composers John Dunstaple (ca. 1390-1453), or Kepler's correspondent Seth Calvisius (1566-1615), or the Rev'd Nevil Maskelyne's contemporary John Marsh (1752-1828), or Flammarion's friend Camille Saint-Saëns (1835-1921), or Arthur Eddington's sparring partner James Jeans (1877-1946), or Bryan May (1947-), the well-known expert on radial velocities in the zodiacal dust cloud, among others (Poulle 1973; Bent 1981, 2-3; Schröder *et al.* 2008; Marsh 2011-; Houziau 2012; Milne 1952, xiv, 8, 65, 68, 78-79; May 2007). It is venturing little to speculate that the most frequently cited name—by at least an order of magnitude—would be that of William Herschel (1738-1822; Figure 1), easily occulting the others listed above.

In Herschel's case the fame of the astronomer far outstrips that of the musician. Most astrophysicists and amateurs will recall having seen an image of his great, and greatly unproductive "40-feet" reflector, will remember that he discovered Uranus and a host of deep-sky objects, and that his name is an obligatory stop on any timeline of observational cosmology with a claim to reasonable depth. In contrast, few will have heard his music, fewer yet will have seen any of it in print or in manuscript, and far fewer still will have enjoyed the opportunity to make it come alive among friends. And that is a shame.

Figure 1 — Portrait of William Herschel, from the European Magazine, 1785. Copyright SPECVLA ASTRONOMICA MINIMA

William Herschel was a talented composer in an age that did not lack performer-composers of ability. His best works are memorable and can stand repeated exposure, such as the D-minor violin concerto (University of California at Berkeley, Jean Gray Hargrove Music Library, MS 781 A-F, 1764), or the Second Sonata of his Six Fugues for organ (University of Edinburgh, Centre for Research Collections, MS Dk.7.35/1/1). Music remained a facet of the man, which did not disappear when he transitioned in 1782 from being a professional musician, to being one of the few professional astronomers in England (Brown 2009, 6, 22; Hoskin 2011, 164). Two decades later (1802), the organist of Notre-Dame de Paris noted Herschel still possessed brilliant improvisatory skills, revealed during an apparently extempore session at the organ console of the cathedral of Napoleon's capital (Brown 2009, 9). George III's Royal Astronomer was still capable of putting in a star turn as a virtuoso at the keyboard.

Present-day access to Herschel's full musical output would help us in forming a rounded image of the lucky discoverer of Uranus, it would be of use in collaborations in cultural astronomy for education and public outreach, and it could provide entertainment for astronomers, be they armchair musicians or active performers.[1]

Why, then, is his music so difficult to sample?

Unplanned scarcity

William Herschel himself is partly to blame for the current relative scarcity of copies of his music. This was not a deliberate act of coyness against posterity, but rather a condition of regular professional practice in the 18th century. Herschel only issued his music in print twice in his lifetime; the first time was in 1769 with his Six Sonatas for Keyboard with the Accompaniment of Violin and Violoncello (Herschel 1769), and the second time in 1780 with his *Favourite Eccho Catch* (Herschel 1780; Whiston 2008 for a modern edition). Similarly, most of Johann Sebastian Bach's music did not make its way into print during his lifetime (Boyd 2000, 177; Geck 2006, 286-287). Working musicians composed works primarily for performances in which they were locally involved.[2]

The chief mode for the formal presentation of music was through performance, and in this it contrasted with the formal presentation of astronomical data, and theories. Publication, either through print or manuscript dissemination, was one of the two significant modes for formally presenting the results (or discussion of the results) of astronomical observations. The other mode was in fact a performative one, namely the oral presentation of one's astronomical work to a learned society (often the oral and print modes went together). Different disciplinary practices, therefore, are partly responsible for the greater availability of Herschel's astronomical compared to his musical *oeuvre*.

There is also the matter of perceived significance. As mentioned above, in contemporary society, Herschel's role as an astronomer from the time his Uranus discovery became common knowledge to today has been seen as much more significant than his role as a prominent provincial musician. That judgement is certainly reflected in the specialist literature. The articles on William Herschel's astronomy, or the astronomy of others in which he played a part, number about 34 in the *Journal for the History of Astronomy* (*JHA*) from 1977–2016, yet only one article in that time has been devoted to a piece of his music (keep in mind *JHA* was founded by a notable Herschel expert). The tale from the musicological literature is complementary. The *Répertoire International de Littérature Musicale* (*RILM*), which bills itself as "The World's Most Comprehensive Music Bibliography," lists only 12 papers on William Herschel's music, and none of them is a major monograph examining his musical practice in depth. And from 1963 to 1977 there was just one paper analyzing his music (Duckles 1963).

Consonant with the state of the secondary literature is that of the editions. In 1912, the great historian of astronomy, John Louis Emil Dreyer, under the auspices of the Royal Society and the Royal Astronomical Society (RAS), produced a very serviceable edition of *The Scientific Papers of Sir William Herschel* (Herschel 1912). The RAS has made available a complete digital facsimile of their holdings of the Herschel Archive, consisting of scientific manuscripts and other documentary materials of William, Caroline, and John Herschel. In contrast, there is nothing even pretending to be a complete critical edition of William Herschel's music. Only the oboe concertos have appeared in a critical edition (Herschel 1998).

There doesn't appear to be, in fact, even a recent and reliable inventory of his surviving musical manuscripts. The best one can hope for are the all too brief listings in the online *Répertoire International des Sources Musicales* (*RISM*), which is based on the decades-old print version. Depending on how one searches the fields, there are either 31 or 37 manuscripts of Herschel's music extant. These are divided between nine libraries, but the greatest concentration of original Herschel musical scores is located in the Jean Gray Hargrove Music Library of the University of California at Berkeley. Unfortunately, the online catalogue of that institution is not as usefully informative as one might wish; the Herschel manuscripts don't appear in its holdings. The next largest holdings are in the British Library, and in third place comes the Herschel music manuscripts in The University of Edinburgh's Centre for Research Collections.

Only one of those institutions has strived to make its Herschel musical manuscripts accessible to the worldwide community, that being the University of Edinburgh. Their six Herschel scores and one MS with the beginnings of a treatise on music theory are fully and freely available as electronic facsimiles from their website (Open Books, The University of Edinburgh, Herschel). Other institutions could benefit from emulating the University of Edinburgh's enlightened example.

The principal obstruction blocking greater access to the Herschel musical scores lies in the failure of most of the institutions that own them to provide full, transparent, and useful descriptions of the manuscripts (MSS) in their online catalogues, and their reluctance to adopt open-access protocols that would enable them to offer accessible digital facsimiles of the scores. No one's interest is served by hiding portions of the world's astronomical heritage under lock and key.

A small step…

Included here is a modern edition of a piece by Herschel arranged according to 18th-century conventions for a single melody instrument. Set in the first instance for flute, it will fit conveniently on most melodic instruments *Journal* readers are likely to possess.[3]

The original piece is in a largely homophonic texture, despite having at times three parts. None of these are deployed with imitation, and much of the harmony can be effectively implied through broken and arpeggiated figures, making the piece a perfect candidate for setting a single melodic instrument. Some ornamental variation in the rhythmic figures has been introduced, along with trills, a few *tirades*, and an introduction added, as per contemporary practice (Powell 2002, 123-124). This was, after all, an age that could happily publish Handel *da capo* arias for orchestra and voice arranged for a single flute, orchestral movements from Haydn's *Creation* reduced for a pair of flutes, and most famously, *La primavera* from Vivaldi's *Four Seasons* (Op. 8, no. 1, RV 269) arranged for a single flute by Jean-Jacques Rousseau (Bremner 1763; Haydn 1806; Vivaldi 1775).[4] Details of the arrangement presented here can be easily found by comparing it to Herschel's score (https://openbooks.is.ed.ac.uk//record/52803?highlight=herschel) ✶

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To provide musically literate RASC members, other Journal *readers, and musicians collaborating with RASC members in outreach, with something from which they can actually play, a full-sized musical score can be found at www.rasc.ca/jrasc-2016-august.*

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(Endnotes)

1 Even armchair musicians are hard done by. There are few recordings of Hershel's music, and most of them run the gamut from mediocre to abysmal. There are only two worthwhile recordings at present; The Avison Ensemble, *Concertos from the North*, Cavalier Classics 2002, and the Herschel Ensemble, *William Herschel: Six Keyboard Sonatas*, Herschel Ensemble (0702785192214), 2015.

2 There were, naturally, exceptions. Prominent in the generation before Herschel were Georg Philipp Telemann (1681-1767), and Joseph Bodin de Boismortier (1689-1755), and, contemporary with Herschel, Joseph Haydn (1732–1809), and Franz Anton Hoffmeister (1754-1812). All four professionals furthered their contemporary fame, and derived income, from having their compositions published and distributed in print.

3 Herschel is not recorded as a flute player, but it was the single most popular instrument among the class of gentlemen who also acquired their own 7-foot Herschel reflectors; Powell 2002, 111 (on flute popularity). Such people included George III, and Tiberius Cavallo, FRS; Kassler 1979, 171; Spaight 2004, 58.

4 This is as good a place as any to mention that it is a historiographical myth that Haydn was inspired to write *The Creation* (1797-1798) by looking through Herschel's giant reflector. Haydn did visit Slough (1792), but it was during the daytime, and William Herschel was away on business at the time; Joyce 2003.

Letter to the President

April 26, 2016
Alpine, CA USA

James Edgar Regina Centre
RASC
Toronto, CA

President Edgar,

Thank you for your very excellent RASC *Journal*, always written with both precision and literary elegance.

I am a reader far south of Toronto. My grandfather, George E. Home, was born in a farmhouse near Milton, Ontario. Our family moved to Pomona, CA in 1900. We visited Milton once and saw its beautiful Boston Presbyterian Church. The Homes come from Scotland, of course.

I am a member of the SPH, OSA, & IEEE. My latest papers are on Laser Guide Stars. My telescopes are at Mammoth Lakes, CA at 8,000 feet (Meade ETX 90 & 70).

I always enjoy the RASC *Journal*. Congratulations on the continued high quality of content.

Katherine J. Jones, Ph.D.

Pen & Pixel

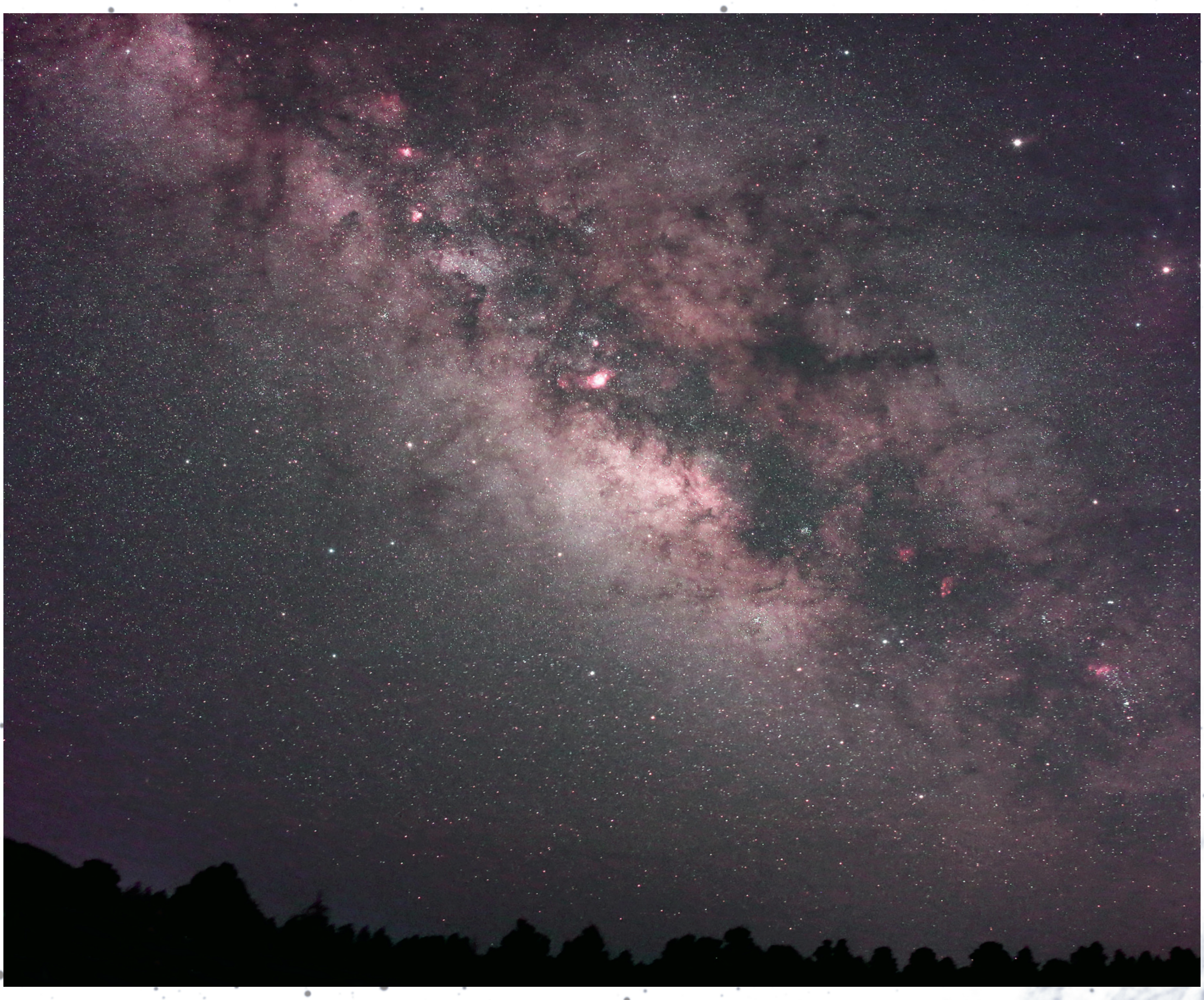
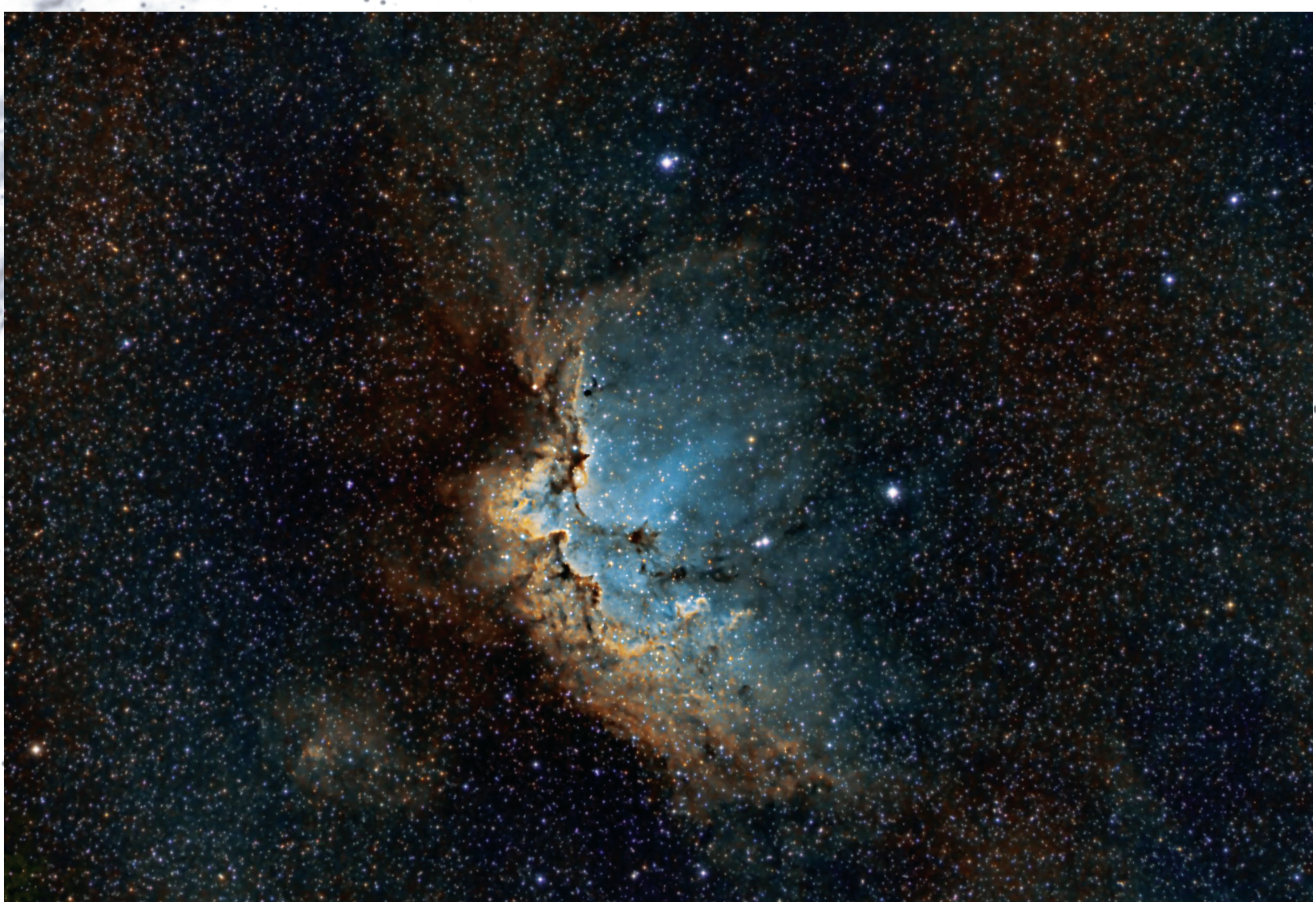


Figure 1 — Klaus Brasch photographed the Milky Way rising under an "exceptionally dark sky." This is a mosaic of 2 × 4 stacked 60-second exposures with a modified Canon 6D, Astronomik CLS filter, and a Canon 40-mm ƒ/2.8 wide-angle lens, shooting at ƒ/4.5 and ISO 6400.

Figure 2 — This beautiful image of NGC 5033, a galaxy that lies in the constellation Canes Venatici, was captured by Ron Brecher from Guelph, Ontario. Brecher took the image using an SBIG STL-11000M camera, Baader LRGB filters, 10″ ƒ/6.8 ASA astrograph, on a Paramount MX. Guided with QHY5 on an 80-mm ƒ/6 refractor for a total of 12 hours and 45 minutes. Processing was done in PixInsight.

Figure 3 — The globular cluster M13 is a favourite of many astrophotographers. Howard Trottier imaged one of the best globs in the Northern Hemisphere from Simon Fraser University's Trottier Observatory in Burnaby, B.C., over three nights in June 2015 with a total of 3 hours in RGB. The observatory houses a PlaneWave CDK700 under a 20′ Ash dome. Deep-sky imaging is done with a Finger Lakes PL16803 camera and filter wheel, as well as Astrodon filters. Processing was done using CCDInspector, PixInsight, and Photoshop.

Figure 4 — Dan Meek imaged NGC 7380 from Calgary in October 2014. The image is a 5-hour narrowband exposure taken with a Tele Vue NP127is telescope and a QSI583wsg camera.



When did Modern Astronomy Begin?

by Alan H. Batten, FRASC
(ahbatten@telus.net)

Abstract

There are several competing dates for the beginning of modern astronomy, but it is argued in this essay that not until the 19th century did astronomy finally assume its modern form.

Introduction

Astronomy has a good claim to be considered the oldest of the sciences. We are all familiar with Greek astronomical ideas, and the Greeks built on what the Babylonians and the Egyptians had discovered before them. Chinese astronomy is even older and Chinese records have proved invaluable for the investigation of cometary orbits and the frequency of supernovae in our own galaxy. Less well-known in the West are the contributions of Indian astronomers. All these early investigations, however, were very different from modern astronomy and were often motivated by astrological concerns; so we might well ask the question in the title of this article.

If I could put that question to each of you individually, I fancy that I would receive several different answers. The most obvious, of course, would be that modern astronomy began with Nicolaus Copernicus (1473–1543) who suggested that the Sun and not the Earth is the centre of the Solar System. True, the idea had been put forward both by Greek and Indian astronomers, but the power of Ptolemy's mathematical heliocentric system, combined with the common-sense appearance that everything revolved around the Earth soon led to heliocentric ideas being forgotten and they were not recalled or taken seriously until the time of Copernicus; even then, they remained controversial for a century or more. The next date that many of you might think of was Galileo (1564–1642) turning the telescope to the sky in 1609. We have all been conscious of this because only recently did we celebrate the 400th anniversary of his discoveries in the International Year of Astronomy. That same year was important for another reason: during it, Kepler published his first two laws of planetary motion, which demonstrated that not only were the orbits of the planets centred on the Sun, but also that they were elliptical, rather than circular, as almost everyone since the time of Plato had assumed. It is one of the interesting sidelights of the history of astronomy that Galileo, for all his promoting of the Copernican system, could not free himself, as Kepler did, from the notion that planetary orbits must be circular. Kepler had sent a copy of his book to Galileo, who ignored it despite the fact that it would have greatly strengthened his arguments.

Another date that we might consider important is the first determination of a reasonably accurate value for the distance of the Sun by Giovanni Domenico Cassini (1625–1712) in 1672. He determined the distance of the Sun by measuring the distance of Mars. Kepler's Third Law, published ten years after the first two, enables us to build a scale model of the Solar System: once we measure one distance between any two planets, we can deduce all the other distances in the system. Cassini's result for the distance of the Sun was only about eight percent too small and was the first realistic estimate of that distance. The importance of this measurement was its potential for understanding the nature of the Sun. Until the distance was known, we could not compute the amount of energy that the Sun is radiating into space. I have discussed the development of our ideas about the nature of the Sun elsewhere (Batten, 2013). It took a long time after Cassini's measurement before astronomers fully understood the amount of energy the Sun is radiating and still more to recognize the source of that energy, but Cassini's measurement was essential for the ultimate development of astrophysics.

The final date that we might consider is that of the publication of Newton's *Principia* in 1687. In that work, Isaac Newton (1642–1727) showed that Kepler's three laws of planetary motion and the falling of an apple to the Earth could all be explained by the inverse-square law of gravitation. Thus, it is often said, he founded both modern astronomy and modern physics.

Without doubt, all these dates I have mentioned are significant. The astronomy we know today could not have come into being if those discoveries had not been made. You will note that all of them except the first are in the 17th century. That century was certainly pivotal in the development not only of modern astronomy but also of the other sciences, yet it did not change the sort of things that astronomers did, mainly the accurate measurement of the positions of stars and of the motions of the planets. The people we have discussed did not call themselves "scientists" but, rather, "philosophers." The word scientist was a 19th-century invention and many people did not like it when it was first coined. Even in the early 20th century you will find that writers such as Eddington and Haldane used phrases like "scientific men" or "men of science." They could get away with it then because, in their lifetimes, nearly all scientists *were* men. Nowadays, when many scientists, including some very good ones, are women, such phrases are not appropriate and the word "scientist" has become completely accepted.

Instrumental Developments

Galileo's telescopes enabled him to recognize the phases of Venus and the satellites of Jupiter, but they could not show him clearly the rings of Saturn. He knew there was something unusual about that planet but he could not tell what it was.

The telescope had to go through a long process of improvement before it could realize its full potential as an astronomical instrument. You have all seen pictures of typical 18th-century telescopes, such as the one shown on the cover of the *Journal for the History of Astronomy*. Such telescopes must have been almost impossible to use. It would have been difficult to find the image produced by the objective. The object would soon pass out of the field of view and would have to be recovered. Even a slight breeze could probably disrupt observations. It is a marvel that anything could be achieved at all with those instruments! As you all know, refracting telescopes are subject to two defects: spherical aberration and chromatic aberration. The first arises from the fact that spherical lens surfaces will not bring all the light from a distant object to a unique focus, and the second from the fact that light of different colours has different foci. The result is a fuzzy image. Both problems can be minimized by using lenses of a long focal length—hence those very long telescopes.

You may ask: Why did they not use reflecting telescopes? Newton in England and Gregory in Scotland had each invented forms of reflecting telescopes, again in the 17th century. Spherical aberration could be eliminated by using a parabolic mirror, rather than a spherical one, and chromatic aberration was no longer a problem. However, silver-on-glass mirrors had yet to be invented. The mirrors of the first reflecting telescopes were made of "speculum metal," an alloy of tin and copper. Not only were they easily tarnished, they also tended to lose their figure as they were exposed to temperature changes, and frequently had to be taken out of the telescope for re-polishing and refiguring. For this reason, they were not favoured by many astronomers in the 18th century. The exception, of course, was William Herschel (1738–1822) who made his own telescopes and favoured reflectors because they were easier to make. Because of the difficulties with speculum metal already mentioned, he frequently made two mirrors for his telescopes, so that he could use one while he was re-polishing and improving the other. After he was able to give up earning his living by music and to concentrate on astronomy, he became more ambitious about the kind of telescopes he made and used. First came his "20-feet" telescope (in those days, it was usual to define the size of a telescope by the focal length of the mirror or lens rather than its aperture, which, for the "20-feet," was 18-inches) and then the famous "40-feet"—actually about 48 inches (1.2 m) in aperture. This giant, the largest telescope in the world at the time, proved very cumbersome to use and Herschel needed two assistants to operate it. He was ahead of his time in building so large an instrument; the technology needed to use it efficiently was not available and it proved to be disappointing. Herschel often went back to the 20-feet even after the larger instrument was completed.

Herschel was a giant among astronomers and a transition figure. Born in the 18th century, he lived into the third decade of the 19th. His discovery of Uranus in 1781, spectacular though it was, was probably the least important of his contributions to astronomy. His major contributions: the discovery of binary systems and his attempts to determine the "construction of the heavens" (i.e. the size and shape of our galaxy) were work of the very late 18th and early 19th centuries. These were part of the foundations of modern astronomy. His son, Sir John Herschel (1792–1871), was to continue his father's work, in particular by extending it to the Southern Hemisphere, but, as one of the pioneers in the development of photography, he made another important contribution to the development of modern astronomy. Although by the end of the 20th century astronomers were moving to the use of other means of detecting and recording light, the astronomy of that century would have been impossible without the photographic plate.

While the elder Herschel was creating ever-larger reflectors, opticians were developing ways of overcoming chromatic aberration in refractors by using compound objective lenses made from glasses of different types that had different refractive indices. That development was particularly associated with John (1706–1761) and Peter (1730/1–1820) Dollond in England and was hastened at the turn of the 18th and 19th centuries by the Napoleonic wars. Officers on both sides wanted good portable telescopes, and reflectors would clearly have been unsuitable. Astronomers were soon to benefit from the technological developments stimulated by war—just as the development of radar during the Second World War eventually led to the beginning of radio astronomy. The first large refractor used at a professional observatory was the so-called "Great Refractor" (aperture 9 "Paris inches" or about 9.5 of our inches and a little less than 0.25 m) built by J. von Fraunhofer (1787–1826) installed in Dorpat (today's Tartu in Estonia) and used by F.G.W. Struve (1793–1864) to create his catalogue of visual double stars and to measure the parallax of Vega. Concomitant with the improvement in the optics of refractors, improvements were also made in the mountings of telescopes and the graduated circles needed for setting them accurately. The "Great Refractor" was the first equatorially mounted telescope and may have been the first to have been housed in a rotating dome. The development of the filar micrometer was also an important factor in making possible precise measurements of stellar positions that led to the great triumph of early 19th-century astronomy, the first successful measurements of stellar parallaxes. Just as Cassini's measurement of the solar parallax was essential for a proper understanding of the Sun, so were measurements of stellar parallax essential for a proper understanding of the other stars.

A Major Achievement

In 1841, the Gold Medal of the Royal Astronomical Society was awarded to F.G.W. Bessel (1784–1846), judged to have been the first of three astronomers who successfully determined stellar parallaxes in the late 1830s. (The other two were Struve, as we have seen, and Thomas Henderson.) The award was presented by Sir John Herschel who, in his presentation address, captured very well the excitement felt by the astronomical community of the time. He saluted Bessel's achievement as "the greatest and most glorious triumph that practical astronomy has ever witnessed" (Herschel 1843). His language might seem a bit flamboyant to us, but his claim about the importance of the early parallax measurements still stands. Modern astronomy would be impossible without accurate knowledge of the distances of the fixed stars.

Although Bessel was a brilliant observational astronomer and mathematician, he was an astronomer of the "old school" who thought that precise measurement of the positions of stars was the prime aim of astronomy (see Kragh, 2008). Struve and G.B. Airy (1801–1892) agreed with him in a very large measure. Moreover, they felt that astronomers had to be willing to spend some of their time at practical tasks, such as time determination in Britain and large-scale surveying in Russia, to justify their having the freedom to pursue what we would call "pure research." They would not have made the distinction we make between basic and applied research and Airy (1848) makes it very clear that he disapproved of astronomers "wasting their time in the mere fanciful abstractions of science." He would not have been impressed by speculations on "the first three minutes" of the Universe! The philosopher Auguste Comte (1798–1857) is often criticized by astronomers for his statement that the chemical composition of the stars was something that we simply could not know. I have discussed this statement elsewhere recently (Batten, 2016); here I wish only to point out that many astronomers of his time, including prominent ones like Bessel and Airy, would have agreed with him!

The Beginnings of Astrophysics and Cosmology

Indeed, it was not until some years after Comte's death that Gustav Kirchhoff (1824–1887) published the results of researches by himself and Robert Bunsen (1811–1899) that pointed the way to astronomical spectroscopy, which has given us precisely the ability to determine the chemical compositions of the stars. But I am getting a little ahead of myself; astronomers were still engaging in the quest to build ever larger telescopes, and the question of whether they should be reflectors or refractors was still unsettled. Lord Rosse (1800–1867), a wealthy Irish peer and a competent engineer decided to build a great reflector—one of six feet (1.8 m) aperture, just the size of our largest instrument at the D.A.O. in Victoria, and, at the time, the largest telescope in the world. Its mirror was of speculum metal; J-B-L. Foucault's (1819–1868) development of silver-on-glass mirrors was still some years in the future. You may have seen pictures of this instrument. Like Herschel's 40-foot reflector, this telescope, which became known as "the Leviathan of Parsonstown," was ahead of its time. Constrained to observe only near the meridian, it still required several people to operate it. Moreover, Ireland, which is not called the "Emerald Isle" for nothing, does not offer an ideal climate for a large telescope to realize its full potential! The performance of the Leviathan was disappointing and the only major result to come out of it was the discovery of the spiral structure of some nebulae. Rosse's 1845 drawing of M51 was remarkably accurate, as comparison with a modern photograph shows. Immediately, some people thought that spiral nebulae were other galaxies, or "island universes," as they were then called, and whose existence the philosopher Immanuel Kant (1724–1804) had predicted, but others supposed that they might be planetary systems coming into being by the process envisaged also by Kant and quantified by Laplace (1749–1827). As we know, the question whether spiral nebulae were other galaxies or objects within our own galaxy was not finally settled until well into the 20th century. Even Simon Newcomb (1835–1909), as late as 1906, wrote that we could never know whether or not there are other galaxies. We make fun of Comte for his belief about what we could never know, but we conveniently forget Newcomb's, equally wide-of-the-mark prediction. But Rosse's drawing was the first hesitant step towards the study of extra-galactic astronomy.

One other large reflector, the Great Melbourne Telescope of 1.2-m aperture, was more successful and, indeed, shows a more modern design. Nevertheless, the first Otto Struve (1819–1905), son of Wilhelm, thought, perhaps partly because of the disappointing performance of the Leviathan of Parsonstown, that, on balance, refracting telescopes were to be preferred. When his father had founded Pulkovo Observatory in 1839, it was equipped with a 15-inch (0.38-m) refractor—then the largest working telescope in the world, since Herschel's "40-feet" instrument had by then been decommissioned. Several larger refractors were built subsequently and Otto Struve wished to restore Pulkovo's dominant position. Towards the end of his active career, he succeeded in equipping his observatory with a 30-inch (0.76-m) refractor. The telescope was used by his son, Hermann Struve (1886–1933), in his classical study of the satellites of Saturn, but otherwise did not produce many great results and was destroyed in the Second World War. Other large refractors were built, but none exceeded 40 inches (about 1 m) in aperture, and, as we know with hindsight, the future of large instruments was to be dominated by reflecting telescopes. Indeed, even a 72-inch (1.8-m) refractor would be technically impossible to build, let alone refractors of the size of the monsters that are now in operation or on the drawing board. Otto Struve was perhaps the last of the great 19th-century observers. He retired from the Directorship of Pulkovo late in 1889, after celebrating the observatory's 50th anniversary. His last years there were unhappy and many complained that he was uninterested in the then newly developing field of astrophysics. The complaint was not entirely fair, but undoubtedly his heart was in the old-fashioned positional astronomy in which he had been brought up and he must have been influenced by the attitudes of Bessel, Airy, and his father. He was open to the possibilities of photography, which was just beginning to be applied to astronomy towards the end of his productive career. He was actively involved in the planning of the *Carte du Ciel*, although he thought that his colleagues were going the wrong way about designing this huge enterprise. In that, subsequent events showed him to have been in the right: the *Carte du Ciel* was the great failure of early attempts at international cooperation in astronomy!

Whatever Otto Struve's personal opinions may have been, astrophysics certainly developed faster in other parts of Europe than it did in Russia. Following the laboratory researches of Kirchhoff and Bunsen, spectroscopy was applied first to the study of the Sun and then to that of the other stars—at first visually, but later, as photography developed and became more sensitive, photographically. One of the first to recognize and to classify the differences in stellar spectra was the Italian Jesuit, Angelo Secchi (1818–1878). His work was extended by the remarkable British couple, Sir William (1824–1910) and Lady (1848–1915) Huggins. Indeed, they were the first to make extensive use of photography in the study of stellar spectra. William also discovered that the spectra of some nebulae consisted only of emission lines, thus settling the age-old question of whether or not all nebulae could be resolved into star clusters. Some people have argued that Margaret's was the real brain behind the Huggins' partnership. I suspect that is going too far, but at least the pair was composed of equal partners and Margaret Huggins was one of the first women to appear in the history of astronomy. Together with Agnes Clerke (1842–1907) and, earlier, Caroline Herschel (1750–1848), she was elected an honorary member of the Royal Astronomical Society. That society had been founded in 1820 by a Royal Charter issued by King William IV. At that time, despite the work of Caroline Herschel, few people envisaged that women would be engaged in astronomy and it was unclear whether the Charter permitted the election of female "Fellows." The solid work of Margaret Huggins and Agnes Clerke pointed up the absurdity of excluding them, and in 1915 the Society petitioned King George V for a new Charter permitting them to elect women on equal terms with men. The work of the Hugginses has been the subject of a recent book by Barbara Becker (2011). Earlier I commented that, until the 20th century, few women were scientists. Perhaps it is appropriate to end this survey of the rise of modern astronomy with this account of the work of one of the first female astrophysicists.

Conclusion

I may seem to have wandered somewhat from the question posed in the title of this lecture: When did Modern Astronomy Begin? I have tried to show how the developments in astronomy during the 19th century transformed the nature of astronomy. The old "positional" or "fundamental" astronomy will always remain an important part of our total effort, but investigations that seemed impossible to Comte, or at best "fanciful abstractions" to Airy and Bessel, have become equally important parts of our science. The foundations of these developments were largely laid in the 19th century, by the instrumental developments that I have described, the successful measurement of stellar parallax, the development of photography, and the rise of spectroscopy that led to the opening up of the possibilities of both astrophysical research and modern cosmology. I have not touched on the developments in theoretical physics that were also important for enabling us to understand the structure of the Sun and other stars, some of which did not unfold until the 20th century. There is a very real sense in which we can say that modern astronomy began in the 19th century, rather than with the admittedly groundbreaking discoveries of the 17th. ✶

Acknowledgment

This paper is offered in appreciation of my recent election as a Fellow of the RASC, and is based on a lecture given to the Victoria Centre in December 2015 and a poster presented at the XXIX General Assembly of the IAU in Honolulu in August of that same year. The citation for my election states that I have made 89 contributions to this *Journal*. I am not sure how that figure was arrived at, but it seems to invite me to round off the total to 90! I do not think I have sufficient time left to score a century.

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General Assembly 2016

Paul Gray accepts Simon Newcomb Award for Martin Hellmich and Halley Davies.

Speakers gave great talks! This is the crowd at Jeremy Hansen's talk.

Jeremy Hansen and Terry Dickinson

Three Handbook Editors: Pat Kelly, James Edgar, and David Chapman

The Royal Astronomical Society of Daves (RASD)

Tina Pollman

The incoming and outgoing Presidents

Congratulating the newest FRASC members, Pat Kelly, Franklin Loehde, and Doug Hube. Jay Anderson is out of the frame.

Taking a break on the walking path.

Ann Hornschemeier and Sarah Gallagher

John Percy's Universe

In Praise of Librarians

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

As an academic, it's not surprising that I have spent a lot of time in libraries. As a boy in the suburbs, I took the long bus ride to the nearest public library and read Jules Verne's science fiction, and Walter Brooks's *Freddy the Pig*. The former seems appropriate for my present profession. The latter perhaps anticipates my later collection of pigurines and other such porcine trivia. In high school, and especially in university, I spent endless hours in libraries. Those were the days before the Internet. In 1961, I joined The Royal Astronomical Society of Canada and, from 1965 to 1968, I served as National Librarian. I tended the books and journals and slides, which were little used. I compiled a catalogue, which was probably little used also. It still exists online[1]. My predecessor was a professional librarian, Len Chester. My successor was Peter Broughton, whose many important contributions to the RASC include our centennial history. The books are now part of the Society's extensive archives.

Librarians and Astronomical Science

My research, then and now, was on variable stars, including their long-term behaviour, and required access to many obscure, foreign, and/or early sources, including observatory publications from around the world. In Toronto, I was fortunate to have access to the best astronomy library in Canada, one of the best in the world. I'm glad that I helped to put its superb collection to good use. Over the decades, however, I have gradually transitioned to using online tools such as ADS (the Astrophysics Data System), and SIMBAD (information and bibliography on stars and other objects outside the Solar System).

Over my career at the University of Toronto, I've had the pleasure of working with 10 different astronomy librarians, all of them consummate professionals. As the role of academic librarians in teaching and research has increased and strengthened, so has their status. Academic librarians are far more than custodians of collections; they are full partners in the academic enterprise. At the University of Toronto, they are equivalent to professors in the human resources system.

Marlene Cummins was our astronomy librarian from 1984 to 2004, and brought the library into the electronic age. She was also very active in the international astronomy community (as was I), and wrote a dozen papers, especially for a regular series of international conferences on Library and Information Services in Astronomy. In 1999, she received the prestigious Academic Librarianship Award from the Ontario Confederation of University Faculty Associations (OCUFA).

Marlene was succeeded in 2004 by Lee Robbins, previously a librarian at Fermilab near Chicago. Besides her contributions to teaching and to heritage, described below, Lee has had to understand and deal with fundamental new issues in university information science: the escalating cost of books and journals (and the proliferation of these), the trends to online and open-access publication, the increasing demand to make publicly funded research *freely* available, and simply the massive amount and variety of scholarly information available—all in an era of declining budgets. Like Marlene, Lee is an active member of the Special Library Association's Physics, Astronomy and Math section, whose listserv is an invaluable tool for sharing ideas and information.

Librarians and Leadership in Information & Communication Technology

During the 1990s, I served as Dean of Science at the University of Toronto Mississauga (UTM). As such, I was on a tri-campus ICT committee. Among the many issues that we dealt with, two stood out. One was whether university computing should be done with a massive central mainframe (think CRAY), or by local networks of smaller computers. Science departments were keen on the latter, especially for research, and that's what we now have, though supplemented by regional or national high-performance machines. The other issue was who should be responsible for the university's diverse and rapidly growing ICT activities. It was Chief Librarian Carole Moore who took the lead. Now, much of academic non-research ICT is housed in the central Robarts Library. The attached library school is now the Faculty of Information Science, or *iSchool*.

Librarians and Teaching and Learning

My first 40 years were spent at UTM, initially known as Erindale College. It was small enough for me to know and work with faculty and staff from many departments, including the library. Initially, the librarians' role was to work with me in selecting books and journals to support our various courses. In the 1990s, UTM spearheaded productive collaborations between instructors, librarians, and the Academic Skills Centre. We established an informal "TLC" group—teaching, learning, communication. Those collaborations seem like a no-brainer; we do it all the time now[2]. After all, the university's stated goal is to develop students' research, reading, and communication skills, and how better to do that than in partnership with the library? Many students enter the university not knowing the difference between "authoritative sources" and *Google*, or knowing what constitutes plagiarism.

Librarian Simone Laughton was (and is) our expert in the area of instructional technology. She and others carried out many research and development projects, with instructors, on how to improve teaching and learning through technology and collaboration. These have included: piloting a new learning management system; creation of on-line courses; collaborating on funded research projects in the scholarship of teaching and learning; reviewing open-source webcasting and conferencing technology; developing online assessment tools; and collaborating on projects to construct engaging and effective teaching and learning experiences with digital data and collections. UTM's library now houses the Academic Skills Centre, just as the main Robarts Library on the downtown campus houses the tri-campus Centre for Teaching Support and Innovation[3].

The library also hosts *T-Space*, an electronic repository where I and other instructors can publish and archive collections of exemplary student (or faculty) papers. The library also assists instructors in setting up and hosting on-line student journals, which can, with an adequate editorial oversight and peer review, achieve higher profile and status.

In the Department of Astronomy & Astrophysics, Lee Robbins has been integral in developing students' research skills, by giving workshops for classes from the 1st to the 4th year and graduate level, including to our two dozen summer undergraduate research students each year, and by ensuring that the department's print and electronic collection, and its web page[4] include essential material on teaching and learning.

Librarians and Outreach

The astronomy group at the University of Toronto has always been deeply committed to outreach, and a different set of librarians has had a significant effect on our success—dozens of librarians in the 100+ branches of the Toronto Public Library. TPL is the busiest public library in the world, and its branches reach people of all ages and cultures, in every corner and community of Toronto.

My first such TPL partnership was many decades ago when, on behalf of the RASC Toronto Centre, I took displays into TPL branches for several weeks at a time. More recently, as part of International Year of Astronomy 2009, we established an ongoing formal partnership (Percy 2012). The libraries provide the venue, facilities, and publicity; we provide the astronomer. The branch librarians choose speakers and topics from our list[5], and then publicize the talks through their website[6] and quarterly *What's On* magazine. The programs are also publicized through the Toronto Centre's excellent events page[7], and through our monthly *Event Horizon* newsletter. Since International Year of Astronomy (IYA), I've done dozens of library presentations, to audiences of up to 100 or more—both children and adults. Many of my faculty, postdoc, and graduate student colleagues regularly participate in this program.

For a year or two beyond IYA, we extended this partnership through the Ontario Libraries Association to libraries far beyond the GTA, to communities as far away as Mattawa. We hope that RASC Centres and members will take up such partnerships with their local libraries. It's a win-win situation!

Librarians and History and Heritage

One of the interesting consequences of my university's celebration of the 2009 International Year of Astronomy, and of the 2012 Transit of Venus, was to establish closer contact between the astronomy group, and the university's Institute for the History and Philosophy of Science and Astronomy (IHPST). We discovered that graduate students in IHPST had established a virtual museum—the University of Toronto Scientific Instrument Collection (UTSIC: utsic.org)—to catalogue and conserve some of the university's historic scientific instruments. At the same time, the David Dunlap Observatory (DDO) was in transition from the university to operation by the RASC Toronto Centre. Many of the DDO's instruments, plus teaching equipment from campus were hidden away in storage. In collaboration with UTSIC—especially Paul Greenham—and with the RASC's Randall Rosenfeld, Lee has catalogued and conserved many of these, and continues to do so. The partnership continued in 2012 with a one-day multidisciplinary Transit of Venus symposium and exhibit at IHPST.

This beneficial partnership has continued with a one-day symposium and exhibit to mark the 80th birthday of DDO, reported in detail in this *Journal* (Robbins and Rosenfeld 2016). Thanks to Lee, we also partner with students in the Museum Studies graduate program, which is part of the *iSchool*. These collaborations have led to public exhibits at IHPST in Victoria College. Lee's impact extends beyond the University of Toronto, through her membership on the Canadian Astronomical Society's Heritage Committee; Randall Rosenfeld is also a member.

This is not the only area in which librarians have helped to preserve our material heritage. Our books, of course, are part of that heritage. When the DDO was sold in 2008 by the university, its extensive library collection moved downtown. Now, much of it has been returned to DDO on loan, where it occupies what was once one of the most elegant in the university.

The photographic plates that were the mainstay of astronomical research until a generation ago are also part of our heritage, and librarians—including Lee—and archivists play an important role in preserving and/or digitizing them (Osborn and Robbins 2009). We all have a responsibility to preserve our astronomical heritage, and this is best done in partnership with those who know how—certainly including librarians. In today's "information age," they contribute to every aspect of the astronomical enterprise. ✶

Acknowledgements

I am grateful to the many librarians with whom I have had the pleasure to collaborate over the past half-century. I also thank Simone Laughton, Carol Percy, and Lee Robbins for their helpful comments for this article.

Notes

1. www.rasc.ca/sites/default/files/RASCLibraryCatalogue1970.pdf
2. During the drafting of this article, I attended a session on "Integrating Research and Writing Training into an Introductory Biology Course," co-presented by a UTM instructor, librarian, and Academic Skills Centre staff member, at the 10th annual U of T Teaching and Learning Symposium, 2016 May 10.
3. teaching.utoronto.ca
4. www.astro.utoronto.ca/AALibrary/education.html
5. www.universe.utoronto.ca/connect-with-an-astronomer/speakers/
6. www.torontopubliclibrary.ca
7. rascto.ca/upcoming-events

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Dish on the Cosmos

Radio Telescopes

by Erik Rosolowsky, University of Alberta
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I spend much of the time in this column talking about major science initiatives in radio- and millimetre-wave astronomy. It might give the impression that radio astronomy is far out of reach for non-professionals, but the radio skies are as open as those in the optical for exploration on your own. Indeed, the first radio astronomers were not professional astronomers on mountains, but the field was born instead out of dabbling, rather than a concerted research effort to see the skies in radio waves.

Karl Jansky is considered to be the first radio astronomer, which began through his efforts to find sources of static that would interfere with long-range radio broadcasts. One of the main interlopers in Jansky's study came and went on sidereal time, tracking with the motions of the stars. After some sleuthing, Jansky realized the radio emission was coming from the centre of the galaxy. Jansky's results were publicized, which attracted some press attention. Alas, they had no importance to the broader work at Bell Labs, so Jansky was soon reassigned to other projects.

Radio waves would have languished longer as a footnote for science had it not been for Grote Reber, a radio engineer, who took it upon himself to begin exploring the radio skies. Reber build his own radio dish in his backyard (Figure 1). Each night, he pointed his dish at a fixed position and let the sky rotation carry different objects in front of the dish. By recording the power in the system slowly over the night, he painstakingly built up a map of the galaxy. Reber's mapping proved that the Milky Way emitted radio waves across the sky and that the emission was not from warm objects like stars. It would be much later before the mysterious emission would be attributed to high energy electrons orbiting in the magnetic field of the galaxy. With these new results, professional astronomers became interested and the field slowly developed to become one of the major fields of astronomy.

Today, it is still possible to be a backyard radio astronomer, but the field has changed appreciably since then. In some ways, it is now much easier because radio-frequency technology has become cheap and effective. You can buy receiver parts that are millions of times more sensitive than Reber's hardware for just a few dollars. The downside is that so can everyone else! Reber's initial observations were made at a frequency of 160 MHz, where he had to observe at night because of the interference from car ignitions (some radio observatories use diesel vehicles since there are no spark plugs). Today, the 160 MHz band is now allocated for satellite and maritime communications, drowning out the galaxy. Just a few MHz down from that band lie broadcast FM radio stations, where the number on the radio dial indicates the frequency of the wave. The long-wavelength radio sky is filled with transmitters. Radio astronomy is now most effective in few "protected" frequency ranges or located far from Earth-bound transmitters.

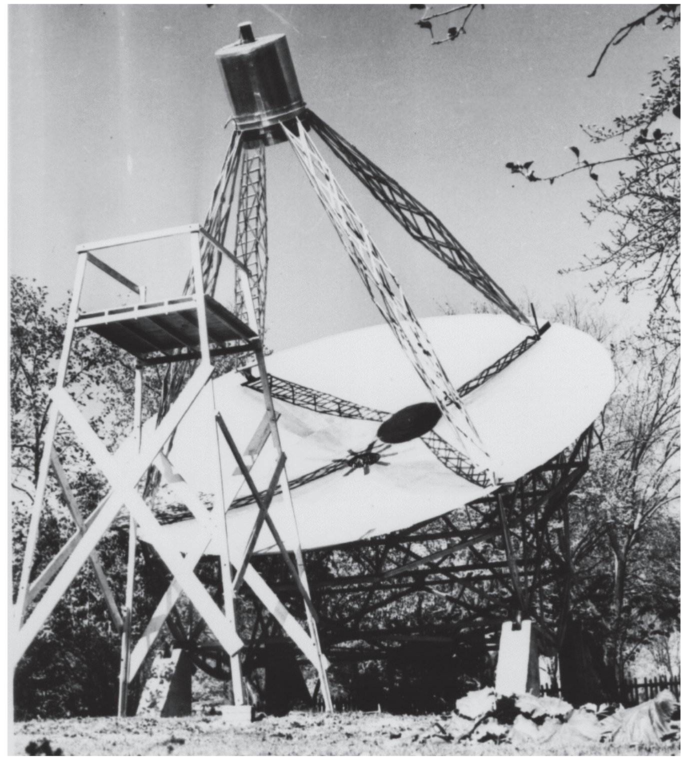

Figure 1 — Grote Reber's Radio Telescope in 1937. The dish was built by Reber himself in his own backyard and used to make the first radio map of our galaxy. (Image Courtesy of NRAO)

Despite these daunting challenges, several backyard astronomers nonetheless brave the interference to tune in on the cosmos. When I lived in Kelowna, British Columbia, I had the good fortune to meet a latter-day Grote Reber: Hugh Pett of the RASC Okanagan Centre. Hugh's ambition is to build a radio telescope interferometer on the slopes of Big White mountain, near Kelowna. The telescopes are sited on the Centre's Okanagan Observatory, which also features public facilities and optical telescopes. However, Hugh is leading several members of the RASC and the nearby Dominion Radio Astrophysical Observatory to create a working observatory of sufficient quality to make scientific observations and show off the novelty radio astronomy to all the visitors at the site. Above all, Hugh aims to do it without the relatively large budgets of a national telescope, taking advantage wherever possible of those steep drops in prices on all the radio components.

Radio telescopes only require two basic parts to run: an antenna and a receiver. Antennae are relatively inexpensive

Figure 2 — The Okanagan Observatory's Radio Telescope Project.

The mounted telescope at the Okanagan Centre's Radio Telescope Observatory, and UBC's Okanagan campus custom motorized mount.

these days: what you would be shopping for is a large radio dish designed to catch radio waves from space. Fortunately, such radio dishes are mass produced so we can watch satellite television, so it is a simple matter of acquiring a satellite dish. Since these are designed to catch satellite frequencies close to the radio astronomical bands, they have all the specifications needed to be a cosmic receiver. The Okanagan Radio Telescope Project uses just such a dish. Out of the box, the satellite dish is not the most nimble telescope, and lacks the ability to reliably point anywhere in the sky using its feeble motors (if it has motors at all). This does not compromise the usefulness of the telescopes. Just like Grote Reber, the telescope can be lined up at a fixed altitude, and the rotation of the Earth will carry the antenna around underneath all the features in the radio sky. More ambitious radio astronomers, like Hugh, can build their own custom mounts, for steering and tracking on fainter sources. Engineering students from UBC's Okanagan campus designed a custom mount for the Okanagan Radio Telescope Observatory, so remember you can always get engineering students excited with astronomy!

Radio dishes are often called antennae since they operate in the same role as other antennae, like the long wire antennae on cars. The radio receiver takes the waves that are collected by the antenna, amplifies them to a level where they can be detected and then converts them into the desired format. Car radio receivers are configured to extract the sound-wave signal from the radio waves and play it through the speakers. Simple radio receivers, like Grote Reber's, just measure the power from of the radio sky over a wide range of frequencies. If you are building your own telescope, such simple receivers can be had from satellite signal-strength meters. We use them to find satellites, but with just a few extra parts (mostly filters) they can be used for radio astronomy. The fanciest radio receivers measure the power in narrow sections of frequency and yield measurements of the power at each of the different frequencies, which is called a spectrum.

Good radio receivers usually have amplification built into them. The radio waves from space are incredibly weak, the ideal amplifier will take the incoming waves and increase their strength (specifically, the amplitude) without changing any other properties of the wave. If you are building your own radio telescope, the best results can be had using "low-noise" amplifiers, which amplify the wave without corrupting it significantly. Hugh has incorporated a good suite of amplification into the radio telescope, chasing not just bright features like the Sun and our galaxy, but specific measurements of the hydrogen gas as it orbits around the galactic centre.

All this can sound daunting, but the thought of grinding your own mirrors can also be pretty ambitious. Many people, like Hugh and his colleagues, find this to be a fruitful endeavour and are captivated by the idea of finding the cosmic radio broadcasters. Thanks to modern electronics, the entry into radio astronomy is incredibly easy. Now all the parts of a radio receiver can be found on a USB stick for your computer. While there are several different options, I recently had great success using the NooElec 820T (available online for $25). This radio receiver/antenna set tunes across the radio band, and with some free software (available at http://gqrx.dk/), you can have your very own radio telescope. Detecting cosmic radio waves with this setup requires some clever signal processing, but the basic result is a wonderful way to see into the invisible Universe yourself (you can, of course, also listen to the radio!).

For more information about the Okanagan Centre's Radio Telescope Project, to subscribe to the newsletter, or to help out, please email Hugh Pett at hughirenep@gmail.com. He assures me that he would love to hear from you. ✶

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.

Binary Universe

In the Magic Garden

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

This winter I started actively imaging with a remote telescope. It's a ton of fun and I'm learning a lot about Photoshop—but that's a whole other story. While I have set myself a fairly simple project with obvious big and bright targets, I have from time to time noticed faint fuzzies in the background of the frames. And, for some reason, I must know what they are.

Actually, a few images into my project, it occurred to me that I could consider these as "observed" objects. Now I review them, describe them, note their location in relation to other objects as I would if I was at an eyepiece, and add them to my NGC, IC, and other deep-sky object life lists. And in SkyTools (see the April 2015 *Journal*) I tick the "Logged" flag.

With SkyTools up and running, it is generally easy to identify the found objects, due partly to the fact that this software has an extensive and deep database as well as very good charts. Still, there are times where I see something in the image that the software does not show. It could be an artefact: the remote camera can sometimes show an afterimage. Invariably, a DSO is truly there but not catalogued in my favourite planning app.

So what do you do when you see an object in the ocular or the photo frame that is not shown in your paper atlas or astronomy application? Where do you go for more information? What do you do when you need to go deeper? Where is the official source, if there is such a thing?

I recall searching for a good digital sky survey product back in early 2011. Curiously, I found and used an excellent tool—Aladin Sky Atlas—but for some reason had forgotten about it. Lost to the sands of time. Or my bad memory. Or getting overloaded. Or FIFO (first in, first out). Probably all of the above. If you'll indulge me, I'd like to share with you my recent little journey...

Back in "The Grey Months of 2016," following suggestions from Google, I headed to a web site (http://aladin.u-strasbg.fr) managed by the Centre de Données astronomiques de Strasbourg (CDS). If I remember correctly, I was in a bit of a funk with my main tower computer (struggling with alarmingly frequent blue screens in Windows 10, an apparent issue with drivers, but I digress). I was anxious about installing more software. So I happily jumped into the "Aladin Lite" page. This version does not download anything locally and instead uses HTML 5 and JavaScript so should run within any modern browser. In fact, I tested Lite with Chrome on Android and it works well.

This online browser-based tool is certainly interesting in terms of showing a different base image layer and letting one pan about and zoom. Quick and fast! But I have not found a way to activate a layer for identification. I was able to get to an area of interest but I was not able to label objects in the field. (Some subsequent digging in the documentation revealed that it should be possible but I have not tried it.) I moved on.

I tried astrometry.net—that's really for plate solving with generally large and bright objects. Tried Google Sky, which is easy and fun to use but, again, I could not seem to identify extremely faint and small things. Tried the SkyServer DR9 site—without success. Tried Astrometrica briefly but realized it is better for tiny, faint Solar System objects.

Along the way I learned a bit more about the Palomar Observatory Sky Survey (POSS), the Sloan Digital Sky Survey (SDSS), the Two Micron All-Sky Survey (2MASS). That was helpful.

After a lot of exploring, trying, experimenting, learning, testing, and some disappointment, I finally returned to the Aladin website, bit the bullet, and downloaded the stand-alone product (version 9). When I fired it up, memories came flooding back (Figure 1)! I *had* used this before! On many occasions, actually. Looking back, I think it fell off my radar simply as I moved from computer to computer and upgraded my Win OS a couple of times.

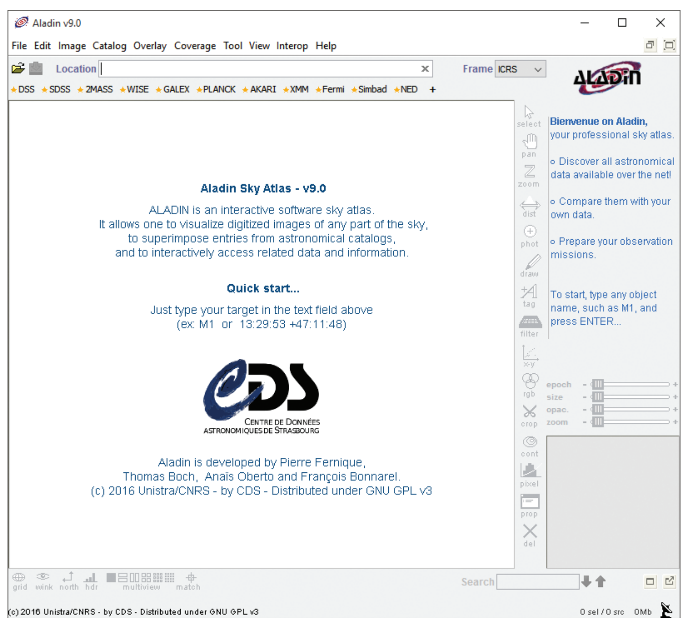

Figure 1 — The Aladin Desktop interface.

Deployed in Java, Aladin Desktop should work on any computer. You just need a Java Virtual Machine behind the scenes. That means it is compatible with Windows, Linux, and Mac. I'll relay my typical use of late with a specific example.

When I acquired my test image frames for a region near NGC 4653 and zoomed into the luminance shot (Figure 2), immediately I spotted many small, faint non-stellar objects all around

Figure 2 — Photograph of area north of NGC 4653. Annotated manually showing small fuzzies.

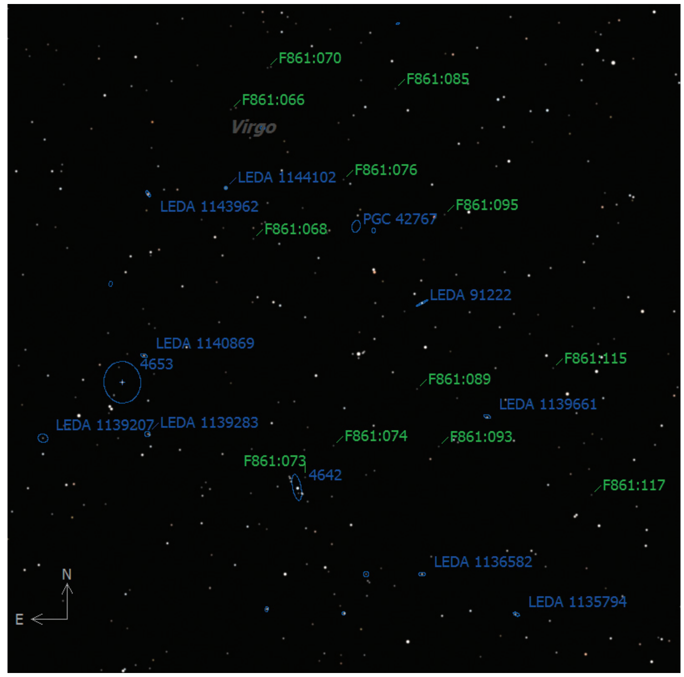

Figure 3 — Skytools software chart of same region. Fuzzies not identified.

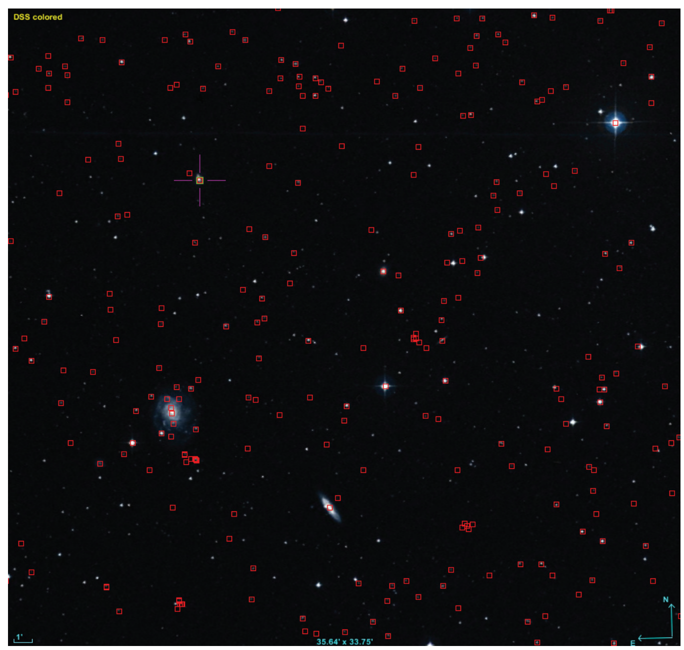

Figure 4 — The Aladin Desktop view of NGC 4653 region. Red squares note identified objects from SIMBAD catalogue.

the field. In particular, I clearly saw two small, round, fairly bright fuzzies near the top-left of the photo, almost due north of the spiral galaxy. My first impression was of distant old elliptical galaxies.

In SkyTools, after opening the Interactive Atlas chart and then Context Viewer, I set the date, time, location, telescope, and camera accordingly. I adjusted the field of view options and panned to mimic the photograph. I *turned off the Moon* (wish I could do that in the real sky) and *turned on the ALL* option to reveal every deep-sky object (Figure 3). I saw good correspondence: the edge-on NGC 4642 to the southwest of the big spiral and the small oval PGC 42767 to the north-east. Huh. No markings near the top-left; just an orange star, J124345.2-002116.

I launched Aladin Desktop. In the *Location* box I typed "NGC 4653" and hit "Enter." After a few seconds, the app loaded the "DSS colored" image that appeared in the main *view* frame. With my mouse middle roller wheel, I zoomed out (one can use the *zoom* slider on the right). From the right vertical toolbar, I clicked the *pan* button and dragged the image down and left, once again, to mimic the photo (and now SkyTools). Panning can be done without switching tools by dragging with the middle mouse button. Also, one can centre the view very quickly by double clicking on the preferred object. If you need to rotate the image, click *pan* button, hold your Ctrl key, and drag an image corner. From the top horizontal toolbar, I clicked the *Simbad* button. This activated a new layer in the *stack* frame, above the DSS coloured layer. After a moment, a shoal of red squares appeared. Wow. Many objects were identified in this field (Figure 4). If one chooses the NED catalogue, blue ovals will show.

OK, now it was time to figure out what I was seeing. I switched back to the original pointing mode by clicking the *select* button. I then clicked the red marker in the spot of interest (one can drag around multiple targets as well). A tray appeared in the bottom of the Aladin window (the *measurement* frame) with a table (Figure 5).

Under the *main id* column, I saw the clunky identifier "2MASX J12434505-0021266," and noting it as blue

main id	RAdeg	DEdeg	errHalfMaj	errHalfMin	errPosAng	B	V	R	J	H	K	otype
2MASX J12434505-0021...	190.937712	-0.357414				15.640		14.740	12.594	11.823	11.644	Galaxy

Figure 5 — The measurement multi-column table can show a list of selected objects.

underlined text, I clicked on the hyperlink. A browser window opened (Figure 6) in short order.

Aha! I noted detailed information of a known galaxy. The small interactive image to the right (made with Aladin Lite, ironically) exactly matched what was in my photograph: a larger round fuzzy on the bottom with a smaller round fuzzy above. Around magnitude 15.6 in B. One mystery solved. And one more entry for the life list! All that said, only one of the two objects was tagged. Oddly, it seemed the smaller of the two distant galaxies was not marked and not catalogued. Which is a good reminder that there is an ever-increasing body of galaxies yet to be classified.

This little story is meant to show how you can use the powerful Aladin tool to identify many faint objects that are not labelled in your atlas. I'm sure my use of Aladin Desktop is very limited but more and more I am using it to help me record dim DSOs.

Aladin has been around for a long time, since 1999. Over the years, it has become a popular visualisation tool for amateurs, students, teachers, and professional astronomers. One can view astronomical images in various spectra, from various surveys, and superimpose data from astronomical catalogues and databases. Identified items can be easily investigated. Supported optical surveys include DSS and SDSS; infrared, 2MASS, WISE, AKARI (Figure 7); ultraviolet, GALEX; X-ray, XMM; gamma ray, Fermi; and radio, PLANCK. Catalogues include SIMBAD and NED. You can activate a *dist* mode to measure the angular separation between objects, the *draw* mode to circle things, and the *tag* mode to annotate. The rich tool supports gridlines and blinking. The viewer can show multiple images stacked with various opacities or multiple sub-frames beside each other.

It is free to use, download, and install.

There is a 91-page English user manual available in PDF format. The documentation is provided in other languages. There exist website links to a Frequently Asked Questions page and helpful videos. The on-board Help menu allows one to learn the interface fairly quickly...

I have barely scratched the surface of this amazing resource. I hope you'll find it useful, like I have, as you go deeper and deeper into our magical dark skies.

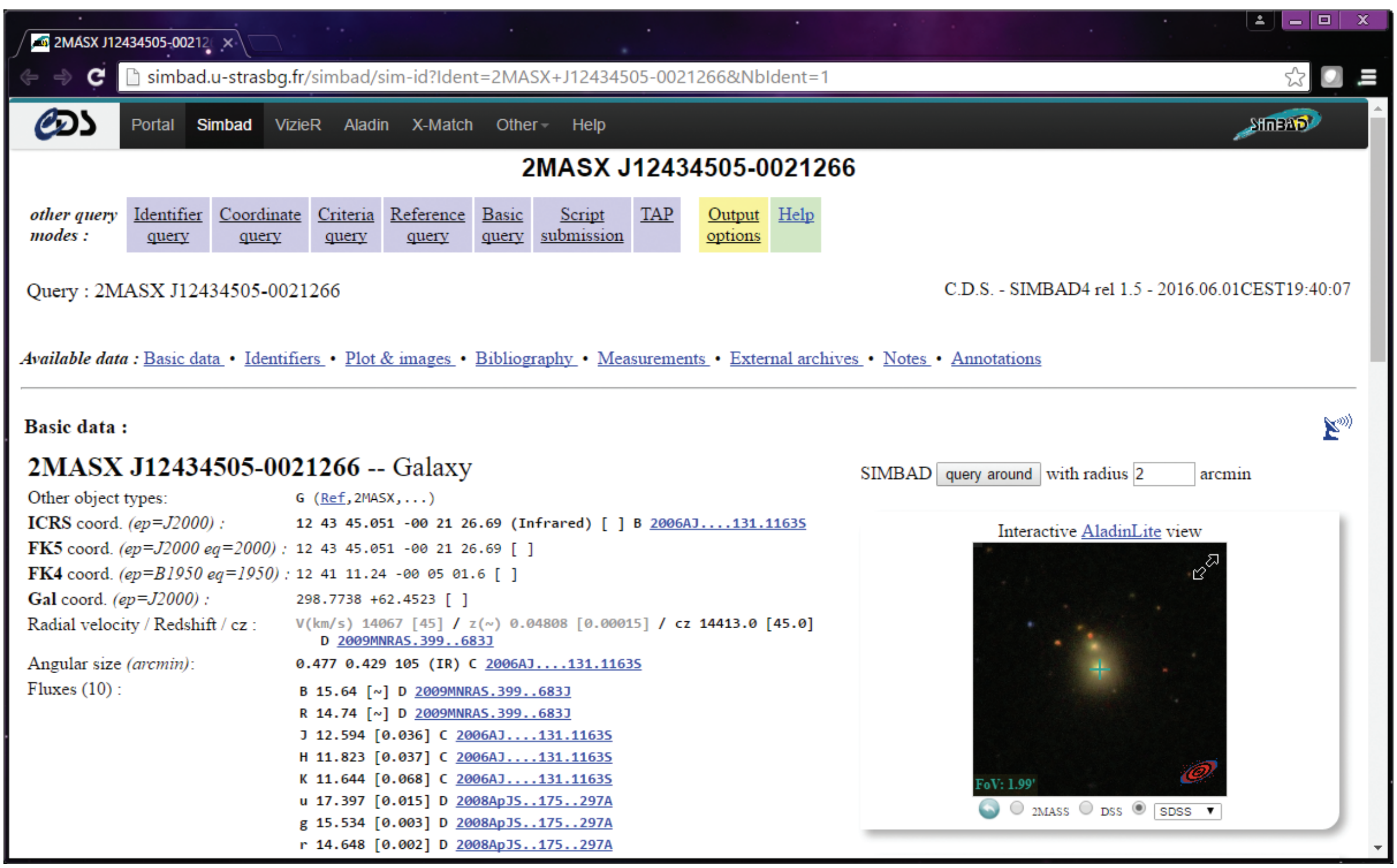

Figure 6 — Data retrieved interactively from SIMBAD, triggered from the Aladin viewer.

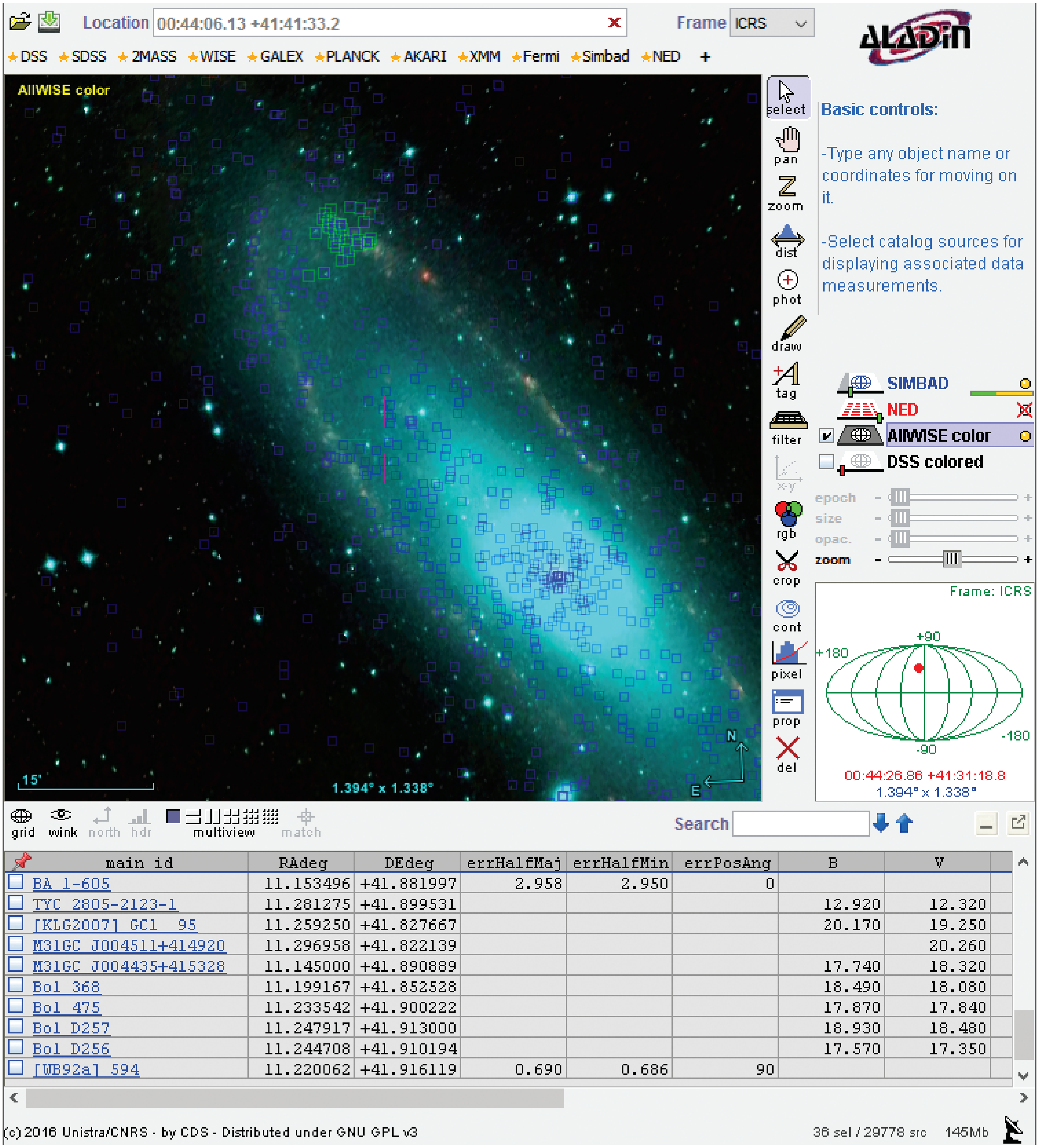

Figure 7 — Messier 31 in infrared, brightened, with multiple objects selected.

Update Bits

There is an updated version of ISS Detector for the Android platform. At the time of writing, 2.01.98. The developer of ISS Detector shared with me that he will provide two complimentary gift codes for the Pro edition that can be redeemed at the Google Play store. Please contact me for a code. First-come, first-served. ✶

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.

Skyward

When Skywatchers Meet

by David Levy, Montreal and Kingston Centres

> *"A joy that's shared is a joy made double."*
> – American Proverb

If looking through a telescope at Saturn's rings, the crescent Moon, or a comet, is a fun thing to do, then surely showing such a thing to somebody else is even more fun. I learned that lesson on 1960 October 8. All those years ago, I quietly stepped into the meeting room of the Montréal Centre of The Royal Astronomical Society of Canada, and shared my interest in astronomy with other people for the first time. Two hours later I stepped out the same doorway, this time armed with a map of the Moon containing craters numbered 1 through 300, plus 26 mountain ranges and valleys lettered A-Z. My task: To identify all those features and make my own map of the Moon.

Four years later, during the summer of 1964, I finished that task and spent an evening observing with an older member of the Society, a student named David Zackon. He was about to leave for college and was looking for someone who could use his telescope while he was away. When I told him I had completed the lunar map, he replied, "You've just borrowed a telescope for the next eight months."

I still have his receipt for the $400 my father paid him to buy that telescope outright—and I still use it almost every clear night. Its optics are so perfect, its images so true, that I have seen blue and red colouring in the Great Nebula in Orion with it. And in 1987, I discovered a comet with this telescope. But the most fun I have had with this particular telescope was in sharing the sky, using it with other people. That is where its true value lies: therein lies the heart of this telescope's message.

I have been a member of The Royal Astronomical Society of Canada for 52 years. Each year all its members are invited to gather for the Society's General Assembly. It sounds esoteric, and although there is a business meeting involved, most of it is just plain fun. We hear what our fellow members have done during the last year; we get caught up on the latest astronomical news and discoveries, and we enjoy each other's company. Sometimes there is an astronomical song contest, and occasionally the younger members even form a human pyramid. But more than all of these reasons, we gather to share our passion for the night sky.

In 1970, I gave a brief lecture at the Halifax Centre, one of many locations for astronomy across Canada, called "The Art of Comet Hunting." In it I said:

> *Comet hunting has attracted the fancies of many men, including William Brooks, who, in the late 19th century, hunted in his yard with a 9-inch refractor and picked up over 20 comets; Charles Messier, better known for his "non-comets"; Leslie C. Peltier, who between 1925 and 1954 gathered 12 comets and an assortment of novae; and David H. Levy, who between 1965 and 1970 has found nothing—absolutely nothing.*

In 1993, I was asked to present the Society's Ruth Northcott Lecture at the General Assembly in Halifax. I titled my talk "The Art of Comet Hunting—Part II." By this time, I had a dozen or so comets to my credit, but when I delivered the lecture, I had co-discovered one more: Comet Shoemaker-Levy 9, which a year later would collide with Jupiter in humanity's first experience with a collision between a comet and a planet.

These are the kinds of ideas and observations that can enrich a General Assembly. These are the things that make our night-sky experiences even better. ✶

David H. Levy is arguably one of the most enthusiastic and famous amateur astronomers of our time. Although he has never taken a class in astronomy, he has written over three dozen books, has written for three astronomy magazines, and has appeared on television programs featured on the Discovery and the Science Channels. Among David's accomplishments are 23 comet discoveries, the most famous being Shoemaker-Levy 9 that collided with Jupiter in 1994, a few hundred shared asteroid discoveries, an Emmy for the documentary Three Minutes to Impact, *five honorary doctorates in science, and a Ph.D. that combines astronomy and English Literature. Currently, he is the editor of the web magazine* Sky's Up!, *has a monthly column,* Skyward, *in the local* Vail Voice *paper and in other publications. David continues to hunt for comets and asteroids, and he lectures worldwide.*

Second Light

Gravitational Waves from Merging Binary Black Holes

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

On 2015 September 14 something remarkable happened. The signature of the final merger of two black holes was detected by the Laser Interferometer Gravitational-wave Observatory (LIGO). The signal lasted 0.2 seconds. For more information, including a slow-motion simulation of the final 0.33 seconds check out https://en.wikipedia.org/wiki/First_observation_of_gravitational_waves. Matching the observed signal to model simulations led the LIGO-Virgo collaboration to conclude that the black holes involved had masses of ~36 and 29 solar masses, and the event happened at a redshift of 0.09 (relatively nearby). The black holes could have formed and become a binary system through a number of different mechanisms, but Chris Beczynski of Warsaw University and his collaborators have run 640 million simulations and conclude that they most likely arose from the evolution of an isolated and wide binary star system (see the June 23 issue of *Nature*).

Gravitational waves were a clear prediction arising from Einstein's general theory of relativity, and indirect evidence for them was seen in the double neutron star system PSR (for pulsar) B1913+16 by Russell Hulse (then a graduate student at Princeton) and his Ph.D. supervisor, Joseph Taylor. Using observations from the Arecibo Observatory in Puerto Rico, they found that the orbit of the system was decaying as predicted by the radiation of gravitational waves. For this they were awarded the 1993 Nobel Prize for physics.

Pioneering work in the 1960s showed that, with sufficient sensitivity, gravitational waves could be detected directly. LIGO was fully funded by the National Science Foundation in 1994, and construction began in Washington state that year, followed in 1995 by ground breaking in Louisiana. Operations began in 2002 and continued through 2010, with no detections of gravitational waves. It was shut down for an upgrade to "advanced LIGO," and restarted observations in engineering mode—testing that the detectors were all properly calibrated—in September 2015. It was during the engineering phase that the characteristic "chirp" of a gravitational wave was detected. The first "science run" began on September 18, and ended on 2016 January 18. Results from that run have not yet been released, though rumours abound.

For many years, people have argued over the best way to form binary black holes, but in the absence of any data, there were no real constraints on the models. The most "natural" way to form them would be to have a binary stellar system composed of two massive stars. This is what Belczynski has investigated, using the knowledge gained from the first direct detection.

It is generally thought that the most massive stars formed in the early Universe, before the interstellar media of galaxies had been enriched much with "metals" (anything heavier than helium) from supernovae. It is generally through radiation from the metals (particularly carbon and carbon monoxide) that the clouds of gas cool enough—down to about 10 Kelvin—for normal star formation, like we see in the Milky Way, to proceed. If the gas cannot cool, then a lot more of it has to gather in one place to collapse into a star, hence the stars formed through that process will generally be a lot more massive than what we see forming in, say, the Orion molecular cloud.

Moreover, if the stars have few metals in them, they do not eject much mass through winds during their lives. So even if there are smaller stars in the early Universe, they could still explode and create black holes.

There are actually three different kinds of mergers that could radiate detectable gravitational waves: black hole-black hole, black hole-neutron star, and neutron star-neutron star. And there are a few things that could affect the numbers of mergers. Belczynski allowed for the possibility in his modelling that almost all stars survive the "common envelope" phases as binary stars, blow off the common envelope and separately go supernova. This would increase the number of surviving black hole binaries by quite a bit. He calls that his optimistic model, but it seems to be excluded already by the available data. He also allowed for the possibility that when the supernova explodes, the black hole receives a "kick" that could eject it from the binary. These kicks are known to affect neutron stars. If black holes can also be ejected, that would lead to fewer remaining binaries.

The observation—though just a single data point—seems to support the normal binary merger route, without kicks, and without common envelope survival. Belczynski's models point to a formation time of about two billion years after the Big Bang, or less likely, about 11 billion years after the Big Bang. Two billion years after the Big Bang is near the peak of early star formation, and the masses of the observed black holes fall squarely into the peak prediction.

So we have a new window to the Universe. Only time will tell what it might reveal, but I can confidently predict that it will be weirder than we can imagine. ✶

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.

Imager's Corner

Rules of Thumb

by Blair MacDonald, Halifax Centre
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In this edition we will take a look at some astrophotography "rules of thumb" that have been circulating around the Internet. Many of these are now considered as the way things *must* be done and in most cases there is very little basis for this belief.

These rules of thumb are often quoted on many Internet forms, usually in the same manner as the person that starts out offering a technical opinion with "I'm no expert, but...". They don't seem to realize that the simple fact that they are not an expert gives less weight to their opinion, not more. Now, I have to state up front that many of these rules of thumb have a kernel of truth, even if it is small and it is usually based on preserving the accuracy of the data. From a simple poll I took of some astroimaging buddies it seems that most of us are interested in making a pretty picture, not scientific imaging and that the majority quote the most popular rules of thumb like a mantra. The most often-quoted rules are things like darks *must* be used in calibration, flats *must* be exposed so that the peak is at the midpoint of the histogram, and lately I've been hearing that deconvolution *must* be performed before any non-linear stretching.

Let's take a look at each of these and see if they hold up under closer scrutiny. First on the list is the one about darks being mandatory. For proper scientific imaging with a CCD camera, this statement is certainly true. Now think about the imager using a modern DSLR. Most of these cameras have built in dark suppression that removes the dark current as it builds up on the chip. With these cameras there is no need to subtract a dark frame or a bias frame. In fact, doing so will add additional noise to the image. These cameras artificially add a bias value to each pixel, so once you find out what this value is, you can make an artificial bias frame with zero noise to subtract from your images for proper flat fielding and not add any noise other than that of the flats in your calibration. Don't believe me? Check out the two images below, the first (Figure 1) is calibrated normally using darks, bias, and flat frames while the second (Figure 2) uses no darks, an artificial bias, and a standard flat frame.

For those who like numbers, the details are in the table on the right.

As you can see the image calibrated without darks has a slightly better SNR. Now keep in mind that this only works with modern DSLRs designed, at least for Canon models, after 2008. By the way, for those Canon users out there, the

Figure 1 — Standard calibration applied

Figure 2 — No darks and artificial bias used during calibration

bias value added in the camera is 2048. If you are a dedicated CCD user, you're out of luck, as I don't think they are currently using chips with on-sensor dark suppression, but stay tuned—it is coming.

Now as for the rule of thumb that flats must be exposed so the histogram peak is mid scale. This one is interesting because there is no harm in doing this. The only caveat is that it is simply not necessary, and if doing sky flats at dusk, it can make for long flats, relatively speaking, that may leave some trailed stars that could be difficult to remove with a median combine. Modern sensors are very linear. In fact, measurements of my Canon 60Da show it to be linear from very dim exposures up until saturation occurs. This means that I simply don't have to worry about keeping the histogram in the centre to keep the flats linear. Exposures to the right of center remain linear up to the point of saturation. Exposures to the left of centre, as long as they are photon-noise limited, will average to a low-noise master flat that is just as good as the sum of mid-range exposures. What all this means is that I can expose my flats anywhere from the photon-noise limit on the left to just before

Image	Point (x, y)	Mean	Standard Deviation	SNR
With darks & bias	2900, 1590	14026.830	336.941	41.63
	2750, 3010	14346.093	343.348	41.78
Without darks & artificial bias	2900, 1590	14045.083	331.520	42.37
	2750, 3010	14376.046	341.903	42.05

Figure 3 — Deconvolution applied before stretching

Figure 4 — Deconvolution applied after stretching

saturation on the right and all will be well. In a nut-shell a mid-range exposure for flats will work just fine, but it is in no way mandatory.

Finally the idea that deconvolution must be applied before any non-linear stretch, well…

Like most of these rules of thumb, this one starts off with some truth and then quickly gets turned into a hard and fast must-do rule. Mathematically speaking, the light leaving a star is transmitted through a "channel" until it reaches our detector. This channel includes everything from the surface of the star to the sensor used in our cameras. As it travels through the channel, it is convolved with the impulse response of said channel, otherwise known as the point spread function (PSF). This generally produces a blurred image due to the atmosphere and optics that form part of the channel. Much of this blurring can be undone if you know the precise PSF of the channel through which the light has travelled by a process known as deconvolution.

In many branches of engineering we have to guess at the impulse response, but in astrophotography we have the advantage that stars are so far away that they appear as point sources. Thus the image of a point source, as spread by the channel, is the point spread function used for deconvolution. This means that the image of a star is the PSF that should be used in deconvolution of our images and this is where the rule of thumb comes from. Any non-linear stretch changes the PSF by enlarging the image of the star. In order to be as accurate as possible, the PSF used should be an unstretched star and the deconvolution should be applied to an unstretched image.

Of course, like most rules of thumb that have their basis in accuracy, this one quickly falls apart. First, the image of a star generally is polluted by noise as the star brightness approaches the sky background, so we generally use a Gaussian PSF to simulate a star—so much for accuracy. Next is the fact that the PSF for most scopes varies across the image plane. This requires that the PSF be adjusted for different parts of the image, just like was done in processing *Hubble* images before its "glasses" were installed. The combination of using a Gaussian PSF and the fact that the PSF needs to change across the image plane means that any hope of *accuracy* is no more than a pipe dream, so the best rule of thumb is to use deconvolution whenever you have some portion of the image that is low in noise and needs sharpening. One rule of thumb that I would follow is to apply it using a mask to limit the effect to the bright parts of the image and limit the noise increase in the dimmer parts.

Here is a quick test to demonstrate that there is very little difference between either of the methods of deconvolution. The first Image (Figure 3) has had 11 iterations of RL deconvolution applied before stretching using a star near the centre as the PSF. The stars were also protected with an inverse star mask to prevent the usual dark halos around them.

The next image (Figure 4) was stretched, then had 11 iterations of RL deconvolution applied using a 13-pixel Gaussian as the PSF. No mask was used on the image.

As you can see there is very little difference between the two images.

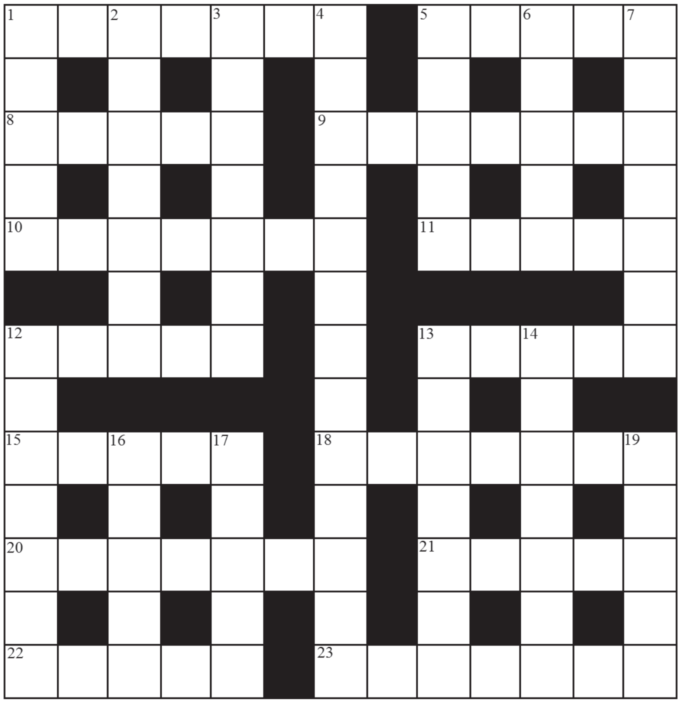
Rules of thumb can be useful, but only if you know where they come from and understand when to apply them and when to ignore them. Whenever you see a post about the "proper" way to do something in astrophotography, whether it is how to take flats or how to solve a tracking problem, think about it for a while and test it to see if it holds up. Assuming it does, then you can incorporate it into your technique, if it doesn't then ignore it and move on to the next "rule of thumb."

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.

Astrocryptic

by Curt Nason



ACROSS

1. Look after Mort's return to a southern observatory (7)
5. Struggling resistance before morning on Zeta Peg (5)
8. She co-discovered a galactic luminosity relation at Animal House College (5)
9. Holy man with little credit gets hug and one kiss at a Centre observatory (2,5)
10. Popular party person and familiar meteorologist (7)
11. Steer around a volume of space (5)
12. Get a laugh on our new Centre (5)
13. Ram's brightest headlight starts return of eastern priest (5)
15. Active galaxy goes up in smoke (5)
18. He roams around seeking microwave source from a comet (2,5)
20. Cut a tie from a dusty disc neighbor (3,4)
21. Little Dipper starts to fill with air in the heather on board (5)
22. Orbital points back on some French plane (5)
23. Motion made at GA hospitality suite to turn egg into star (7)

DOWN

1. European capital invested in lofty observatory (5)
2. eBay action cast in stone by LPA guru (3,4)
3. Solar waves flare but half return in the Moon (7)
4. See 10 OB stars veer around in such places (13)
5. Scope enhancements made by public chauffeurs (5)
6. Moon mapper used low res to no end (5)
7. Gap in Saturn's rings to range on Venus (7)
12. Hybrid scope in Chinese currency for targeted NA peninsula (7)
13. Greet mother with a backache around Jupiter (7)
14. Yearning for dark matter mass (7)
16. Big Dipper was a similar vessel for northward migrants (5)
17. Big birds don't fly around Saturn for starters (5)
19. Hadar detected by HR replacement at Dwingleloo (5)

Answers to June's Astrocryptic

ACROSS

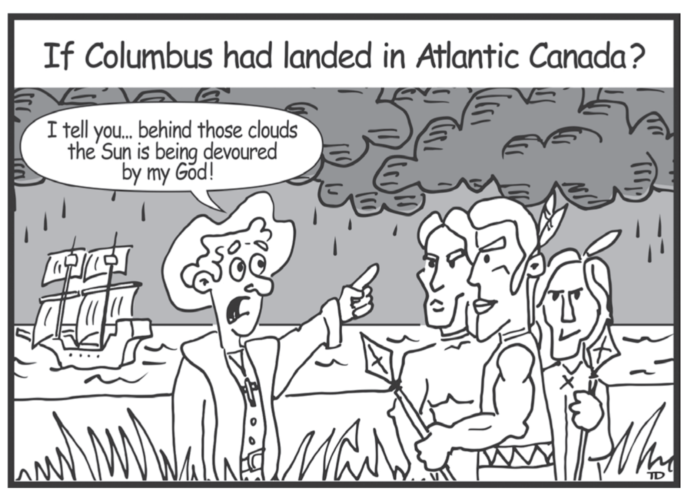
2 JUPITER (Ju+(pi(t)er); **5** GIBBS (rev+BS); **8** ALLER (all+Er); **9** NASMYTH (hidden); **10** SLOAN (hid); **11** HYPERED (hype+red); **13** CRONUS (2 def); **14** HESPER (anag); **17** BERNARD (a -> e); **19** SEVEN (se(V)en); **21** LACERTA (anag); **23** INNES (hid); **24** SPEED (deeps (rev)); **25** Allison (all+ISON)

DOWN

1 JEANS (2 def); **2** PULKOVO (up(rev)+lk+oVo); **3** TARANTULA (anag); **4** RONCHI (anag); **5** GAS (sag(rev)); **6** BAYER (b+anag); **7** SCHEDAR (anag-a); **12** PEEKSKILL (peeks+kill); **13** CYBELES (a(Y)nag); **15** PAVONIS (p+rev+is); **16** ADHARA (ad+h+ara); **18** ROCHE (anag); **20** NASON (2 def); **22** RED (rev)

It's Not All Sirius

by Ted Dunphy



THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

Great Images

by Michael Watson

A beautiful image of our nearest companion. Michael Watson created this image of the Moon with 15 stacked frames using a Nikon D810 camera body and a 1200-mm focal length, ƒ/8 lens on an Explore Scientific 152-mm (6″) apochromatic refracting telescope, mounted on a Sky-Watcher AZ-EQ6 SynScan mount. Stacked in Registax 6 and processed in Photoshop CS6.

Journal

Great Images

Sunflower: A spectacular image of the Sunflower Galaxy captured by Daniel Posey. This is 5h 45m of data was captured during two observing sessions. The first session from May 2013 consists of 1h 55m of 5-minute frames with Victoria Centre's QSI 583c through a Meade LX200 14″ SCT at ƒ/10. An additional 3h 50m of 5-minute frames through the same telescope was captured with Posey's 6D at ISO 1600 in May 2016. It was all stacked and processed in Pixinsight.