The Journal of The Royal Astronomical Society of Canada

Journal

Le Journal de la Société royale d'astronomie du Canada

PROMOTING ASTRONOMY IN CANADA

April/avril 2017
Volume/volume 111
Number/numéro 2 [783]

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- Darkness over the RAO
- Short History of Astrophotography: Part 1
- 1994 St-Robert, Québec, Meteorite

Gold dust

The Best of Monochrome.

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

Editor Nicole Mortillaro, using iTelescope's Planewave CDK 17" with an SBIG STL-11000 in Spain, took this single, 10-minute image of the Monkey Head Nebula in Orion.

Journal
April/avril 2017 | Vol. 111, No. 2 | Whole Number 783

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

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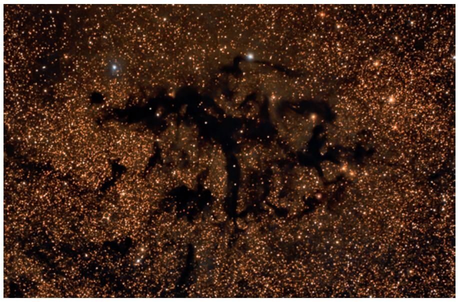

Lynn Hilborn took this image of LDN 673 in Aquila at his WhistleStop Observatory in Grafton, Ontario, on 2015 July 22 and 23. Hilborn used a Canon 6D at 3200 ISO using a TEC140 f/5.3 and 30 × 10 minutes exposures.

Journal

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

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

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

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

President's Corner

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

Politics has always been and always will be a divisive topic. Growing up, it was right up there with religion and money among certain subjects that were just not brought up in polite company. Decades later, this has not changed much at all, and in this era of instant communication and policy creation in 140 characters it is an even more divisive topic, if that is even possible. As an organization, the RASC has traditionally maintained a strictly apolitical posture, publicly supporting no candidate, no party, and no party leader. The reasons for that are as varied and complex as our membership.

On a purely practical level, Canada Revenue Agency rules enacted over the past half-decade strictly forbade registered charities from engaging in political activities on pain of losing their charitable status and their assets. If you followed the news in the 2012–2015 time period, environmentally focused organizations seemed to be the most at-risk. Always on our minds was what constituted "political activities"? Did our light-pollution abatement efforts and meetings with interested municipal governments and park services constitute forbidden activities? Could we support Canadian scientists who had been effectively muzzled by their political masters from speaking publicly?

On a social level, our aim is to be as inclusive an organization as possible. Our tent is a large one, and what unites us despite our personal differences is our fundamental passion for all things astronomy and related sciences. Our focus must remain on what brings us together, not that which is sure to divide and what is fundamentally a fleeting thing and of a moment in time. By emphasizing the value of science and the scientific method, and celebrating the dizzying variety of ways that the night sky is part of the cultural fabric of our many communities, we can have an impact on policy. By keeping the spotlight on the value of science and the scientific method, we can be a part of the scientifically literate community that encourages fact-based decision making. This takes the long view; policy change and influence as a cultural marathon versus tackling of-the-moment issues.

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Our mission statement reads:

> *"To enhance understanding of and inspire curiosity about the Universe, through public outreach, education, and support for astronomical research."*

Where we can have the most impact one mind at a time is through our activities at the Centre and National levels that drive our mission forward. By happy coincidence, these are the activities that we are passionate about anyway, and rarely do we consider their impact on a broader or even political level. By staying above the political fray (while being mindful of the minefields that surround the Canadian charitable landscape) and staying true to our mission, we are all activists for astronomy, for science, and for the value of scientifically grounded evidence-based decision making in public policy. ✶

News Notes / En Manchette

Compiled by Jay Anderson

Brightest supernova isn't?

In 2015, the All Sky Automated Survey for SuperNovae detected an event that was recorded as the brightest supernova ever, named ASASSN-15lh. It was categorized as a superluminous supernova, the explosion of an extremely massive star at the end of its life. It was twice as bright as the previous record holder, and at its peak was 20 times brighter than the total light output of the entire Milky Way.

Figure 1 — This artist's impression depicts a rapidly spinning supermassive black hole surrounded by an accretion disc. This thin disk of rotating material consists of the leftovers of a Sun-like star that was ripped apart by the tidal forces of the black hole. Shocks in the colliding debris, as well as heat generated in accretion, led to a burst of light, resembling a supernova explosion. Image: ESA/Hubble, ESO, M. Kornmesser

An international team, led by Giorgos Leloudas at the Weizmann Institute of Science, Israel, and the Dark Cosmology Centre, Denmark, has now made additional observations of the distant galaxy, about four billion light-years from Earth, where the explosion took place and they have proposed a new explanation for this extraordinary event. "Our results indicate that the event was probably caused by a rapidly spinning supermassive black hole as it destroyed a low-mass star," explains Leloudas.

In this scenario, the extreme gravitational forces of a supermassive black hole, located in the centre of the host galaxy, ripped apart a Sun-like star that wandered too close—a so-called tidal-disruption event, something so far only observed about 10 times. In the process, the star was "spaghettified" and shocks in the colliding debris as well as heat generated in accretion led to a burst of light. This gave the event the appearance of a very bright supernova explosion.

The team based their new conclusions on observations from a selection of telescopes, both on the ground and in space. Among them was the NASA/ESA *Hubble Space Telescope*, the Very Large Telescope at ESO's Paranal Observatory and the New Technology Telescope at ESO's La Silla Observatory.

"There are several independent aspects to the observations that suggest that this event was indeed a tidal disruption and not a superluminous supernova," explains coauthor Morgan Fraser from the University of Cambridge, UK.

In particular, the data revealed that the event went through three distinct phases over the 10 months of follow-up observations—events that more closely resemble what is expected for a tidal disruption than a superluminous supernova. An observed re-brightening in ultraviolet light along with a temperature increase reduced the likelihood of a supernova event. Furthermore, the location of the event—a red, massive, and passive galaxy—is not the usual home for a superluminous supernova explosion, which normally occurs in blue, star-forming dwarf galaxies. These three behaviours more closely resemble what is expected for a tidal disruption than a superluminous supernova.

Although the team says a supernova source is very unlikely, they accept that a classical tidal disruption event would not be an adequate explanation for the event either. Team member Nicholas Stone from Columbia University, USA, elaborates: "The tidal-disruption event we propose cannot be explained with a non-spinning supermassive black hole. We argue that ASASSN-15lh was a tidal-disruption event arising from a very particular kind of black hole."

The mass of the host galaxy implies that the supermassive black hole at its centre has a mass of at least 100 million times that of the Sun. A black hole of this mass would normally be unable to disrupt stars outside of its event horizon—the boundary within which nothing is able to escape its gravitational pull. However, if the black hole is a particular kind that happens to be rapidly spinning—a so-called Kerr black hole—the situation changes and this limit no longer applies.

"Even with all the collected data we cannot say with 100-percent certainty that the ASASSN-15lh event was a tidal disruption event," concludes Leloudas. "But it is by far the most likely explanation."

Compiled with material provided by the European Southern Observatory.

A new value for the Hubble Constant

A team of astronomers lead by Sherry Suyu at the Max Planck Institute for Astrophysics in Germany has made a new measurement of the Hubble Constant, the rate at which the Universe is expanding. The new number, one of several derived over the years, is at odds with some of the previous values. The discrepancy hints at the possibility of "new physics" that will extend our understanding beyond the standard model of cosmology.

The research team used the NASA/ESA *Hubble Space Telescope* and other space- and Earth-based telescopes, including the Keck telescopes in Hawaii, to observe three galaxies and arrive at an independent measurement of the Hubble Constant. "The Hubble Constant is crucial for modern astronomy, as it can help to confirm or refute whether our picture of the Universe—composed of dark energy, dark matter, and normal matter—is actually correct, or if we are missing something fundamental," Suyu noted.

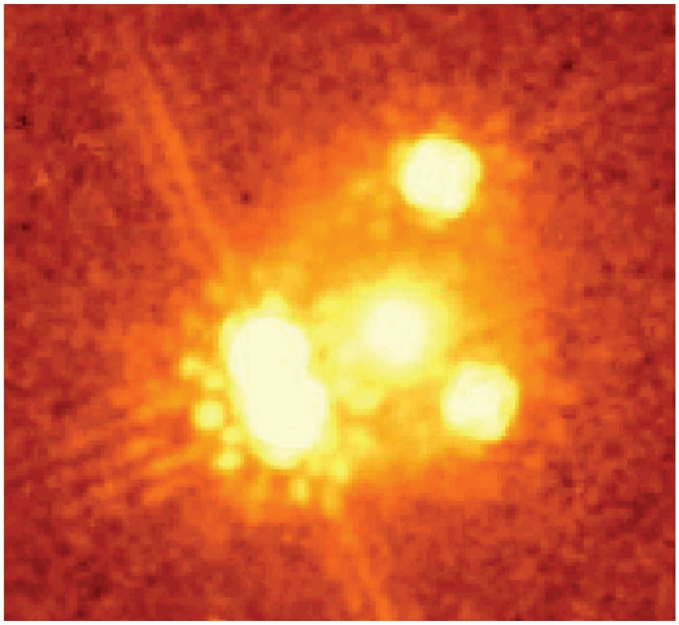


Figure 2 — The light from the single quasar PG 1115+080 is split and distorted in this infrared image. PG 1115+080 is at a distance of about 8 billion light-years in the constellation Leo, and it is viewed through an elliptical galactic lens at a distance of 3 billion light-years. The NICMOS frame is taken at a wavelength of 1.6 microns and it shows the four images of the quasar (the two on the left are nearly merging) surrounding the galaxy that causes the light to be lensed. The quasar is a variable light source and the light in each image travels a different path to reach the Earth. Source: NASA/Space Telescope Science Institute, Christopher D. Impey (University of Arizona)

The most recent value was obtained by studying three galaxies, each of which is bending light from a distant quasar, a cosmic object whose brightness fluctuates randomly. In each case the gravitational lens creates multiple images of the quasar. Because mass is not evenly distributed through these massive galaxies, some areas bend or slow light more than others. Light from the individual quasar images will arrive at slightly different times depending on the route it takes through the lens, just as drivers who set off from one city to another at the same time, but travel by different routes, will arrive at different times. By exploiting the variable nature of the background quasar and analyzing that delay, the researchers could arrive at a figure for the Hubble Constant.

Among the parameters needed to derive the new value for the constant are the distribution of mass along the line of sight from quasar to telescope, the time delay for the light in each of the quasar images, and the distribution of mass within the lensing galaxies. "These three things allow us to get a precise measure of the Hubble Constant," noted Chris Fassnacht, a physics professor at UC Davis and a member of the team.

The Hubble Constant estimate—71.9±2.7 kilometres per second per megaparsec—is accurate to 3.8 percent. The figure is in close agreement with measurements by other astronomers based on observations of supernovae and of Cepheid variable stars, but is a faster rate than that obtained from the *Planck Space Telescope* (67.80±0.77 km/sec/Mpc), which measured radiation from the cosmic microwave background.

The Planck measurement does rely on some assumptions—that the Universe is flat, for instance. Or, the difference could be a statistical fluctuation that will disappear as the estimates get better. Or, it could be something more exciting. "If you still see something when the error bars shrink, maybe it's new physics, beyond the Standard Model of cosmology," Fassnacht said. The research team plans to shrink those error bars by carrying out the same measurements for up to 100 lensed quasars, Fassnacht said.

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

A Massive Galaxy Long Ago and Far Away

The preponderance of stars in massive elliptical galaxies was formed within a short time early in the Universe's history. The very earliest stars would have been composed primarily of hydrogen and helium, creating heavier elements (known

as metals) in their cores that later enriched the surrounding environment as they were released in supernova explosions. Later generations of stars sipped from this enriched medium, adding their own enhanced metals to the interstellar medium until star formation came to an end.

The appearance of these metals in very distant galaxies can provide limits on the duration of star formation in the early Universe. One way of doing this is to measure the amount of magnesium relative to the amount of iron in a suitable galaxy. Magnesium in a galaxy comes from young, massive stars that have exploded, while iron comes predominately from binary white-dwarf systems that evolve into supernovae, a process that takes much longer in the aging of a stellar population. A higher Mg/Fe ratio implies that a galaxy has completed its star-forming period early and quickly in its lifespan.

Harvard-Smithsonian Center for Astrophysics astronomers Charlie Conroy, Jieun Choi, and eight colleagues used the spectrometer on the Keck Telescope (along with some secondary datasets) to obtain very sensitive magnesium measurements in COSMOS 11494, one of the most massive and luminous elliptical galaxies known. The galaxy, seen at an epoch only three billion years after the Big Bang ($z = 2.1$), has a stellar mass of about three hundred billion solar-masses (the Milky Way's stellar mass is about ten times less) but is currently making stars at a rate only about half that of the Milky Way. However, its magnesium-to-iron ratio—about four times that of the Sun— indicates that earlier in its life it was making stars at a phenomenally high rate, perhaps as many as 600 to 3000 solar masses per year, making it one of the most vigorous examples of star formation known. Why it suddenly quit making stars is still a mystery.

The scientists conclude that the bursts of star formation in this galaxy must have been due to mergers with other galaxies. In

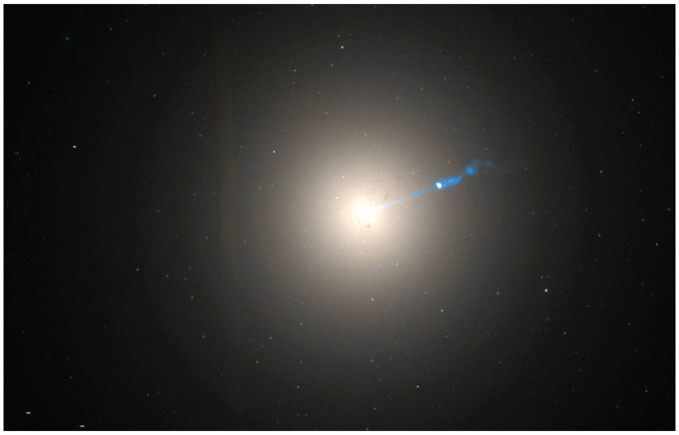


Figure 3 — Elliptical galaxy IC 2006 in Eridanus. A study suggests that the most massive elliptical galaxies stopped star formation near their centres roughly three billion years after the Big Bang. Source: ESA/Hubble & NASA (Judy Schmidt and J. Blakeslee (Dominion Astrophysical Observatory)). Earth. Source: NASA/Space Telescope Science Institute, Christopher D. Impey (University of Arizona)

fact, they estimate that the galaxy probably doubled in sized as a consequence of accreting smaller galaxies. Such mergers would have reduced the Mg/Fe ratio, so that in the present epoch it would probably resemble the elliptical M87 in Virgo or IC 2006.

Unfortunately, this particular elliptical is so unusual that it cannot be considered a typical progenitor for any local elliptical galaxy. The team argues that additional observations of more, less-extreme ellipticals in the early Universe are now needed to fill in the rest of the story. The instruments on the *James Webb Space Telescope*, to be launched next year, should be capable of doing so.

Compiled in part from information provided by the Harvard-Smithsonian Center for Astrophysics.

Halo Stars Travel in Gangs

The Milky Way's disk is immersed in a vast spherical halo of old stars and globular clusters embedded in a dilute and very hot gas but containing very little dust. Most of the globular clusters lie closer to the core than our Sun does, but individual stars have been found in orbits nearly a million light-years distant, a significant part of the way to the Andromeda Galaxy.

An analysis of data from millions of stars observed by the *Gaia* space mission has revealed that many of the stars in the halo travel in groups.

The Milky Way has likely formed in part from the merging of many smaller systems. How exactly that happened is still a puzzle. To learn more about the history of formation of the Milky Way, astronomers from the University of Groningen in the Netherlands and UC Riverside in the U.S. have inspected the motions of stars in the so-called galactic halo. Stars in the halo are more pristine and spend most of their time outside of the disk-like structure that gives the Milky Way its name. It is thought that these halo stars are the stars that joined the Milky Way during a past gravitational assimilation of small companion galaxies.

For this study, a team lead by Amina Helmi (University of Groningen) combined the vast *Gaia* dataset with data from the Radial Velocity Experiment (RAVE) survey. *Gaia* is a global space astrometry mission that is making the largest, most-precise three-dimensional map of our galaxy by surveying more than a billion stars brighter than 20th magnitude with a precision of 20 microarcseconds. RAVE was a large spectroscopic survey of Milky Way stars that collected spectra of nearly a half-million stars before ending its mission in 2013.

The researchers discovered that a large fraction of the halo stars travel in groups. Says Helmi, "This indicates that the stars indeed originate from small galaxies that were cannibalized by the Milky Way a very long time ago." The astronomers describe these groups as large flows of stars like flocks of birds travelling together through the Milky Way. "We believe there might be tens or even hundreds such flocks. At the moment, we only see small groups with just a few stars, but that is probably because we do not yet have all the necessary data."

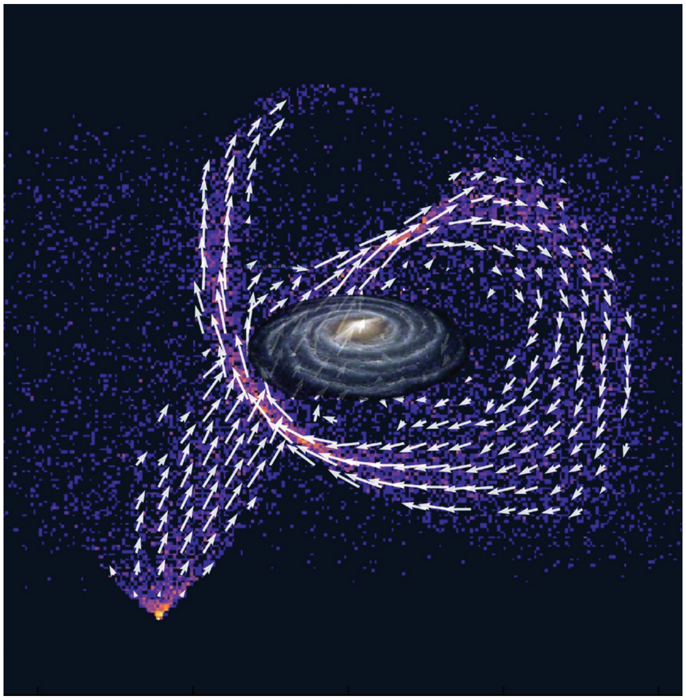


Figure 4 — The Milky Way disk is embedded in a roundish halo of stars. The stars (in purple) are from a computer simulation of the remains from a merger with a small galaxy. The arrows indicate the motion of these stars that are now part of the halo. Larger arrows indicate faster motion. The astronomers suspect that tens to hundreds of such flows of stars are crisscrossing the Milky Way. Image: Amina Helmi/Jovan Veljanoski/Maarten Breddels/University of Groningen.

The team of astronomers were bewildered of the behaviour of halo stars that spend most of the time in the outskirts of the Milky Way. Surprisingly, more than 70 percent of those stars appear to be moving in retrograde orbits compared to the vast majority of stars in the Milky Way. Such a high fraction is unexpected in current models. "One may compare stars from the outer halo with commuters that drive the wrong way. We do not yet quite understand why," notes Helmi.

These discoveries were made using halo stars that, in their journey through the Milky Way, are by chance close to the Sun. In the future, *Gaia* will provide us with data from stars from all over the Milky Way. According to Helmi, "With such data we will get many new insights on how the Milky Way formed and be able to reconstruct its genealogy tree." ✶

Compiled in part with material provided by astronomieNL / University of Groningen.

Quantifying and Monitoring Darkness over the RAO

Phil Langill[1, 2] *& Benjamin George*[1]

1 – University of Calgary
2 – Rothney Astrophysical Observatory

How dark is it?

How dark is it? A basic question about a fundamental concept. And it's a question that's asked whenever people interested in seeing the stars get together. I saw this question in a whole new light when it was posed to me by a councillor with the Municipal District of Foothills back in 2007. He was a neighbour who lived not too far from the Rothney Astrophysical Observatory, and who knew that paradigms were shifting and residential development was about to ramp up in this beautiful area on the welcome mat of the Rocky Mountains. This discussion began a process that led to the development of the MD's Dark Sky Initiative light-pollution bylaw instituted in 2009 www.mdfoothills.com/residents/planning/environment/dark_sky_initiative.html. And all through that process I was tasked with quantifying darkness.

It's actually a very difficult thing to do, made even more complicated when you want to use a language that the average person can grasp. My first attempts utilized RAO telescopes and astronomical filters and careful photometric calibration using Landolt standard stars. But that was far too involved for the purpose of this bylaw. There had to be a better way.

I can't recall exactly, but it was probably a member of the RASC Calgary Centre who told me about it in 2009. A new gizmo called the Sky Quality Meter (SQM) might be the just the thing I was looking for. So in short order a model with internet connectivity, and an internal lens for more focused directionality, was strapped to the Clark-Milone Telescope, pointing to the sky. The goal at this point was to learn the characteristics of the SQM and determine if it was indeed to right tool for the job.

Over the next ~3 years, that SQM-LE was pointed all over the sky and it was found to be very sensitive and stable. With the observatory situated SW of Calgary, when the CMT tracks an object the SQM sees more and more of the sky away from the city, pointing progressively westward toward the mountains. The SQM was sensitive enough to measure the sky slowly darkening while tracking, whether the Moon was up or not. It was also surprising to discover that, when opening the dome in the middle of the night to begin a late-night observing run, the SQM revealed what looked like a very dark Moonless sky was actually brighter than the inside of the closed dome.

And during this testing phase it was consistently found, when detailed photometric calibrations were made of star fields when doing scientific work, that the photometric zeropoints in the V filter came out quite close to what the SQM was measuring during the darkest part of the observing run. So the SQM actually lets one know what photometric limit to expect while observing. During the nicest darkest Moonless RAO nights the CMT-SQM reported that the "brightness" of the sky bottomed out between 20.65 and 20.75 magnitudes per square arcsecond. All things considered, the SQM is an awesome tool for quantifying the darkness of the nighttime sky.

The Units of Radiance

But what on Earth is a magnitude per square arcsecond? This jargon-laden unit is the one major challenge of using this instrument to communicate to the public exactly what darkness is. So simply put, the SQM measures the *radiance* of the sky. Historically, radiance was measured in candelas per square metre; meaning a brightness spread over some area. Being an astronomical tool, the brightness is described using the magnitude scale. Used by astronomers for centuries, it is a logarithmic scale where, counterintuitively, higher numbers describe fainter objects. For the RASCals reading this, the magnitude scale is probably quite familiar so no further elaboration is required.

If one quotes the magnitude of a patch of empty sky, rather than the magnitude of a star, and picks a very small patch of sky equal to one arcsecond by one arcsecond, then one has described the apparent surface brightness, or radiance, of the sky in magnitudes per square arcsecond (mag/arcsec^2). A careful calibration of the response of the SQM to light input shows that a reading of 20.0 mag/arcsec^2 S equates to 1.080 x 10^{-3} candelas per square metre. Conversions between these units are given here http://unihedron.com/projects/darksky/magconv.php?ACTION=SOLVE&txtMAGSQA=20

All sorts of technical specs of the SQM can be found in the 2005 paper by Pierantonio Cinzano www.lightpollution.it/download/sqmreport.pdf. Of particular note is the shape of the responsivity of the SQM. The filter used is very broad with a 50% or higher transmission from 360 nm to 600 nm. The peak transmission is close to 90% between 500 nm and 540 nm. Cinzano reports that this is quite similar to the bandpass of the Johnson V, or visual, astronomical filter. So the SQM "sees" the sky much like a CCD camera through a Johnson V-band filter. This explains why the zeropoints being derived from photometric V-band calibrations matched so closely to the SQM's reading. The field of view of the SQM-LE is about 20 degrees. That's like looking at a patch of the sky through a toilet-paper roll held right up to your eye. Details of the filter response and field of view can be found here http://unihedron.com/pipermail/sqm/2008-October/000023.html

A Second SQM for the RAO

So, after examining the CMT-SQM over those initial years, it was found that the device was not only scientifically valuable, it would indeed be the ideal tool for monitoring sky darkness at night over the observatory. And while it was handy to have an SQM that could be pointed around the sky, nobody else using them mounted theirs to a telescope. In order to join the community of researchers monitoring Artificial Light At Night (ALAN), a second SQM-LE was put into service at the RAO in the summer of 2012. At that time, an AllSky camera was being used at the RAO to assist with remote observing, so it was natural to assemble the two instruments together. The Zenith-SQM and AllSky camera are shown in their weather-proof housing in Figure 1.

Except for mostly minor interruptions, the two instruments have run constantly, even to this day. Real time data can be found online here http://ucalgary.ca/rao/multimedia. There was an extended time in 2015 (September and October) where the Zenith-SQM started to hang intermittently and so was sent back to the manufacturer to be diagnosed. It turned out the SQM was fine, and the problem was the data cable connection had become loose. The big idea was that the SQM data could be correlated to the weather conditions as captured by the AllSky camera, and an accumulated archive of data could someday be analyzed.

Almost Too Much Data

The analysis presented here finally happened in the summer of 2016, with the impetus coming from two sources. First was a very interesting analysis done by James Cleland of light pollution data from the *Great World Wide Star Count* and from the *Globe At Night*. His findings were reported in the June 2016 *Journal* of the RASC, Vol. 110, No.3 www.rasc.ca/jrasc-2016-june. One result in particular caught my eye—the sky over Calgary got darker between 2007 and 2014. Given the growth of Calgary over that interval, could this be possible? Would the Zenith-SQM corroborate this?

Figure 1 — The Zenith-SQM (A) and AllSky camera (B) inside their weather-proof housing, which is weighted down and reinforced against strong winds. The camera is level and oriented north and east. The SQM is mounted to the north side of the camera housing and points straight up. The photo on the right shows the Plexiglas weatherproof bubble that covers the instruments.

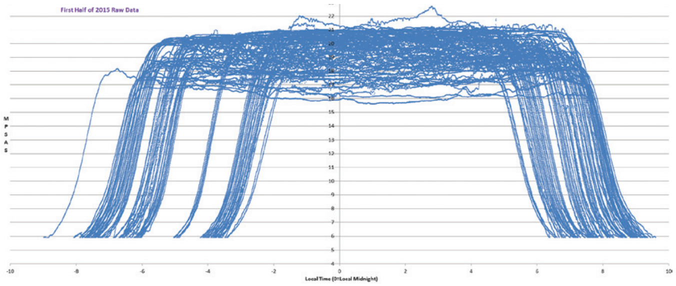


Figure 2 — Over 100,000 raw Zenith-SQM data points covering roughly the first half of 2015. The plot shows the radiance of the sky in Magnitudes per Square Arcsecond (mag/arcsec^2) from sunset to sunrise.

And the second was the appointment of a very talented and eager summer student, the coauthor of this article. When the mountains of Zenith-SQM data and AllSky images dating back to 2012 were finally gathered and peered into, it was terrifying. For the first few years, the software running the Zenith-SQM was configured to take a measurement every 15 seconds, day and night. Then an upgrade to the software allowed readings to stop when the Sun was above the horizon. Then measurements were taken every 30 seconds. The philosophy was it was better to have the data in hand and worry about details of its analysis later, but this was definitely overkill. Figure 2 shows over a 100,000 raw Zenith-SQM data points for roughly the first half of 2015. Despite the daunting task, BG masterfully corrected and reduced all the data. It was essentially a four-step process.

The first-order modifications to the data included both a time shift so that all the time stamps corresponded to Mountain Standard Time and a sensible averaging process so that the data set could be reduced by a factor of ~10. The second-order modification involved removing all the data corresponding to the phase of the Moon being greater than 0.75, and the Sun being less than 5 degrees below the horizon. After all this work, it was painfully obvious that the "weather factor" had to be addressed. Since the goal was to monitor star-filled nighttime skies, nights of cloud cover, snow cover, rain drops, fog, frost, and aurora had to be removed. The third-order modification involved going through the entire archive of AllSky images and removing nights where ill weather affected the data for more than half the night. This analysis removed ¾ of all the data. Figure 3 shows examples of AllSky camera images used for this purpose.

And finally, two fourth-order corrections had to be carefully done. First, when the Zenith-SQM was sent back to its

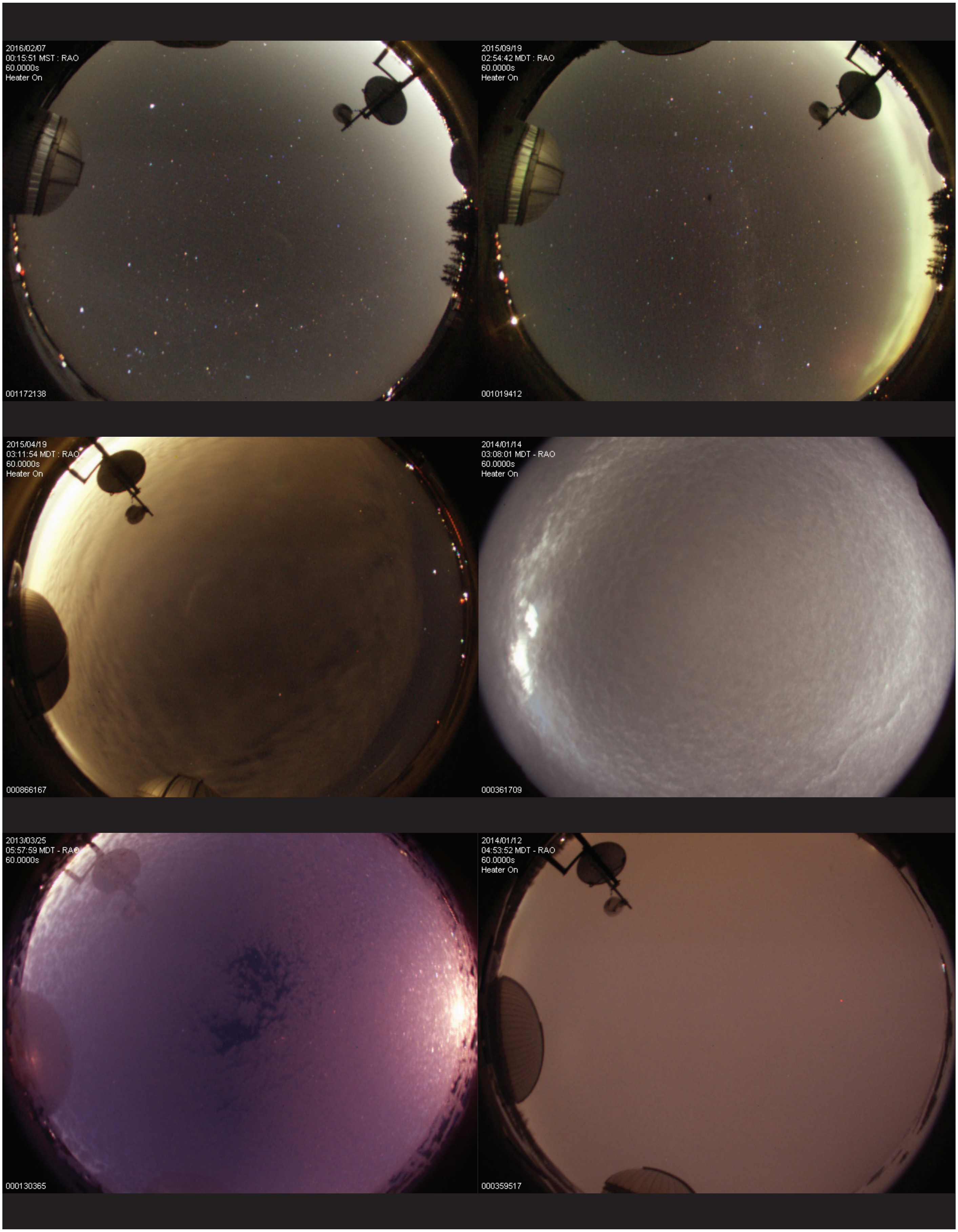


Figure 3 — Examples of 60-second exposure nighttime images recorded by the AllSky camera. These images were used to critique weather conditions that might skew the Zenith-SQM data. The microwave dishes in the images indicate the NE direction, toward the city of Calgary.

manufacturer in September-October 2015 for inspection, a re-calibration was performed. It was discovered that an additive offset of -0.06 mag/arcsec^2 was needed to get the Zenith-SQM measuring precisely again. Forty months earlier, when the unit was initially put into service, no such offset was needed. After consulting with the manufacturer it was concluded that having been exposed constantly to sunlight and the out of doors in an essentially air-tight housing, the plastic coating on the sensor likely was degrading. Under consultation, it was deemed that the degradation was linear with time, so an additive offset of -0.0015 mag/arcsec^2 per month was added to the Zenith-SQM data. The Zenith-SQM was measuring the sky to be darker than it actually was.

The second fourth-order correction is needed to account for the loss of light due to the Plexiglas bubble cover. The manufacturer of this cover is not known, but it was purchased in the 1970s to be used with solar observing experiments on a high-altitude balloon payloads. It is very likely that the payload team was aware of potential UV damage problems and thus purchased a high quality UV-resistant bubble. That was indeed the hope when it put into use over the Zenith-SQM and AllSky camera in 2012.

So, over the years, the data has been inspected for evidence of a gradual loss of transparency, and the cover has been visually inspected every three or four months each time it was cleaned. Neither the data nor the inspections suggest that the transparency of the bubble has changed over time. This makes the second fourth-order correction a straight forward additive constant. To determine that constant it was a simple matter of comparing the measurements of the Zenith-SQM with the Plexiglas cover both on and off. It was found that when the Plexiglas cover is on, the Zenith-SQM reads 0.066 mag/arcsec^2 higher, so this value has to be subtracted from all the data.

The Results in Natural Sky Units

The ~3 years of carefully parsed data is ready to be presented. The challenge now is deciding how to display it all in a way that allows straight-forward conclusions. With regard to those cumbersome mag/arcsec^2 units, a 2015 paper in *Scientific Reports* had an interesting idea. Discussing *Worldwide Variations in Artificial Skyglow*, www.nature.com/articles/srep08409, Christopher Kyba et al. described sky darkness as measured with SQMs in Natural Sky Units, or NSU.

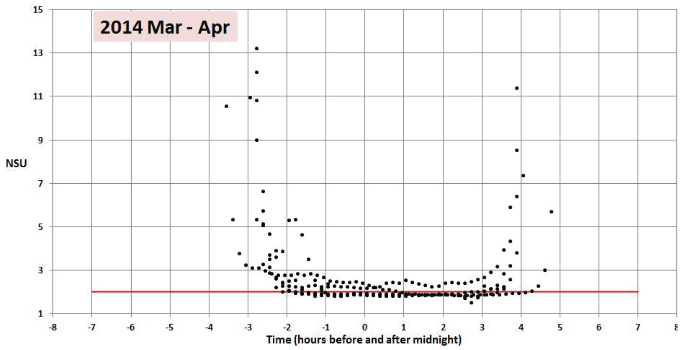


Figure 4 — A representative example of a two-month set of parsed SQM data plotted in NSU. On a few nights the radiance of the sky over the RAO got below 2 NSU.

The conversion between mag/arcsec^2 and NSU is defined according to the power-law relation NSU = 10^{0.4(21.6 – SQM)}, where SQM is the reading from one's sky quality meter in the units of mag/arcsec^2. Notice that if your reading is 21.6, this equation gives NSU = 1. The reason that the baseline value of 21.6 mag/arcsec^2 is used is because that is the average SQM reading at Kitt Peak National Observatory under dark, moonless conditions. This is also, more generally, the darkness of a typical historic clear night sky, according to Kyba et al.

So if your location has night skies of NSU = 1, your sky is as dark as at Kitt Peak. An NSU value of 2 corresponds to exactly two times as much sky radiance overhead compared to Kitt Peak (corresponding to 20.85 mag/arcsec^2), and an NSU value of 3 means your night sky is three times "brighter" than Kitt Peak (20.41 mag/arcsec^2). Describing the darkness of the sky at night in NSU makes the concept more linear, and unlike the magnitude scale, higher numbers mean brighter skies. So NSU as a brightness unit that represents sky radiance is perhaps more intuitive for the general public.

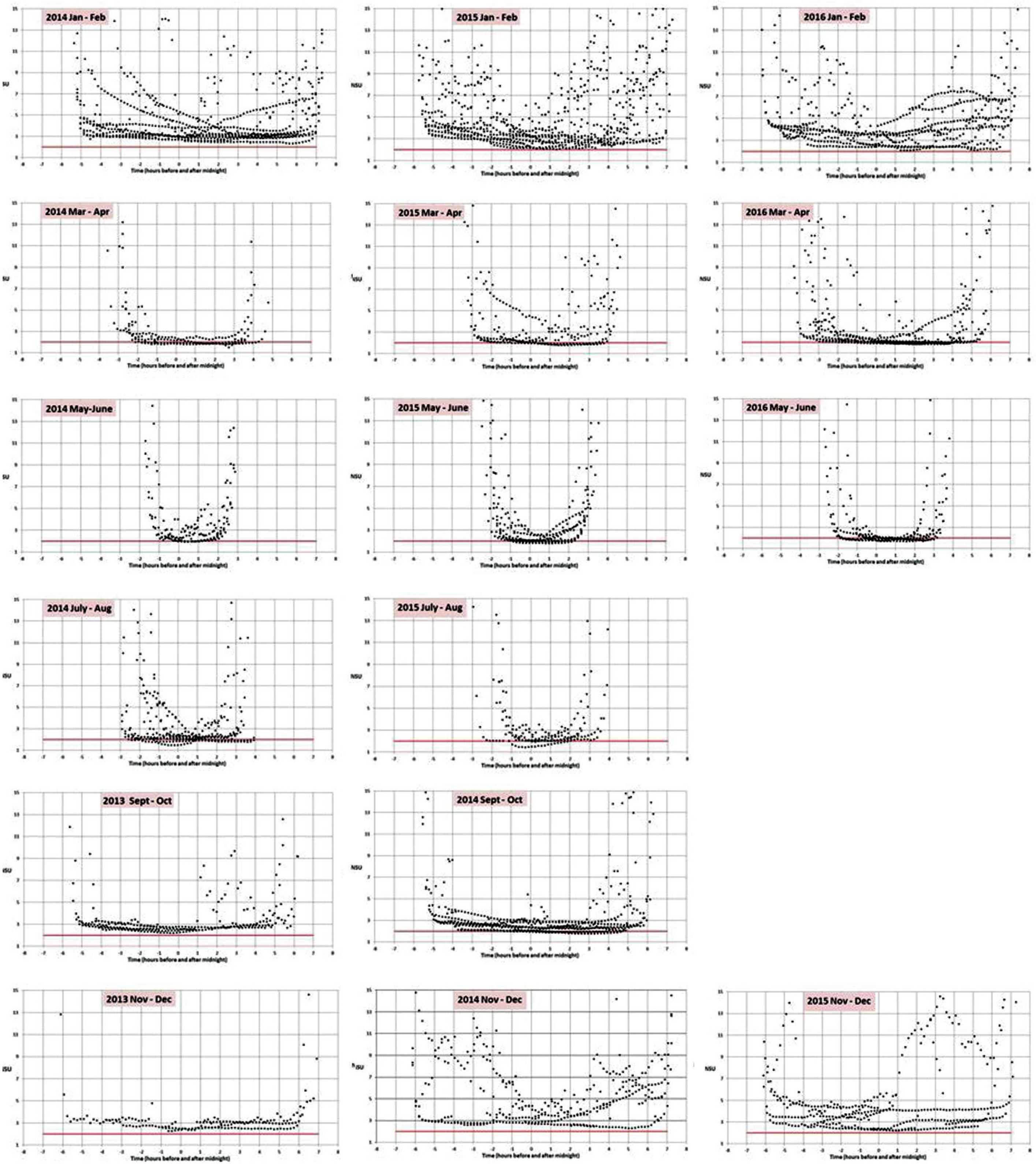


Figure 5 — A bi-monthly comparison of nighttime sky brightness over the RAO from late 2013 to mid-2016. The Sept–Oct 2015 data is missing because the Zenith-SQM was down for repairs. Sky darkness is displayed in NSU between sun setting and sun rising.

Figure 4 shows the radiance of the nighttime sky over the RAO as measured by the Zenith-SQM over the two-month block of time of March and April 2014. Radiance in NSU is plotted as a function of time relative to local midnight. A red horizontal line corresponding to 2 NSU is included to help guide the eye. The change in the duration of the night is noticeable over this time span. There is a small range in radiance minimum, but on a couple of nights the radiance goes slightly below 2 NSU. For the RAO, these are very dark nights.

Figures 5 shows the overall results in two-month interval bins so that the change in that interval over the years can be examined. There appears to be some seasonal variation between winter and summer, with summer nights reaching NSU = 2 consistently. The winter month nights are generally ~0.5 NSU brighter, which might be attributable to snow cover and seasonal festive lighting.

Looking across the ~3 years of data, the sky brightness seems to be holding quite constant, with perhaps a hint of a slight darkening. If so, this would be consistent with Cleland's observations in his *JRASC* 2016 article. Even a constant sky radiance is quite amazing, given the marked population growth of Calgary and subsequent development. Perhaps the City Planners are getting things right with regard to smart lighting.

The RAO is extremely fortunate to be sitting under such lovely dark skies, when the clouds and the Moon cooperate.

The true importance of this analysis is that it serves as a baseline of comparison for the future. As stated in the introduction, development is ramping up in the rural areas around the observatory. The Dark Sky Initiative bylaw has been on the books for seven years now, and for the most part, the RAO's neighbors are doing a great job keeping their lights down and off. But looming in the near future is the construction of the last leg of the City's ring road, and a new residential development, bringing many bright lights closer than ever before. We're working hard to keep stakeholders and neighbours educated so as to keep the RAO under dark skies for as long as possible.

Two final notes. First, the RAO has several hand-held SQMs which are available for loan. If any RASCal would like to give them a try, feel free to contact the author to make arrangements. And second, the 2018 Annual General Meeting of the RASC is being held in Calgary. This is a very special AGM for the RASC as it marks the 150th anniversary of the Society in Canada, and the 60th anniversary of the Calgary Centre. If you come to Calgary to partake you are invited on a free tour the RAO. Transportation and meal will be provided. ✶

Feature Articles / Articles de fond

A Short History of Astrophotography: Part 1

by Klaus Brasch

Abstract

In the past several years, two excellent histories of astronomical photography have been published (Ré, 2010 and Hughes, 2013). The former is available only as e-book and the latter in both e and paper formats. In addition, several websites have collections of vintage astronomical photos and illustrations (see e.g. Pinterest 2016). Each presentation places emphasis on different aspects of the story, as have we. Ré's work makes no effort to be comprehensive, highlighting instead selected individuals and applications to the end of the film age. Hughes's monumental work covers a very broad array of topics, with again emphasis on the people and the social settings of their respective eras. Our focus here is on Solar System photography and the evolution of the technologies that have advanced both the science and art of astronomical imaging from Daguerreotype to web cams and CCDs. We also place great emphasis on contributions by amateur astronomers.

Introduction

As we gaze in awe at the spectacular images of Solar System objects provided by *Hubble* and other space telescopes, assorted satellites, probes, and surface landers, it's easy to forget that prior to the start of the space age in the 1960s, our knowledge about these bodies was fragmentary at best and downright wrong at worst. Most of what was known to that point was based on three centuries of visual telescopic work, the bulk with modest telescopes and by amateurs, and less than a century of spectroscopic, photometric, and photographic work, which really came into its own only in the 20th century.

Thus as late as the 1960s, the rotation periods of both Mercury and Venus had not been determined with precision, and any knowledge of surface conditions on Venus was shrouded by the planet's dense and enigmatic atmosphere. Some visual observations at the time even suggested that permanent or semi-permanent surface markings could be glimpsed through gaps in the rapidly moving Venusian cloud deck (Dollfus, 1961). Our ignorance about conditions on Venus at that stage is nicely summarized by Roger Launius in his 2014 November 7 blog (Launius, 2014) on *Visions of Venus at the Dawn of the Space Age*: "…perhaps surprisingly, in the first half of the twentieth century a popular theory held that the sun had gradually been cooling for millennia and that as it did so, each planet in the solar system had a turn as a haven for life of various types." Although it was now Earth's turn to harbour life, the theory suggested that Mars had once been habitable

Figure 1 — Venus that never was (Schenk, 2012)

and that life on Venus was now just beginning to evolve. Beneath the clouds of the planet, the theory offered, was a warm, watery world and the possibility of aquatic and amphibious life. "It was reasoned that if the oceans of Venus still exist, then the Venusian clouds may be composed of water droplets," opined JPL researchers as late as 1963; "if Venus were covered by water, it was suggested that it might be inhabited by Venusian equivalents of Earth's Cambrian period of 500 million years ago, and the same steamy atmosphere could be a possibility" (Figure 1) (Schenk, 2012).

Likewise, despite having been scrutinized more closely than any other planet, our understanding of the ever-tantalizing Red Planet Mars in the early 1960s was at a crossroads (Brasch, 2016). Though the infamous "canals" debate was largely (but not completely) over, the nature of the planet's albedo features remained unclear, the true make-up of the polar caps and associated seasonal changes was only partly understood, and there was still the fading hope that lichen-like vegetation covered at least parts of the surface (Richardson and Bonestell, 1964). This hope was based largely on spectroscopic work by William Sinton in 1958, hinting that absorption bands due to organic C-H bonds were detected over the Martian dark features but not its deserts. Based on this evidence and the long-observed seasonal changes on the planet, the authors concluded "If there is extraterrestrial life in the Solar System, Mars is the only planet for which we have the slightest evidence for it." This view was perhaps best illustrated by the magnificent vision of future space exploration as depicted by Chesley Bonestell (Figure 2).

Although Jupiter's features and moons had been judiciously monitored telescopically since the mid-1800s, the physical nature and chemical composition of the Great Red Spot and other atmospheric phenomena was still poorly characterized in the pre-space era. Much of what was known was largely based on visual work by amateur astronomers engaged in long-term central-meridian timings of Jovian features in order

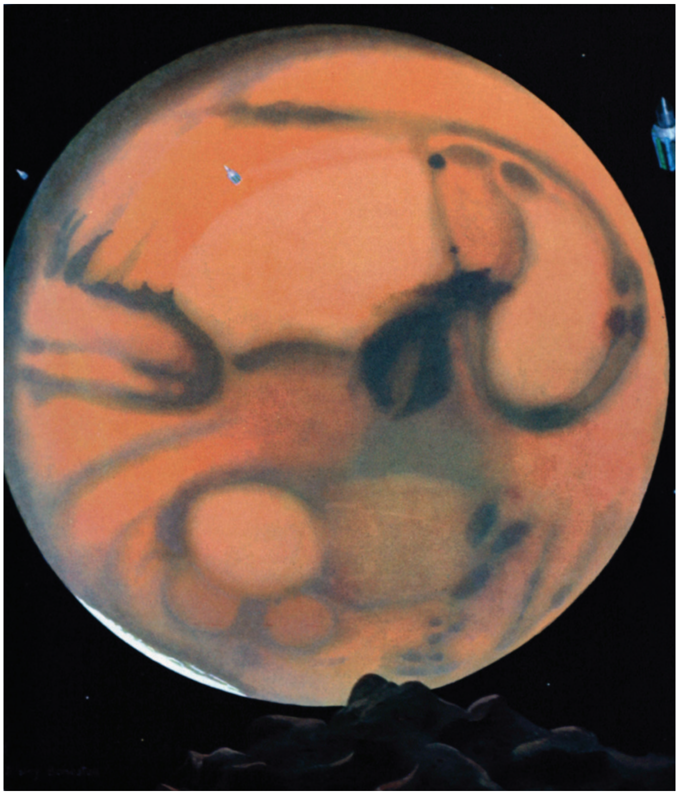


Figure 2 — Mars as depicted by Chesley Bonestell ca. 1960 (Wikicommons)

Figure 3 — Great Dopart Refractor (Tartu Observatory)

to determine their rotation and relative drift rates (Peek, 1958). Finally, major uncertainties also existed about Saturn's atmosphere and complex ring system (Baum, 2009), and virtually nothing was known of the composition and dynamics of the atmospheres of Uranus and Neptune and the surface of Pluto.

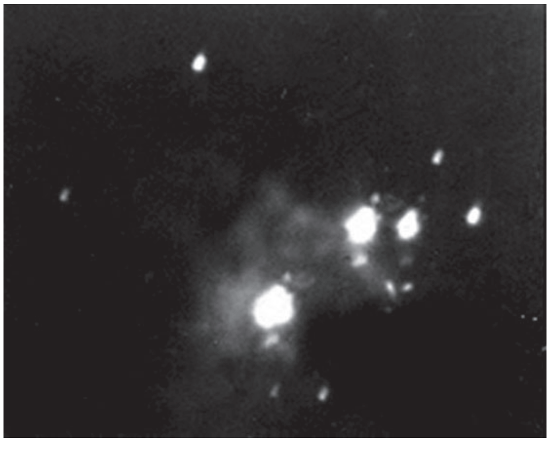
All that changed in 1957, with the launch of the first artificial satellite *Sputnik 1* and the International Geophysical Year (IGY), which made it clear that the long-anticipated space age had arrived, and that worldwide scientific cooperation could at last be achieved. *Sputnik* and the IGY provided the impetus for many of my generation to view science not only as an exciting adventure, but also as a vocation that could lead to the advancement of knowledge and betterment of humanity. Naive perhaps, in retrospect, but youthful idealism that propelled many of us toward rewarding careers as scientists and engineers, researchers and teachers who would impact several subsequent generations.

Beyond Visual Astronomy

The mid-1700 to 1800s saw several important technological developments that greatly improved both the quality of astronomical observations and extended them beyond the visual realm. Numerous individuals and devices played pivotal roles in this regard. Key among them was the invention of the achromatic lens, likely in 1733 by Chester Moore Hall (and possibly others) and patented in 1758 by John Dollond in England, and the English fork equatorial mount by Henry Hindley of York around 1740. Although it would take several decades and additional trial and error by John Dollond and his brother Peter, and Alexis Clairault in France and others, before quality crown and flint achromatic telescopes were produced, they were applied almost immediately to astronomy (Learner, 1981). Around 1814, gifted German optician and instrument maker, Joseph von Fraunhofer (1787–1826) invented the spectroscope and diffraction grating, and went on to manufacture vastly improved refracting telescopes, including the legendary 9.4-inch (24 cm) Great Dorpat Refractor in 1824 (Ré, 2010). This equatorially mounted telescope, complete with clock-drive mechanism, became the prototype of all subsequent refracting telescopes and mounts (Figure 3). Recently restored, this historic telescope is still housed at Tartu Observatory in Estonia. At last refracting telescopes became available that were not overwhelmed by chromatic and other aberrations and could automatically track objects across the sky. Shortly after that, multi-talented French physicist Leon Foucault, inventor of the pendulum named after him, also first applied silver to glass telescope mirrors (1857) and developed his famed knife-edge test for telescope mirrors. Coupled with development of the fork and English equatorial mounts by Jesse Ramsden, William Lassell and others eventually led to the rise of large glass-mirrored reflecting telescopes, replacing the cumbersome speculum metal mirrors used prior to that (Learner, 1981). Finally, the mid-1800s saw the development of photographic methods, which revolutionized astronomical research for good.

The Dawn of Astrophotography

In 1839, Louis Daguerre in France commercialized a metal-based process to take stable photographic images. This complicated wet-plate method known as daguerreotype, was used a year later, by the talented English-born American scientist, J.W. Draper, (1811–1882), to capture the first daguerreotype image of the full Moon in 1840 (Figure 4). It took several decades more before Henry Draper (1837–1882), the son of J.W. Draper and a New York physician and amateur astronomer, first imaged the Moon and the Orion Nebula in 1880, using the newly invented dry-plate photographic method (Figures 5-6). This was followed three years later by a much-improved image of M42 by English astronomer and telescope maker, A.A. Common (1841–1903). This long-exposure image (Figure 7) showing extensive nebulosity, earned him the gold medal of the Royal Astronomical Society. In 1887, Welsh engineer Isaac Roberts (1829–1904) obtained the first long-



Figures 4 — J.W. Draper's first daguerreotype of the full Moon (Wikicommons)
Figures 5 — H. Draper's first dry-plate of the Moon (Wikicommons)
Figures 6 — H. Draper's first dry-plate of the Orion Nebula (Wikicommons)

Figures 7 — A.A. Common's much improved photo of M42

Figures 8 — Isaac Robert's superb 1887 photo of the Andromeda nebula (Wikicommons)

exposure photograph of the Andromeda Galaxy (Figure 8), a magnificent image even by modern standards that also earned him the gold medal of the Royal Astronomical Society. For more details, see Hughes (2013).

While there was clearly no single "father" of astrophotography, Henry Draper certainly qualifies as one of them. In addition to obtaining the first photographs of the Orion Nebula, he also secured many other fine images of celestial objects, including the first spectrum of the star Vega and the first wide-field image of a comet.

Successful large-scale planetary photography was not achieved until 1885, however, when the brothers Pierre Paul Henry (1848–1905) and Mathieu Prosper Henry (1849–1904) used a 33-cm (13 inch) photographic refractor at the Paris Observatory to image both Jupiter and Saturn (Figure 9). They did this using a refractor of large focal ratio (*f*/10.4) coupled with an 11x enlarging lens. These two innovative astronomers were not only capable instrument makers and astrophotographers but also key players in the *Carte du Ciel* (Map of the Sky) and the *Astrographic Catalogue* (Astrographic Chart) projects. These were complementary components of a 19th-century international astronomical effort to catalogue and map the positions of millions of stars down to 11th or 12th magnitude.

Arguably, however, few astronomers of that era were as versatile and productive as E.E. Barnard (1857-1923) (Figure 10). Born to a poor family in Nashville, Tennessee, he eventually rose to prominence at Yerkes Observatory and as professor of astronomy at the University of Chicago. In addition to being an exceptional visual observer, he also discovered Saturn's moon Iapetus, Jupiter's 5th moon, Amalthea, Barnard's Star, and 15 comets; he really excelled at astrophotography. Although he mastered all aspects of astrophotography, his crowning achievement was a stunning series of wide-angle photographs of the Milky Way, revealing for the first time its many dark nebulae and clouds of interstellar dust (Figure 11). These images, still used today, were published posthumously in

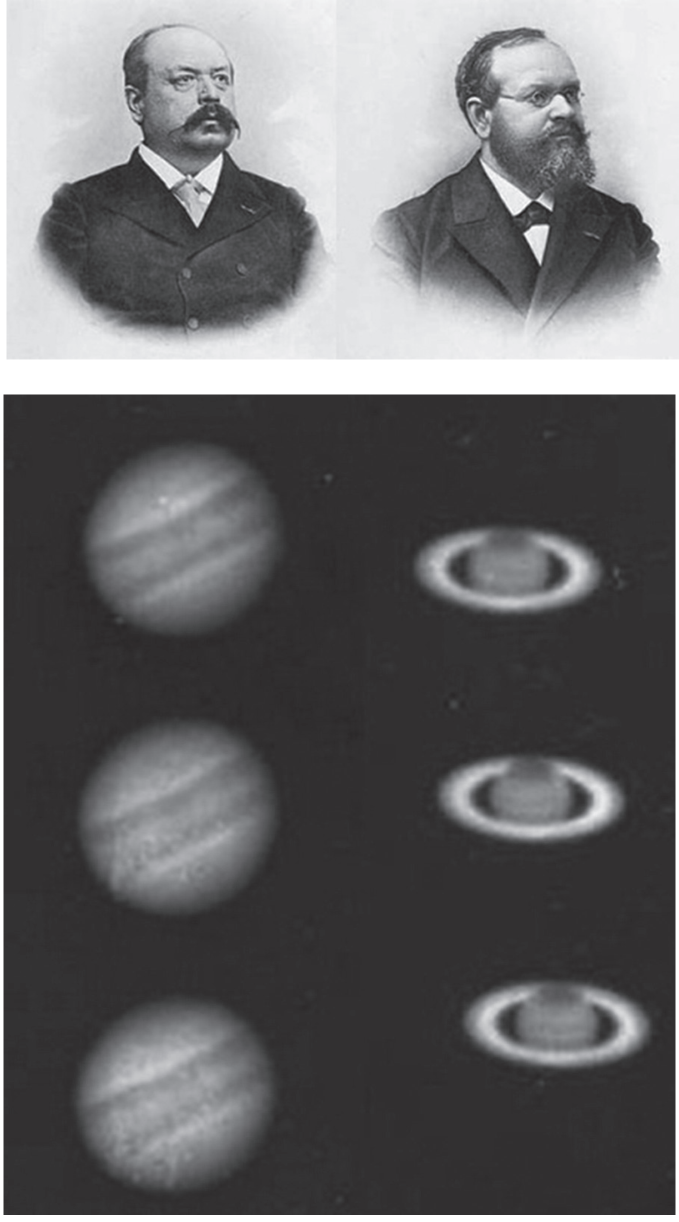


Figure 9 — The brothers Pierre and Mathieu Henry and their first detailed photos of Jupiter and Saturn taken in 1885 at Paris Observatory

1927 as *A Photographic Atlas of Selected Regions of the Milky Way* (Sheehan, 1995; Sheehan and Conselice, 2015).

The early 1900s saw a flourish of quality astronomical photography, including both Solar System and deep-sky objects, as well as spectroscopy. Among the earliest high-resolution planetary photographs were those obtained in 1904 by Carl Otto Lampland (1873–1951) with the 24-inch Clark refractor at Lowell Observatory (Figure 12). Lampland designed and built special enlarging cameras for planetary photography, while also maintaining telescopes, including the observatory's 42-inch reflector, with which he subsequently obtained many excellent images of star clusters and nebulae. He built thermocouples to measure temperatures of the planets, and noted large differences between night and day temperatures on Mars, implying a thin atmosphere. In addition to having an asteroid named in his honour, impact craters on both the Moon and Mars also bear his name (Putnam, 1994).

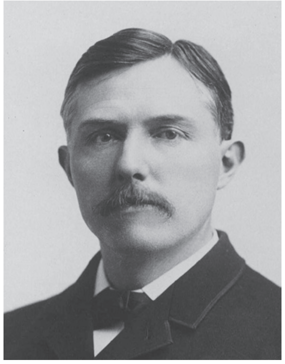


Figure 10 — E.E. Barnard (Wikicommons)

Planets, due to their small apparent diameter, and thereby requiring long telescope focal lengths and/or image amplification, as well as excellent optics and seeing conditions, proved immensely difficult to photograph successfully in the late 19th and early 20th centuries. Moreover, the grainy "isochromatic" plates of the day were not sufficiently red sensitive to register Martian surface detail well. Much of that changed with the introduction of panchromatic photographic plates in 1909, coinciding with a particularly favourable opposition of Mars. The result was that several observatories, including Lowell, Lick, Mt. Wilson, and Pic du Midi, obtained some of the first truly detailed images of the Red Planet (Figure 13).

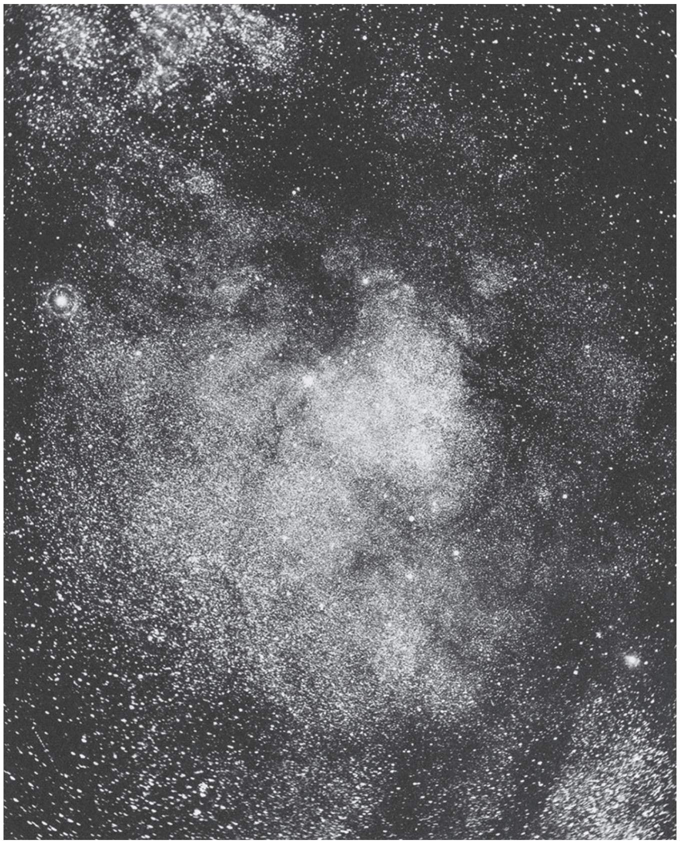


Figure 11 — One of E.E. Bernard's superb wide-field photos of the Milky Way (Wikicommons)

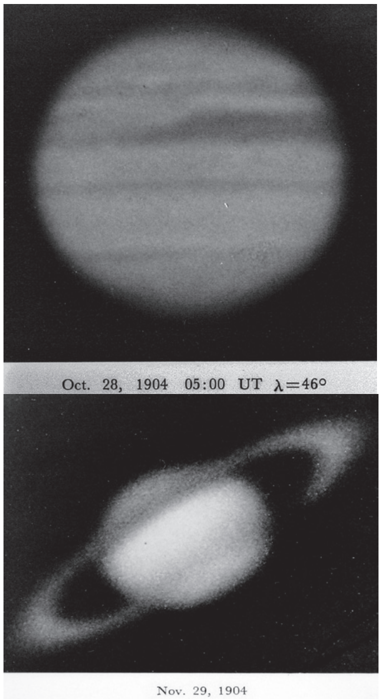
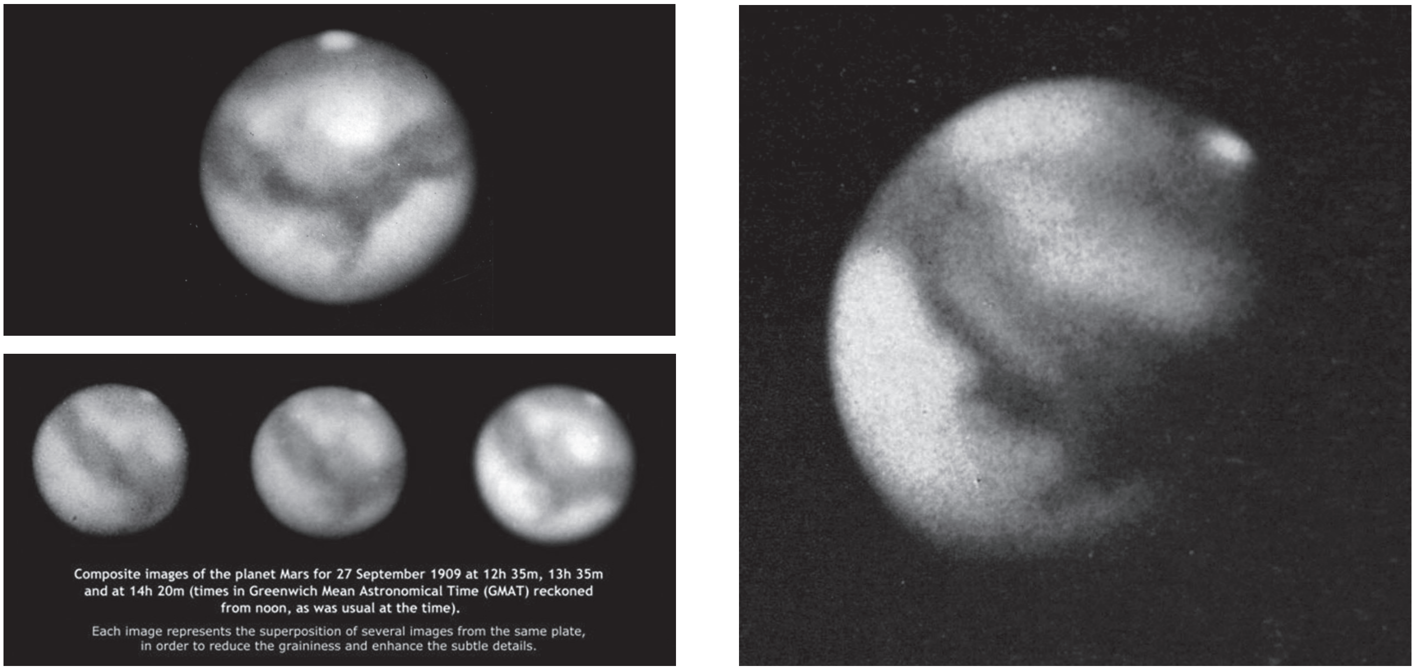


Figure 12 — 1904 photos of Jupiter and Saturn by C.O. Lampland (Lowell Observatory)

Ever loyal to his employer Percival Lowell, Lampland devoted his early efforts to attaining images of Mars sharp enough to reveal the putative "canals," which several visual observers claimed to have seen. Lowell was of course their most ardent proponent, maintaining they were irrigation canals of a dying, water-starved civilization on Mars. Indeed, as late as 1921, in a report titled "Is Mars Habitable?" (Lampland, 1921), Lampland states unequivocally that in the 1905 opposition of the planet, he "…succeeded in photographing several canals, and at the next opposition of 1907 obtained greatly improved results in photographing practically all the canals observed visually at that opposition."

Even after most other prominent observers at the time had largely dismissed the canals as spurious, E.C. Slipher (1883–1964) (Figure 14), Lampland's successor as master planetary photographer at Lowell Observatory, strove valiantly to capture convincing images of Martian canals. To that end he adapted and perfected a method of effectively combining several images taken in sequence using a method called integration printing (Brasch, 2014). This resulted in sharper, less grainy, and with more contrast, detailed images of the planets than could be generated with single exposures using the grainy photographic emulsions of the day. Slipher used this technique to great advantage for the rest of his career, and obtained some of the finest planetary images of the first half of the 20th century (Slipher, 1962; 1964) and (Figure 15). By combining this approach with selective-filter photography, Slipher and others were able to clearly reveal the dramatic


Composite images of the planet Mars for 27 September 1909 at 12h 35m, 13h 35m and at 14h 20m (times in Greenwich Mean Astronomical Time (GMAT) reckoned from noon, as was usual at the time).

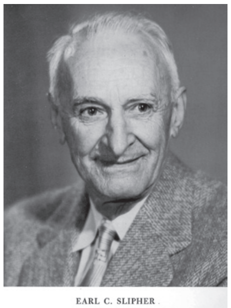
Each image represents the superposition of several images from the same plate, in order to reduce the graininess and enhance the subtle details.

Figure 13 — Mars photos taken during the 1909 opposition by E.E. Barnard (Yerkes), G.E. Hale (Mt. Wilson) and F. Baldest (Pic du Midi), respectively, using newly developed panchromatic plates. (All images Public Domain)

changes in the Venusian cloud deck. This labourious and time-consuming printing technique became standard practice at other major observatories as the photographic equivalent of image stacking, routinely practised today by digital astroimagers.

In 1958, Lowell astronomers H. Johnson, R.F. Neville, and B. Iriarte (Johnson et al., 1958), applied this same method of integration printing to generate a composite photograph of the Pinwheel Galaxy M33, using several 45-minute exposures of the galaxy on Kodak 103a-0 plates, obtained with the same 13-inch photographic refractor with which Pluto had been discovered nearly three decades earlier (Johnson et al., 1958). Prints were then made from a single such plate and compared to a composite image generated by combining the other ten plates with the same superpositioning apparatus developed by E.C. Slipher. The composite reveals an impressive increase in structural detail and a gain of 1.2 magnitudes over the single exposure, from 18.5 to 19.7. For details see (Brasch, 2014).

During the first half of the 20th century, study of the Moon and planets was essentially abandoned by most professional astronomers in favour of galactic astronomy and stellar physics. Thus, with the exception of a handful of professionals, among them Gerard Kuiper at Yerkes, several astronomers at Paris and Pic du Midi observatories (Dollfus, 1961; 2010), and of course Lowell Observatory, Solar System studies became primarily the purview of amateur astronomers. Consequently, such largely amateur organizations as the venerable Société Astronomique de France (founded in 1887), the British Astronomical Association (founded in 1890), the Royal Astronomical Society of Canada (founded in 1903), and relative newcomer, the Association of Lunar and Planetary Observers (ALPO, founded in 1947), focused their efforts on


EARL C. SLIPHER

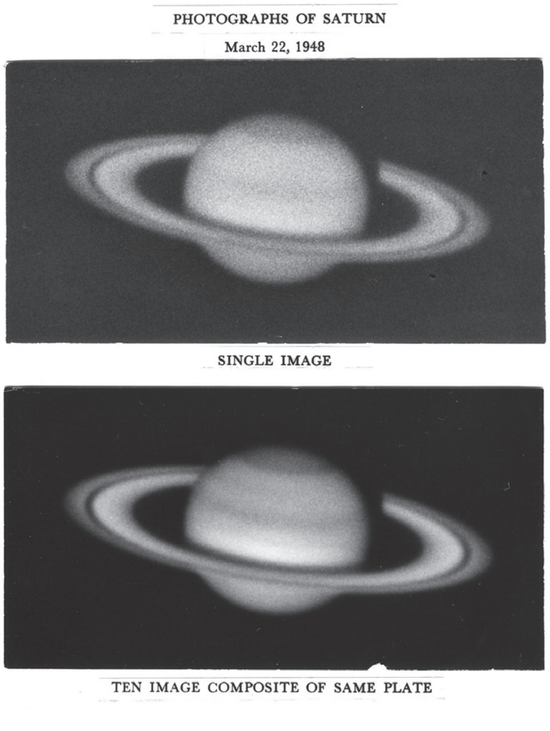
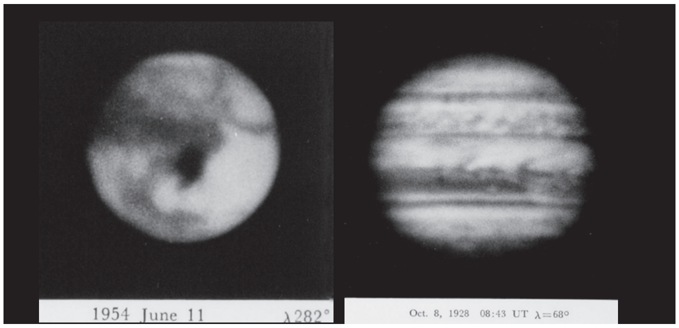


Figure 14 (left) — E.C. Slipher, and Figure 15 — a ten-image composite of Saturn showing reduced grain and higher contrast.



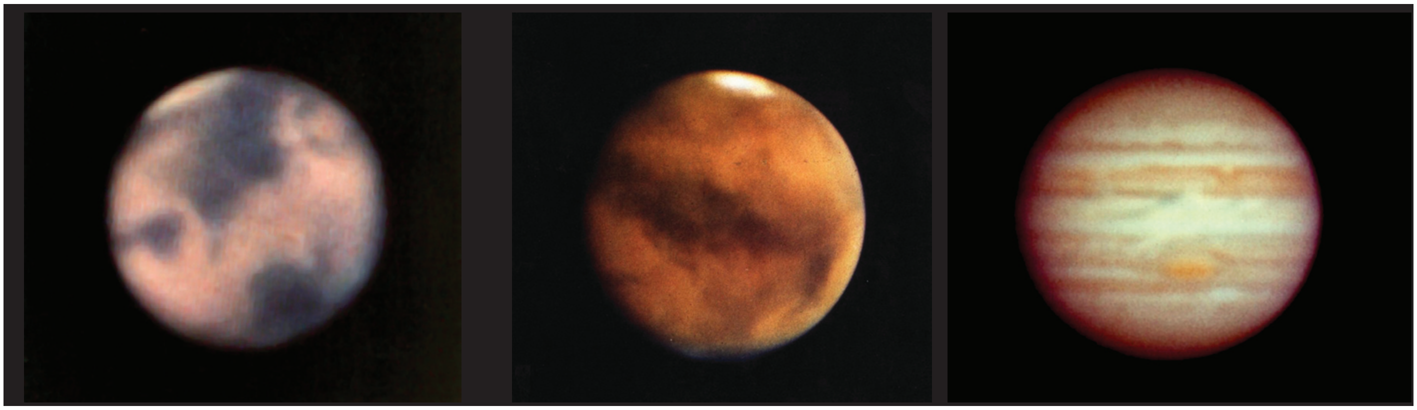
Figures 15a, 15b — Examples of some of E.C. Slipher's finest photographs of Mars and Jupiter compiled using integration printing. (Lowell Observatory archives)

monitoring lunar and planetary features, both visually and (eventually) photographically.

Modern amateur astrophotography began in earnest in the late 1950s and early 1960s, at a time when a number of suitable panchromatic and relatively fine-grained 35-mm films became available. In addition, affordable single-lens reflex cameras were manufactured, which quickly became favourites of amateur photographers (Brasch, 2012). At the same time, books like Henry E. Paul's *Outer Space Photography for the Amateur* (Paul, 1960) and *The Messier Album* by Evered Kreimer and John Mallas (1979) provided crucial "how to" information for thousands of hobbyists, and popular magazines like *Sky & Telescope* and *Astronomy* regularly featured amateur astrophotos and technical advice. In the realm of deep-sky photography at that time, German amateur Hans Vehrenberg was in a league of his own, beginning in 1965 with his photographic *Atlas Stellarum* and culminating with publication of his *Atlas of Deep-Sky Splendors* (Vehrenberg, 1983).

As with all photographic emulsions available then, most were black and white, very grainy, and suffered from marked reciprocity failure, and even excellent colour films like Kodachrome and Ektachrome were generally too slow for most astrophotography. This is not to imply that colour films were not used for planetary photography, or that professional astronomers did not experiment with them. In this regard, two examples stand out. During the two very favourable oppositions of Mars in 1954 and 1956, W. Finsen at Union Observatory in South Africa (Finsen, 1961) and Robert Leighton at Mt. Wilson observatory, produced the first and remarkably detailed composite images of the planet on Kodak colour films (Figure 16). Among other things, these images finally revealed the true hues of most Martian features, including the diffuse albedo markings, clouds, polar regions, and dust storms (Finsen, 1961). By the mid-1960s and 1970s, new fine-grained colour films became available, yielding correspondingly more detailed planetary colour images, including some that approached modern digital images.

Perhaps the finest film-based image of Saturn was taken in 1974 by Stephen Larsen at Catalina Observatory, near Tucson, Arizona (Figure 17). The 61-inch Kuiper telescope, now part of Stewart Observatory, was built in 1965 specifically for the Lunar and Planetary Laboratory founded to study the planets and map the lunar surface for the Apollo program. This remarkable composite image of Saturn was produced using 16 images taken in rapid succession with the telescope. Larson describes how this complex procedure was carried out: "We had just built a bulk 100 ft. 35-mm camera with a date and time stamp exposed onto the film, and [I]was trying it for the first time. I was not impressed with the seeing, so stopped the aperture down to 40″. Got everything set up and focused, started exposing and went downstairs for some coffee. The Ektachrome film was processed commercially in Tucson, and I spent a few hours picking out the best images. There must have been a spell of good seeing with a couple dozen good images in a row that could be combined. Our method of compositing was to project the image onto a reference print attached to a sliding light-tight 4 x 5 film tray. The film could be moved precisely in the enlarger head to null out the reference print. The enlarger was turned off in the dark, the film tray moved in place, and a short exposure made before returning the reference print to position the next image. Resolution was sufficient that you could see some differential atmospheric dispersion at the planet's edge. I attached a dispersion compensator usually used at the telescope to effectively bring the RBG color layer together to eliminate the disper-



Figures 16 — Figure 16: Examples of early planetary photos using Kodachrome and Ektachrome films; Mars 1954 by W. Finsen (Union Observatory), Mars 1956 by R. Leighton (Mt. Wilson), Jupiter 1967 by Charles Capen (JPL/NASA). (All public domain)

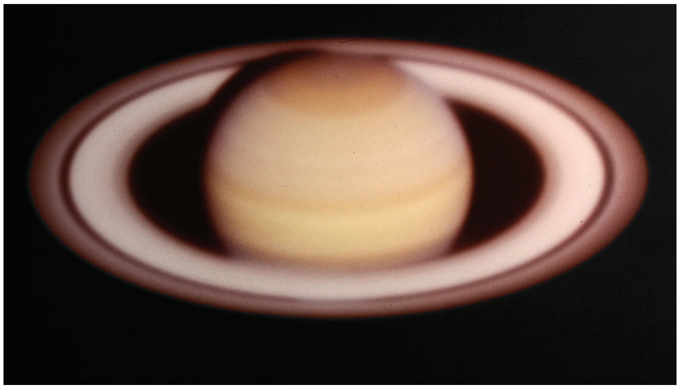


Figure 17 — This remarkable composite image of Saturn was produced in 1974 by Stephen Larson at Catalina Observatory using 16 images taken in rapid succession with the 61″ Kuiper telescope. (Courtesy S. Larson)

sion. Once all the exposures were made, I processed the 4 x 5 Ektachrome film in tanks the standard way. Such composites reduced the film grain noise by approximately the square root of the number of images used (~4x in this case)."

He further adds: "Of course, today, amateurs do this digitally with video rate cameras and software to select the best images and then co-add them. This is followed by digitally sharpening the image. This last sharpening was not done back in the film days. All we could do was alter the brightness, contrast, and color balance." ✶

Note: The author is indebted to Lowell Observatory archivist Lauren Amundson and Stewart Observatory astronomer Stephen Larson for use of their historic images.

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

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MIAC's Fieldwork in the 1994 St-Robert, Québec, Meteorite Fall: A Personal Account

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Abstract

As a large meteoroid entered the Earth's atmosphere and flashed across the sky in the early evening on 1994 June 14, the fireball was widely witnessed by persons in the states of New York, Vermont, and New Hampshire, as well as by residents in Ontario and Québec. Undergoing an explosion that rattled windows and caused skyscrapers to sway, it showered fragments onto farmland outside of the small town of Saint-Robert, Québec, some 60 kilometres northeast of Montréal. The first fragment was discovered only minutes afterwards, with the help of some curious cows. Within days, the Meteorites and Impacts Advisory Committee to the Canadian Space Agency (MIAC), which was charged with the recovery of Canadian meteorites, swung into action. By posting information about the event, interviewing local residents, authenticating found fragments, and looking for new ones, MIAC teams helped in the recovery of 19 additional pieces of the meteorite. Through visual observations of the meteor obtained by MIAC members and satellite observations obtained by the US Department of Defense, the meteoroid's pre-atmospheric orbit was determined.

Introduction

At 8:02 p.m., a few minutes before sunset on the evening of Tuesday, 1994 June 14, a ~one-metre-wide, ~two-tonne rocky asteroidal fragment entered the Earth's atmosphere. As it screamed through the atmosphere at ~13 km/sec, it broke apart at an altitude of ~36 km, sending a shower of meteorites down onto farmland outside the pastoral town of Saint-Robert, Québec, 60 km northeast of Montréal. One of them fell on the farm of Paul-Aimé Forcier, and attracted the attention of some of his cows. A few minutes later, one of his sons, 21-year-old Stéphane, arrived home on his bike. As he was approaching his field, he had heard "…this bang. Then I heard this whooshing sound, like a boomerang." He then noticed the curious cows "standing around in a circle staring at something." Walking over to see what they were looking at, he noticed a hole in the soft ground ~15 cm wide and ~20 cm deep. Grabbing a shovel, he dug out a 2.3-kg slightly charred stone roughly the size of a grapefruit. When he heard about the meteor reports on the television that evening, he called the provincial police, who gave him contact information for federal authorities in Ottawa. So begins the story of the recovery of the St-Robert meteorite, the 47th authenticated meteorite recovered in Canada.

MIAC's Fieldwork

Scarcely three hours after the fall of the meteorite, Peter Brown, then a graduate student at Western University but already recognized as a leading meteor expert, received a phone call from Pierre Senecal, an International Meteor Organization member from Montréal. As Peter relates in his handwritten field notes of events during the early days of MIAC's fieldwork—from which much of the following information in this section of the paper is gleaned—Senecal told him he had been sitting outside on his back patio at about 8:00 p.m. when he heard "a loud explosion, like dynamite." He went on to say that media outlets across the city were deluged by calls over the next two hours from thousands of people who had also heard the explosion. Many persons also reported seeing a fireball "along the south shore of the St. Lawrence, opposite Montréal."

The following morning, Peter received a phone call from Richard Herd, the Curator of National Collections at the Geological Survey of Canada. Richard informed him that he had been contacted the previous night by the Department of National Defence as a result of numerous fireball reports from Ontario and Québec. He relayed that he had also received a report of a meteorite recovery. Both Peter and Richard were members of MIAC, the Meteorites and Impacts Advisory Committee to the Canadian Space Agency, a small group of volunteer geologists and astronomers charged with the recovery of Canadian meteorites, and they quickly went into action. Richard went out to Saint-Robert to check out the story. When he ascertained that the stone Forcier had dug out from its small plunge pit was indeed a meteorite, he arranged for the fragment to be brought to the Battelle Memorial Institute, Pacific N.W. Laboratories for short-lived cosmogenic radionuclide measurements to be undertaken by John Wacker. Richard personally hand delivered the fragment to the laboratory within 72 hours of its fall—yielding one of the earliest counts of a freshly fallen meteorite.

Peter felt that it was crucial for someone to be on site following up on the fall. But he could not leave London at that time due to a university commitment, and Richard was away escorting the sample to the Battelle laboratory. So Peter phoned MIAC member Stephen Kissin from Lakehead University, one of the country's leading meteoriticists, to see if he could initiate MIAC fieldwork to gather information, authenticate any fragments that might turn up, and search for additional fragments. Steve arrived at Saint-Robert on June 17, accompanied by Denis Pagé, a French-speaking amateur astronomer from the RASC Québec Centre.

Through discussions with the Forcier family on Saturday, June 18, it was learned that three other persons in the area believed they had also found meteorites: Réjean Derosiers, Pierre Laliberté, and Lucien Villiard. Steve and Denis went to Derosiers' farm, and immediately authenticated his find, a 6.5-kilogram fragment he had extracted from a plunge pit in his corn field. When they went to Laliberté's farm and examined the 5.4-kilogram stone that he had found when his plow sank a bit into a plunge pit, however, they were unsure that it was a meteorite, as it was heavily encrusted in mud and they couldn't see any fusion crust.

Peter arrived in Saint-Robert on June 19 accompanied by Marie-Josée Nadeau, a University of Toronto postdoc, who helped out for a week as a French translator. On Monday, June 20, Steve, Peter, and Marie-Josée began the day by putting up posters in public areas in nearby Yamaska, describing the fall and providing contact information. They then went to the local elementary school in Saint-Robert, where the principal allowed them to interview eight children who said they had seen the fireball; as it turned out, however, their observations were of the meteor's dust trail. After lunch, Marie-Josée stayed on to give a one-hour talk to the entire school.

Steve, Peter, and Marie-Josée then returned to Derosiers' farm to see the meteorite he had found, and then proceeded to Laliberté's, to double-check his fragment. Once Laliberté washed it in water and removed the mud and dirt encasing it, the fragment was immediately seen to be a "textbook" ordinary chondrite, with only slight fading of its fusion crust.

The three-member team then went to Lucien Villiard's farm to examine a small specimen that had hit the roof of one of his sheds, making a small impact hole. Villiard's son had first noticed the stone, which had rolled off the shed, while cutting grass on June 15. After hearing about Forcier's meteorite find, he relocated the stone and showed it to Steve and Denis during the June 18–19 weekend. Villiard was not happy about letting them see either the fragment or the shed, but as Steve relates, "It was only after much discussion with Marie-Josée and his pretty daughter, Annie, that he allowed us to do this." They then obtained photos of the meteorite and a GPS reading.

By Tuesday, June 21, one week after the fall of the meteorite and Forcier's discovery, both search activities and meteorite finds began to increase. Two friends of MIAC, Sylvain Legrand and Pierre Lacombe of the Montréal Planetarium, joined the search team. In the morning, the team met at Derosiers' house, where Richard, accompanied by "a substantial media entourage," had come in an attempt to purchase some of the meteorites for the National Collection of Meteorites (Richard eventually succeeded in purchasing the Forcier meteorite for $10,000, and arranged for the acquisition of the Derosiers meteorite, the largest St-Robert fragment, through donation and tax credits).

As the media event got underway, a local farmer, Pierre Sasseville, showed up with a 755-gram fragment he had found the previous day in the middle of a path 100 metres behind his house. In the early afternoon, another fragment arrived at the Derosiers. This specimen, 598 grams, was found by Jeanne Vanier, one of the children who had heard Marie-Josée's talk at the local school, who had dinged it while mowing grass just off their house's driveway.

On the following day, Chris Hale and MIAC member John Rucklidge from the University of Toronto joined the searchers. Most of the day was spent doing farm-to-farm interviews. This type of fieldwork played a major role in MIAC's fact-gathering efforts. Interviewees were asked if they had observed the meteor's flight path or its dust trail; had heard any whistling or detonation sounds simultaneous with the flight; heard any whistling or sputtering sounds afterwards; or heard any "thuds," indicative of a nearby meteorite fall. They were also encouraged to examine their properties for the presence of plunge pits. In the late afternoon, Sasseville phoned to say he had found a second meteorite, a chipped 701-gram fragment found on a road, possibly chipped by a lawnmower.

On June 23, MIAC member Damien Lemay, an active amateur astronomer who was a past RASC National President, joined the group. There were now enough searchers so that they could divide themselves into two teams to continue interviewing area farmers. Within three minutes of the first group's start, as Sylvain walked from his first interview to the next house, he found a 533-gram fragment only 12 centimetres from the road. He picked it up, brought it over to his team, and nonchalantly asked an astonished Peter if this was the kind of thing they were looking for.

At the same time that Sylvain found his fragment, group two was in the office of the Saint-Robert mayor, discussing the meteorite situation. While in the process of doing so, the well-known American meteorite hunter/dealer Robert Haag walked in. There was some trepidation among the MIAC members that his presence might drastically alter the nature of the search. Up to then, it had been entirely run by MIAC and a few of its close friends, but now there was a fear that the nature of the search might change, and degenerate into a treasure-hunt scene with hordes of outside meteorite searchers. Happily, this feared scenario did not materialize.

In the afternoon, group two visited Sasseville's house to examine a third fragment he had found, a 644-gram specimen found while searching a small sandy area. Sasseville had come up with a novel tool to aid him in his searches. While larger meteorite fragments were usually found in noticeably large plunge pits, smaller fragments were usually in small pits, similar to those dug up by small field animals. Sometimes it was possible to distinguish between animal pits and meteorite pits, since in the former the dug-up dirt usually gets piled up on only one side of the pit's rim, while in meteorite pits the dirt gets evenly distributed along the entire rim. But since this was not always the case, Sasseville invented a technique of using a metal ski pole with the basket near the tip removed to probe the holes. If the pole hit a stone at the bottom of the pit it produced an unmistakable "click" sound. He used this technique to great advantage, and would go on to discover four more fragments in the next few weeks. Once he explained his invention to the other searchers, everyone quickly adopted the "Sasseville pole" technique.

On the next day, June 24, serious concern was raised with regard to Haag's presence when a rumour surfaced that he had purchased a piece of the meteorite the previous day, and might try to leave Canada via the Dorval Airport in Montréal that evening with it, but without a proper export permit. Since the export of meteorites is governed by the Cultural Property Export and Import Act, an export permit has to be obtained before they can leave the country. In light of that concern, a letter was sent to the American Embassy in Ottawa describing what the meteorite would look like, and requested them to "tak[e] an interest in this case." But since nothing came of this, it can safely be assumed that the rumour was false.

Figure 1 — A MIAC team at the end of a long day's search. Left to right: Denis Pagé, Dieter Brueckner, John Hanes, Pierre Sasseville, the author (resting on his Sasseville pole), and Alan Hildebrand.

On Saturday, June 25, Alan Hildebrand, a MIAC member then at the Continental Geoscience Division of the Geological Survey of Canada and arguably Canada's leading planetary scientist, joined the search team. One of his first stops was the Forcier farm, where a second pit had been located close to the plunge pit where their original meteorite had been found. On investigation, it was seen to be very similar in appearance to the first plunge pit, but there was nothing inside it. The Forciers speculated that it probably was a second meteorite plunge pit, but that someone had extracted the meteorite from it and walked away with it sometime during the crush of the extensive publicity crowd that had gathered on their farm following the news of their original find. Alan and Peter speculated that this seemed likely, and that, based on extrapolation from the size of the first plunge pit, the fragment was probably a ~5-kg piece. The validity of this speculation—and, if true, the whereabouts of this possible second Forcier fragment—has never been ascertained.

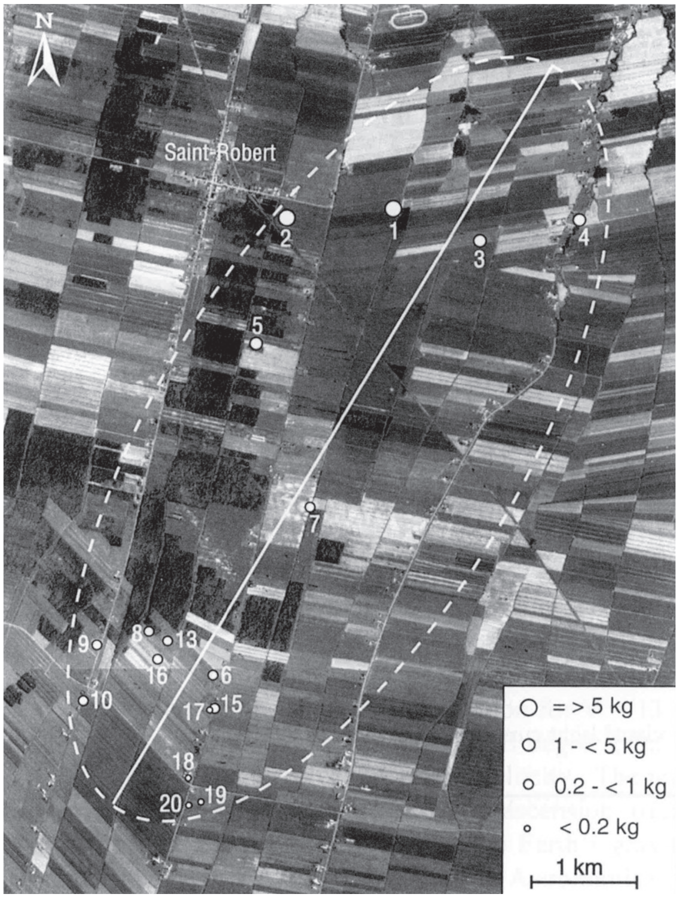

Figure 2 — A map showing the St-Robert strewn field and the locations of the meteorites found. Varying dots reflect the different masses of the fragments. The ~1:50,000 air photos had been taken in August 1984. The mosaic based on these photos and corrected to topographic maps was constructed by D. Niehaus, Continental Geoscience Division of the Geological Survey of Canada. From Peter Brown et al., "The Fall of the St-Robert, Meteorite," Meteoritics and Planetary Science *31 (1996), p. 510.*

On the next day, Sunday, June 26, the search team was joined by two husband-and-wife teams from Queens University, astronomers Judith Irwin and Dieter Brueckner and geologists John and Elizabeth Hanes; and Pierre Sicotte, an amateur from Montréal who helped out with French translation. John turned out to be an excellent searcher, and found his first meteorite, a 55-gram fragment half buried in soil, after about two hours of searching, and his second one, a 76-gram fragment that was completely buried except for its top surface, which was flush with the ground, two hours after that.

It is not my intent in this brief paper to detail all the St-Robert meteorite finds by the local residents or the MIAC teams (Figure 1). Suffice to say that following the discovery of the 11 fragments discussed above, 8 more were recovered over the next month, and a 20th and final one was recovered

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Figure 1 — From the Astroimaging site http://rascastroimaging.zenfolio.com/, the gallery for certificate winners.

The constellation Orion in a tracked (but unguided) exposure on the MusicBoxEQ mount on a tripod, taken at the 2013 Winter Star Party by Halifax member, Dave Chapman, an early Astroimaging Certificate winner. You can see the brilliant stars of Orion and some nebulosity. He writes "The pleasure of observing the winter skies in summertime temperatures is indescribable." Location: Scout Key, Florida, on 2013 February 7 at 8:17 p.m. EST. Dave used a Canon EOS Rebel XSi at ISO 1600 through a 50-mm ƒ/1.8 lens for 60 s.

Figure 2 — Gabriel Jones imaged the Moon reflected in Forgetmenot Pond, in Kananaskis Country, Alberta, taken on 2016 August 15. Jones took this using a Canon G16, 1/60-s exposure at ISO 80 and f/1.8.

Figure 3 — The Milky Way setting over the Observatorio Roque de Los Muchachos (alt. 2400 m) on the island of La Palma (Canary Islands). Randy Hoffman took this image on 2015 October 5.

Figure 4 — It's not just the moon in this beautiful image by Garry Stone. He captured moondogs and light pillars on a chilly Saskatchewan night where temperatures dipped to –27 °C. Stone took the image near the Gardiner Dam with a Canon XS and a Sigma 10-20-mm zoom at 10 mm and ƒ/4.5.

Figure 5 — Harvest time in Southern Alberta; ground lights are from harvesting equipment. Photo taken by Norman Baum using a Canon 60Da with a 16-mm Rokinon lens set to ƒ/2.8; ISO 800, exposure 19 seconds on a Skywatcher Star Adventurer mount. Location 2 miles west of Carmangay, Alberta. Norman is the recent winner of an Astroimaging Certificate.

Pen & Pixel

From the Astroimaging site http://rascastroimaging.zenfolio.com/, the gallery for certificate winners.

Scott Barrie of the Hamilton Centre is a recent Astroimaging Certificate winner in the Wide Field category. This was shot from his rural front yard northwest of Milton, Ontario, in the fall of 2000 on 35-mm film. The camera was a tripod-mounted Nikkormat FT, using a Nikkor 24-mm ƒ/2.8 lens. An unusual shot, considering the aurora is seldom seem at such low latitudes.

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Recovery dates, masses, locations, and find circumstances of individual meteorites recovered from the St-Robert, Québec fall of 1994 June 14

Fragment Number	Date Recovered	Mass (g)	Fragment Location		Comments
			°N	°W	
1	June 17	6552	45°58′07″	72°58′41″	In 45 cm-deep pit. Chipped on impact.
1a	June 20	19.9	45°58′07″	72°58′41″	Endpiece from no. 1.
1b	June 17	9.1	45°58′07″	72°58′41″	Chip from no. 1.
2	June 16	5438	45°58′07″	72°59′24″	In 30-cm-deep pit.
3	Sept. 13	3708	45°58′02″	72°58′03″	In 30-cm-deep pit. Weathered and muddy.
4	June 14	2297	45°58′08″	72°57′19″	In 25-cm-deep pit. Three corners chipped.
4a-d	June 15	~1.5	45°58′08″	72°57′19″	Chips from no. 4.
4e	June 18	~0.1	45°58′08″	72°57′19″	Chip from no. 4.
5	June 22	1500.7	45°57′31″	72°59′46″	In 20-cm-deep pit. Angular.
6	June 19	755	45°55′56″	73°00′04″	Found on path. 6-cm-deep pit.
7	June 22	701	45°56′40″	72°59′21″	Found on road. Chipped by lawnmower?
8	June 23	644	45°56′00″	73°00′30″	Embedded.
9	June 20	598	45°55′53″	73°00′55″	Embedded in lawn. Oriented specimen.
10	June 23	533	45°55′38″	73°01′09″	Found 12 cm from paved road.
11	~July 19	516.96			Embedded in ground. Broken in two.
12	~July 19	459.12			Embedded.
13	~July 16	442.88	45°55′55″	73°00′27″	In 10-cm-deep pit. Cut pine needles and branches.
14	~July 19	323.6			Embedded?
15	June 26	290.44	45°55′35″	73°00′06″	In 15-cm-deep pit in very soft lawn.
16	July 30	253.75	45°56′19″	73°00′31″	In 15-cm-deep pit covered in maggots in wet clay.
17	July 23	158.5	45°55′34″	73°00′07″	Embedded in stony lawn. Chipped on bottom.
17a	July 24	0.23	45°55′34″	73°00′07″	Chip from no. 17.
18	June 15	80.52	45°55′14″	73°00′18″	Hit roof of shed. Chipped.
19	June 25	75.64	45°55′05″	73°00′18″	Embedded 4 cm.
20	June 25	54.68	45°55′07″	73°00′13″	Quarter of broken individual. Embedded 2 cm.

Table 1 — A table providing detailed information on the meteorite fragments recovered from the St-Robert fall. The individual fragments are listed in order of decreasing mass, and their numbers correspond to the numbered locations shown in Figure 2. Recovery locations for three fragments are poorly known and not shown. After Alan Hildebrand et al., "The St-Robert Bolide of June 14, 1994," JRASC 91 *(1997), p. 268.*

in September. A map of the fall ellipse, measuring ~8 km x ~3.5 km and oriented at ~210°, showing the locations of the found meteorites is shown in Figure. 2; additional details for each of the finds are given in Table 1. Since this paper to some extent is a personal account, an account of my participation in MIAC's fieldwork is given in the next section.

The Author's Experiences in MIAC's Fieldwork

Because of my work in the history of meteoritics and my general interest in meteorites, I was invited to join MIAC shortly prior to the Saint-Robert event. Having already participated in meteorite searches (for the legendary "lost" Port Orford meteorite in Oregon), I enthusiastically accepted the invitation to join the Saint-Robert searches. The first of my half-dozen or so search trips to Saint-Robert took place in the week following John Hane's two finds. When I arrived, Richard Herd was in the process of giving search instructions to a small group of volunteers, and showing them the only meteorite he had with him at the time, which unfortunately was an iron meteorite. I joined the group, we formed search lines and traversed a field, but found nothing. I didn't consider this a very auspicious beginning to my search efforts.

My second search was a little more eventful. After searching for some time, I found a beautiful fragment. I excitedly picked it up and went over to Peter, who had organized this particular search, to show him my find. With a broad smile on his face,

Figure 3 — John Hanes and the author set off on a search for meteorite fragments in a huge farmer's field. This photo, from the early stages of MIAC's fieldwork, was taken prior to our use of the extremely helpful Sasseville pole method of discovery. No fragments were found on this particular search.

Figure 4 — John Hanes holds up the just-excavated 254-g meteorite he had found with the use of his Sasseville pole (on the ground next to his right knee). The author had already searched the area where the fragment was found, but had (sadly) missed this particular plunge pit.

Figure 5 — Alan Hildebrand and another MIAC searcher about to board the small aircraft that we flew at a height of ~200 m in a search for possible large undiscovered plunge pits at the northeast, downrange end of the fall ellipse. We were not able to spot any.

Figure 6 — The author with Pierre and Mme Sasseville outside their home. This photo was taken shortly before he and Pierre set off on what turned out to be an unsuccessful search. Later that day, Pierre confided to us that he had only recently found three new fragments in the ~300–500-g range.

Peter explained to me that it was in fact a piece of the Allende, México meteorite, which he had gone ahead of the searchers to "plant" in order to see if they were good enough to be able to find it. I found it, but was somewhat chagrined at my friend's ploy (but understood his motive).

My next few searches were carried out with John. In the first, after plotting out a search strategy with Alan, John and I traipsed through farmers' fields for an entire day (Figure 3), but came up empty handed. On another search with John, however, we had better luck. After traversing a field that had many small pits, we left the field to move on to search another field. As we were walking back towards the road, John poked his Sasseville pole into hole after hole. I told him that that wasn't necessary, as he was walking back over an area that I had just searched and probed with my Sasseville pole. Needless to say, seconds after saying that, his pole made the clear, distinctive "click" sound of a "hit." Alan joined us, and proceeded to dig out a beautiful 254-g meteorite from a 15-centimetre-deep plunge pit (Figure 4). I was thrilled for John in making his find, but miffed that I had missed finding it.

Perhaps the most novel of my searches involved looking for large plunge pits from the air. Alan thought it possible that some meteorites larger than those already found might exist. If so, they would in all likelihood have travelled farther to the northeast, downrange in the fall ellipse. He thought that a 20-kilogram meteorite, for example, would probably be about ~25 centimetres in diameter, and that the top of its plunge pit would probably be of similar size. In the hope that such holes, if they existed, might be visible by an aerial search, he arranged for a small fixed-wing airplane to fly himself, another MIAC searcher, and me over the area at a height of ~200 metres (Figure 5). Although we were easily able to spot small high-contrast objects, such as sea gulls, we were not able to discern any dark holes in the shade of the field crops.

Figure 7 — The author happily holds the 1500-g fragment that Pasquale Valiente had found and had just pulled out from its hiding place under his bed to show the MIAC search team. With the help of Denis Pagé, who acted as a go-between, this meteorite was later acquired by the Royal Ontario Museum.

One of my later searches, in mid-August, was carried out in circumstances that were somewhat secretive. Peter, Denis, and I went to Sasseville's house prior to starting a search. When we asked him if there was anything new to report, he said no, and we had a short friendly chat (Figure 6). Peter and I then left to return to the car, but Denis stayed on with Sasseville for a while. When he joined us, he told us that he had found the meeting "very deceptive." Speaking in French with Denis, Sasseville had told him that he had in fact found some more meteorites, but didn't want to tell us because he was very upset with all the media frenzy that was surrounding new finds.

As Denis later explained:

> *Peter and I abandoned Howard in the fields to go get some fireball reports. When we came back at the end of the day, Howard was finishing a search with Pierre. To really make Pierre think I kept the secret, I asked him (in French) if he told Howard about what he told me in the morning. 'No' he said. Maybe this reinforced his trust…Few minutes later, Pierre filled the kitchen's table with brand-new meteorites in the 400 grams range!*

Figure 8 — The 1500-g Royal Ontario Museum meteorite. This fragment has an unusual angular shape, and displays at least two separate fusion crust ages on its surface faces. This suggests that the meteor experienced at least two episodes of fragmentation before becoming subluminous. Royal Ontario Museum Image Number ROM2008_10167_10.

Once Denis convinced Sasseville that MIAC was not responsible for the media frenzy that was occurring, and in fact we were trying to avoid that as much as possible, he shared his new finds with us.

One final search episode of mine merits discussion. We heard that a local farmer, Pasquale Valiente, had found a large meteorite, and we went to his house to examine it. Upon entering, he showed us a large blackish rock in his kitchen that was clearly not a meteorite. When we told him this, he grabbed a fridge magnet and showed us that it stuck to the rock. No, we told him again, it was definitely not a meteorite. He then flashed us an impish smile, and said he just wanted to make sure we knew what a genuine meteorite looked like. Going to his bedroom, he pulled out a beautiful 1500-gram meteorite from under his bed (Figure 7).

This meteorite has remarkable surface features. As Alan explains, each of its faces displays a different ablation history. One face shows very broad regmaglypt development (regmaglypts are thumbprint-like depressions on the surface of meteorites that are produced during the melting phase of the meteorite's passage through the atmosphere), indicative of broad ablation; another face shows cm-sized regmaglypts, indicative of moderate ablation; while the broken corner shows only incipiently developed ablation, presumably formed at a later episode of atmospheric fragmentation (Figure 8). The fragment was found embedded in a 20-centimetre-deep pit in a cornfield, with its angular point facing down into the sandy soil.

Denis played a major role in helping the Royal Ontario Museum (ROM) acquire this outstanding specimen. When he heard that Valiente wished to sell the fragment, Alan Hildebrand and John Rucklidge suggested that he should get in touch with Fred Wicks, the Curator and Head of the Department of Earth Sciences at the ROM. Valiente wished to remain anonymous to everyone except Denis during the negotiations, so he served as the go-between throughout nine weeks of negotiations, as Wicks endeavoured to secure the necessary funds. Although Valiente initially asked $10,000 for the meteorite, the ROM was able to obtain it for $7,500. Today, it occupies a place of honour in the ROM's Teck Suite of Galleries: Earth's Treasures.

In mid-August 2016, I heard that Dave Dillon, the Curator in Western University's Department of Earth Sciences, would like a St-Robert fragment for display, and might be able to raise some funds for a purchase. I asked Alan Hildebrand if any of any small fragments were for sale. The only one he knew of was a 290-gram fragment that had been recovered in the front yard of Marie Claire Roussel and Gilbert Jorrett's house. Gilbert had noticed a hole in their lawn while mowing it on June 26, and, when he investigated it, he found the meteorite in a ~15-centimetre-deep plunge pit. Alan wrote that its fusion crust was almost undamaged, that it had "a lovely hook on one end," and that "it is the prettiest of the smooth specimens I have seen."

I thought this would be a wonderful acquisition for Western, and helped raise funds for it. In November, Western purchased the specimen for $1,800 with funds supplied by the Office of the Dean of Science; the Departments of Earth Sciences, Astronomy, Physics, History of Medicine, and Philosophy; Kathleen Okruhlik, the Chair of Philosophy, and myself.

Conclusion

MIAC members became aware of the St-Robert meteorite within hours of its fall, and initiated plans for fieldwork within two days' time. Over the next month or so, several MIAC teams posted information about the meteor event throughout the fall area, spoke at a public school, went door-to-door interviewing farmers, authenticated meteorites that had been found, and undertook searches for new fragments. Most of the 20 fragments that were found were on homes' lawns, in fields near homes, or on the road. Roughly half of these resulted from local residents being made aware of the fall through MIAC's canvassing efforts or by media reports. The other half were found through dedicated searches by local residents or MIAC teams. Of the 20 fragments found, 16 were found by local residents, while 4 were found through MIAC searches. The total weight of all the found fragments amounts to 25.4 kilograms, but it is estimated that ~100 kilograms of material landed in the ~8 km x ~3.5 km strewn field in the form of 55 gram or larger fragments. By analyzing the visual observations of the fireball obtained by the MIAC teams and satellite observations obtained through the U.S. Department of Defense, Peter and Alan et al. were able to determine the pre-atmospheric orbit of the meteoroid. Prior to this, only four meteorites had well-determined orbits—Pribram, Lost City, Innisfree, and Peekskill.

Sources

The sources for this paper are almost entirely from the large collection of MIAC papers collected by Stephen Kissin during his many years as a leading member of MIAC and its predecessor, the Associate Committee of Meteorites of the National Research Council of Canada (ACOM). I organized these papers, and added some relevant papers donated by Peter Brown and myself. With the help of Western University's Phil McCausland, these papers were brought to the attention of the RASC's Archivist, Randall Rosenfeld, who enthusiastically agreed to accession them into an ACOM/MIAC Archive. They are now part of the Society's Archives at its national office in Toronto.

Acknowledgments

I thank Peter Brown for making his handwritten log of MIAC's early fieldwork available, and for his valuable discussion and helpful comments on a draft of this paper. I also thank Stephen Kissin, Randall Rosenfeld, Archivist of the RASC, and Phil McCausland of Western University for their helpful comments on the draft. I further thank Randall Rosenfeld for providing me with copies of material from the ACOM/MIAC Archive, and Phil McCausland for his invaluable help in preparing for publication the figures used in the paper. I am enormously grateful to my fellow MIAC members for inviting me to join them in their fieldwork and cheerfully participating in searches with me, and to the local residents of Saint-Robert who granted us permission to search their fields and provided much valuable information concerning their finds. ✶

CFHT Chronicles

H0LiCOW

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

This month's column will focus on exciting science news out of CFHT. The H0LiCOW section is an expansion of the team's January 26 press release. I have added additional information in some spots.

By using distant galaxies as giant gravitational lenses, an international group of astronomers has made an independent measurement of how fast the Universe is expanding. The study was enabled by a powerful combination of ground-based telescopes including those on Maunakea—Subaru Telescope, Canada-France-Hawaii Telescope, Gemini Observatory, and W.M. Keck Observatory—as well as the space-based NASA/ESA *Hubble Space Telescope* and *Spitzer Space Telescope*. The newly measured expansion rate for the local Universe has incredibly high accuracy. Comparison of the Hubble Constant measured using different methods gives astronomers insights into the physics of the early Universe.

The Hubble Constant—the rate at which the Universe is expanding—is one of the fundamental quantities describing our Universe. A group of astronomers from the H0LiCOW collaboration, led by Dr. Sherry Suyu, Max Planck @TUM professor at the Technical University Munich and the Max Planck Institute for Astrophysics in Garching, Germany, used multiple observatories to observe lensed galaxies in order to measure and refine the Hubble Constant.

This new measurement is completely independent of—but in excellent agreement with—other measurements of the Hubble Constant in the local Universe that used Cepheid variable stars and supernovae as points of reference. Cepheid variable stars are a specific class of stars, stars that pulse radially and change brightness over a stable period of time. In the early 1900s, astronomer Henrietta Swan Leavitt studied thousands of Cepheids in the Magellanic Clouds. She discovered a relationship between the luminosity of a Cepheid and its period. Once the luminosity of a Cepheid is known, astronomers can use a simple algebraic equation[1] to determine the distance to the star. If the Cepheid star is outside the Milky Way, whether within our Local Group or more distant, astronomers can use the Cepheid luminosity measurement to determine the distance to that galaxy—which leads to an independent measurement of the Hubble Constant.

Similarly, Type Ia supernovae are used to determine distance. Type Ia supernovae occur when a white dwarf accretes material from a larger companion star. The maximum limit on the mass of a white dwarf is 1.44 times the mass of the Sun. If the white dwarf's mass exceeds that limit, it goes supernova. Because the process behind a Type Ia supernova is so exact, the luminosity of the supernova is always the same. Astronomers measure the brightness of the supernova as seen from Earth and can calculate the distance to the galaxy where it occurred—again leading to an independent measure of the Hubble Constant.

Despite agreement with Cepheids and Type Ia supernovae, this new value measured by Suyu and her team is different from the measurement made by the ESA *Planck* satellite. But there is an important distinction—*Planck* measured the Hubble Constant for the early Universe by observing the cosmic microwave background, astronomers' earliest view of our Universe, while the H0LiCOW method probes the local Universe.

While the value for the Hubble Constant determined by *Planck* fits with the current understanding of the cosmos, the values obtained by the different groups of astronomers for the local Universe are in disagreement with the accepted theoretical model of the Universe. "The expansion rate of the Universe is now starting to be measured in different ways with such high precision that actual discrepancies may possibly point toward new physics beyond our current knowledge of the Universe," elaborates Suyu.

The targets of the H0LiCOW study were massive galaxies positioned between Earth and very distant quasars—incredibly luminous galactic cores. The light from the more distant quasars is bent by gravity around the huge masses of the

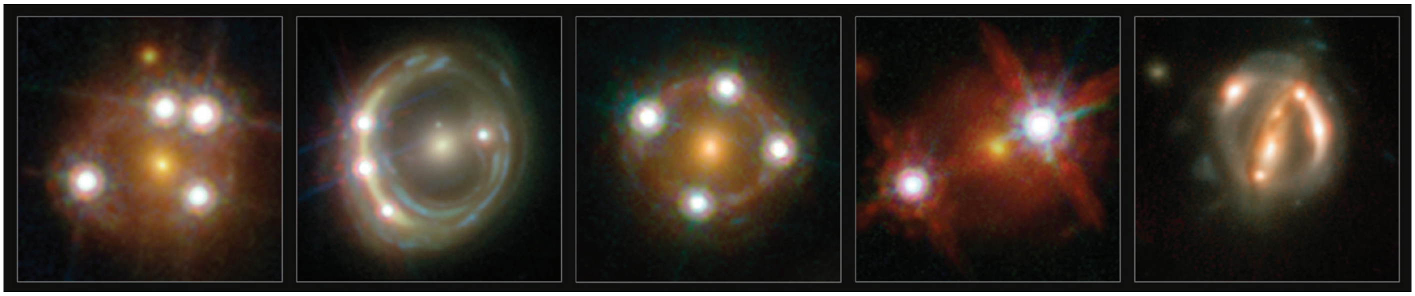

Figure 1 — (www.spacetelescope.org/images/heic1702b) This montage shows the five lensed quasars and the foreground galaxies studied by the H0LiCOW collaboration. By using these objects, astronomers were able to make an independent measurement of the Hubble Constant. They calculated that the Universe is actually expanding faster than expected on the basis of our cosmological model. (Credit: NASA, ESA, S. Suyu (Max Planck Institute for Astrophysics), M. W. Auger (University of Cambridge))

Figure 2 — Detailed image of the lensed galaxy taken by the Gemini Observatory. (Gemini Observatory/AURA)

galaxies—a phenomenon known as strong gravitational lensing. Strong gravitational lensing creates multiple images of the background quasar, some smeared into extended arcs, as seen in Figure 1.

Gravitational lensing was first predicted by Albert Einstein more than a century ago, and the theory states that, when light from distant objects passes near a closer but massive object, the light from distant objects is bent and distorts their images as seen from Earth. If, for example, a distant quasar is almost perfectly aligned with a closer galaxy and Earth, it creates what is called an Einstein ring. This ring is mostly made of multiple images of the well-aligned quasar. This phenomenon is called strong lensing. However, other background objects located further away from the line of sight to the lens will also contribute to the distortion produced by the lens, and produce a weaker distortion that contributes to the distortion caused by strong lensing.

Because the distortions in the fabric of spacetime created by these large galaxies are not perfectly spherical and the lensing galaxies and quasars are not perfectly aligned, the light from the different images of the background quasar follows paths that have slightly different lengths. Since the brightness of quasars changes over time, astronomers can see the different images flicker at different times; the delays between flickers depend on the lengths of the paths the light has taken. These delays are directly related to the value of the Hubble Constant. “Our method is the most simple and direct way to measure the Hubble Constant as it only uses geometry and general relativity, no other assumptions,” explains co-lead Dr. Frédéric Courbin from EPFL, Switzerland.

Using the accurate measurements of the time delays between the multiple images, as well as values from computer models, has allowed the team to determine the Hubble Constant to an impressively high precision: ±3.8 percent. “An accurate measurement of the Hubble Constant is one of the most sought-after prizes in cosmological research today,” highlights team member Dr. Vivien Bonvin, from EPFL, Switzerland. And Suyu adds: “The Hubble Constant is crucial for modern astronomy as it can help to confirm or refute whether our picture of the Universe—composed of dark energy, dark matter, and normal matter—is actually correct, or if we are missing something fundamental.”

The H0LiCOW team determined a value for the Hubble Constant of 71.9±2.7 kilometres per second per Megaparsec. In 2016, scientists using *Hubble* measured a value of 73.24±1.74 kilometres per second per Megaparsec. As discussed above, the ESA *Planck* satellite, which measured the constant with the highest precision so far, obtained a value of 66.93±0.62 kilometres per second per Megaparsec. There is an important distinction in these measurements—*Planck* measured the Hubble Constant for the early Universe by observing the cosmic microwave background. All the methods cited above have one thing in common; their measurements are made at a high level of precision.

The wide-field imaging capabilities of the Canada-France-Hawaii Telescope, Gemini Observatory, and the Subaru Telescope, all located on Maunakea, and the *Spitzer Space Telescope* were used to determine which galaxies were contributing to the weaker gravitational-lensing signal, an essential piece of the puzzle. A greater knowledge of the galaxies that contribute to the lensing signal is needed in order to have a more precise determination of the Hubble Constant.

The CFHT observations were made using the u filter on Megacam. The u filter has a central wavelength of 355 nm and a bandwidth of 85 nm, looking at the boundary of ultraviolet and visible light. The CFHT observations complement the Subaru data, seen in Figure 3. Dr. Cristian Eduard Rusu, who authored the third paper in this study, used the multi-filter, wide-area coverage of Subaru’s Suprime-Cam and

Figure 3 — Subaru Telescope image in three colours of the lensed region. (Rusu)

MOIRCS cameras to estimate accurate colours and physical propeties of the various galaxies surrounding the gravitationally lensed quasars used in this study, as well as an upcoming study. Calibrating this information against a large-scale survey obtained with the Canada-France-Hawaii Telescope, as well as a major cosmological simulation, Rusu carefully estimated the collective effect of the surrounding galaxies on the measurement of the Hubble Constant.

Spectroscopy of the lensing galaxies from the W.M. Keck Telescopes on Mauna Kea built on the imaging data and allowed the team to develop a more accurate model of the lensing galaxies.

Once the lens model was complete, the team used precise photometric monitoring of the four quasar images to determine time differences between the images that lead to the impressively high precision of 3.8 percent.

The H0LiCOW research was presented in a series of papers to appear in the *Monthly Notices of the Royal Astronomical Society*.

Our second science news of the month is a very happy announcement: Laurent Drissen, the astronomer behind our instrument SITELLE was honoured in February with the Synergy Award for Innovation by the Natural Sciences and Engineering Research Council of Canada (NSERC). The prize recognizes examples of collaboration that stand as a model of effective partnerships between industry and colleges. Dr. Drissen from Université Laval in Québec City partnered with ABB Inc. to build two instruments: SPIOMM at Observatorie du Mont Mégantic in Québec and SITELLE at CFHT.

I have written about SITELLE in this column before. It is an imaging Fourier Transform Spectrograph that allows astronomers to collect millions of spectra during one scan. There are very few instruments in the world that have the same capabilities as SITELLE.

When instruments are designed, a choice has to be made between the field of view of the instrument and the number of colours that can be observed in one exposure. Imagers can observe a large field of view but not many colours. On the other hand, a spectrograph can observe at best a few objects at a time, but can record thousands if not hundreds of thousands of colours in a single exposure. This dichotomy is very well illustrated with MegaCam and ESPaDOnS at CFHT. MegaCam has a very wide one-degree field of view, but can observe only one colour at a time and has 11 filters available so it can potentially observe one field in 11 different colours. On the other hand, ESPaDOnS can only observe one star at a time with a very small field of view, but can record many tens of thousands of colours or spectral elements in one exposure.

Figure 4 — Prof. Laurent Drissen in front of an image produced by SITELLE of the supernova remnant IC 443. This image is one of the most spectacular produced by SITELLE and is a good example of the capabilities of the instrument. Image: CFHT.

It is technically very difficult to have both a wide field and a large number of colours recorded simultaneously by one instrument, but Prof. Drissen and his team at the Université Laval, working with ABB Inc., were able to achieve this by using interferometry. This technique uses the interference of electromagnetic waves to extract spatial and spectral information simultaneously across the observed field of view. Using this powerful technology, ABB Inc. developed SITELLE, which is able to take images of thousands of colours over a field of view of 11 arcminutes, thus giving astronomers access to potentially millions of spectra to perform detailed analyses of the physical properties of their sources of interest.

The capability of SITELLE to record a large number of spectra over a large field of view leads to unique research opportunities for astronomers using CFHT. For example, astronomers can map the abundances and radial velocities of various elements over entire galaxies in a single scan. SITELLE has been available at CFHT for a little less than a year and already two scientific papers were published using data from this instrument. The first paper reports on the kinematics of NGC 6720, also known as the Ring Nebula. The authors were able to derive the deepest and the most spatially resolved maps of ionized hydrogen and nitrogen ever made of this nebula. The second paper, just published this month, included radial-velocity measurements of a hundred clumps in the ejecta of the classical nova AT Cnc, yielding an estimate that the last eruption of this nova was 330 years ago. These kinds of studies demonstrate how the unique capabilities of SITELLE will help astronomers using CFHT to advance our knowledge of the Universe.

[Ed: see Dish on the Cosmos for a different slant on the same research.] ✶

Footnote

[1] B = L/(4πd2)
Where B is the brightness of the object measured on Earth, L is the object’s intrinsic luminosity, and d is the distance to the object.

Skyward

Of Eclipses and Planets

by David Levy, Montreal and Kingston Centres

A very special year has begun. As readers around the world celebrate the incoming year, they also are firming their plans for viewing some extraordinary events in the sky.

The most important thing happening this year, particularly for viewers living in the United States, will be a total eclipse of the Sun. On August 21, the shadow of the Moon will track across the United States from the coast of Oregon in the morning, crossing the country and reaching the vicinity of Kansas City around noon, and then leaving the east coast of South Carolina late in the afternoon. Almost all of North America will experience a partial eclipse of the Sun.

But there is a tremendous, almost indescribable difference between a 99-percent partial eclipse and a 100-percent total eclipse. A 99-percent eclipse is still a partial eclipse, and it takes the extra one percent to turn the partial into a total eclipse. If it is only partial, the sky will begin to darken slightly as the Sun's appearance changes from whole Sun to a crescent. As the eclipse deepens, the crescent will get progressively thinner until, at the 99-percent level, all that is left is a thin line of sunlight. If you look toward the west, you will see the dark shadow of the Moon approach you, pass by, then recede as it races to the east. However, the eclipse is still a partial, and then the crescent will widen and brightness will return.

That last one per-cent makes all the difference. This is what you might see: the Sun's line of light continues to shrink until all that is left is a point of light. From the west the shadow continues to grow and darken. Looking back at the Sun, you will see what looks like a diamond ring. The diamond is a single bright point of sunlight, and surrounding the darkened Moon, the Sun's corona is starting to appear.

The Sun has vanished, leaving in its place a jewelled crown. The corona begins to appear and stretch out. The corona is the outer atmosphere of the Sun, and its temperature can exceed a million degrees Celsius. But as hot as it is, the corona is far thinner than the rest of the Sun; it is almost a vacuum.

There may also be erupting prominences coming out of the edges of the Sun. They look like small flames, but they are quite a bit larger than the Earth. After a minute or two, the edge of the Moon's shadow approaches, a second diamond ring appears in an outburst of light, and the total phase of the eclipse is over.

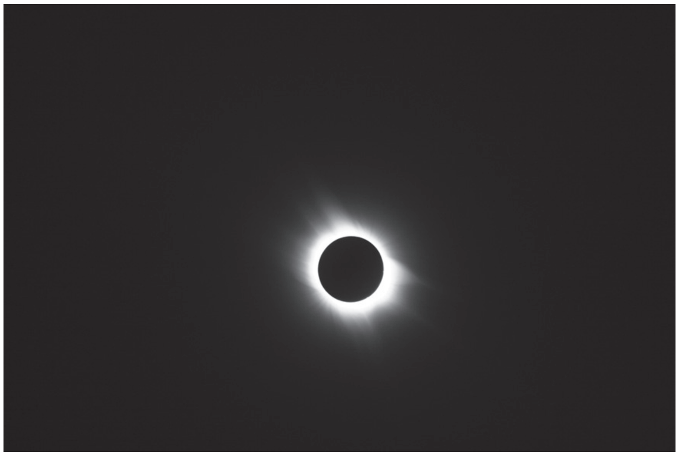

Figure 1 — This is the total phase of the 2006 eclipse of the Sun, which Wendee and I saw from the Aegean Sea. The corona is clearly visible.

It is my hope that you will make every effort to view this summer's total eclipse of the Sun. If you live near Vail, Arizona, where Wendee and I live, and do not travel to a place like Madras, Oregon, where we plan to be, you will see about half the Sun obscured by the Moon. In any event, the ethereal beauty of solar eclipse will remind you that we live on a delicate world that moves around the Sun and that, on rare occasions, our Moon can block out the Sun's light and create a total eclipse, one of the most truly amazing things humanity can witness.

Virgo's Suitors

> *Is it so much, and yet the morn not up?*
>
> *See yonder where the 'shame-faced maiden comes*
>
> *Into our sight, how gently doth she slide,*
>
> *Hiding her chaste cheeks like a modest Bride,*
>
> *With a red vaile of blushes*
>
> — *The Woman-Hater*, Francis Beaumont and John Fletcher, Act I, Scene 1

With these five lines, an adventure begins in the first months of 2017.

When I was in my senior year of high school, I got the distinct impression that my father would probably disown me if I did not try to inherit his love of Shakespeare. Even though I was still too young to appreciate clearly what Shakespeare was all about, it was not difficult to follow his advice. I grew to love *Julius Caesar*, and I adored *Macbeth*. And as Dad became aware that I was enjoying Shakespeare, he even suggested that other 17th-century writers were also worth my attention. To cite an example, he introduced me to Beaumont and Fletcher. I politely ignored him, though now I wish I hadn't.

About a decade ago, while writing my Ph.D. thesis on the night sky in this period of English literature, I rediscovered one of the duo's first plays, possibly the first they

Figure 2 — Shakespeare's observing site. It is likely that William Shakespeare, as an eight-year-old boy, observed the great supernova of 1572 from outside this house. Photos by David H. Levy.

wrote together: *The Woman Hater*. In the very first scene there is a detailed comment about the constellation Virgo.

I was particularly impressed with this allusion, not so much for its literary impact as for the idea that, except for the bright star Spica, Virgo is one of the dimmest constellations in the sky and hardly worth noticing. However, I soon learned that in 1605, when the play was most likely composed, Virgo entertained a special neighbour. The planet Mars was close to Spica. Like two different-coloured eyes, Mars and Spica completed the wedding face of Virgo.

As 2017 opens, Virgo is once again complemented by an intruding planet. This time the world is not Mars, but Jupiter, the largest planet in the Solar System. By the time you read these words, Jupiter and Spica will be in the southern sky most of the night. To see them, just look toward the southeast for the second-brightest object in the sky. If you train a telescope on Jupiter, you will notice its four largest moons surrounding it—Io, Europa, Ganymede, and Callisto. And Spica will be close by. The "vaile of blushes" surrounding her face will not be red, like Mars, as it says in the play, but Jupiter offers an excellent substitute.

This winter and spring, we get the chance to see and understand the relation between the night sky and literature in a real way. It is likely that either Beaumont or Fletcher actually saw the rising of Virgo and Mars in December 1605 around dawn. And now, as you get to see the 2017 version, may you appreciate how the sky as an enduring thing has spanned centuries of humans who have seen much the same sky that we see and, despite the passage of millennia, ask much the same questions we ask. ✶

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. David is also President of the National Sharing the Sky Foundation, which tries to inspire people young and old to enjoy the night sky.

Astronomical Art & Artifact

An Inventive Account of the Astronomy of van Gogh's *La nuit étoilée* of 1888

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

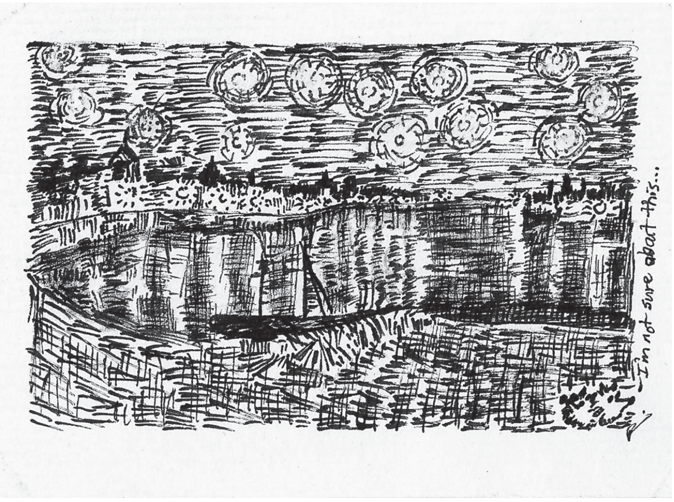

Figure 1 — Van Gogh's Starry Night Over the Rhône, 1888. The colours in this copy are less vivid than is usual for a van Gogh monochrome sketch. Readers who wish to try the procedure outlined in the document, should mount their most powerful finder on an EQ6, place this page of the Journal *open at a distance where the stars focus at infinity, and think of M81 & M82. Drawing by R.A. Rosenfeld, somewhat after van Gogh.*

Abstract

This contribution reports on a curious find in the Archives purporting to explain aspects of the astronomical iconography of Vincent van Gogh's *Starry Night Over the Rhône* (1888).

Unexpected discoveries…

One of the delights of working in an archive is the discovery of the unexpected. This can happen to experienced researchers, even when labouring in collections that have apparently been carefully catalogued and described, in fact it *particularly* happens to those with knowledge of a field (recall the much-repeated dictum of Pasteur's, "Chance favours the prepared mind;" Koelbing 1969). Several of those unexpected discoveries have been reported in past examples of Astronomical Art & Artifact, such as the autograph letter from Alfred Russel Wallace interleaved into the Archives' copy of Wallace's *Man's Place in the Universe* of 1903 (Rosenfeld 2009a), or the false attribution to John Flaxman of the Urania on our seal (Rosenfeld 2009b), the non-existence of our "Royal Charter" (Rosenfeld 2013a—this had been noted by Peter Broughton earlier, but the myth has remarkable staying power), and the unexpected survival of architectural ground plans for the the proposed 1903 RASC observatory (Rosenfeld 2013b; Chant 1940, 304-305), to name a few. Unlike those finds, the document that is the subject of this contribution is peculiarly suited to this number of the *Journal*.

The document

The document has not been noted thus far in the literature, which itself is suggestive. It is concerned with what its author believes may be observed of astronomical phenomena in van Gogh's *La nuit étoilée* of 1888. This oil painting on canvas, measuring 73-cm × 92-cm, is today in the Musée d'Orsay in Arles (inventory number RF 1975 19).[1] The document's is owed to the move of the Archives to the Society's new quarters last spring. Like C.A. Chant, who regrettably did not personally observe the Great Meteor Procession of 1913, but who felt it was his scientific duty to gather, analyze, and report on the event, the Archivist was (regrettably) not present on the day of the move to witness the discovery of the document, yet he feels duty bound to report it to the Society (Rosenfeld & Muir, 2011). The RASC's Webmaster, who enjoys the full confidence of the Archivist, was delegated to act in loco sciniarii.

The sequence of discovery is said to have unfolded as follows.[2] The Webmaster noted out of the corner of his eye the document flutter down on to the venerable library table, as if out of nowhere. Unfortunately, no one else was present at that very moment in the room to note its sudden appearance, otherwise we would have had observations of its apparent path from two points, from which a trajectory could have been determined. It may have come from behind the portrait of C.A Chant when it was shifted. Without the necessary data, the document's flight path cannot be modelled, and so remains uncertain.

The importance of the document, or rather its unusual nature, was realized immediately, and a hasty transcription was prepared. Unfortunately, the document vanished soon afterwards. Perhaps it will reappear at the time of our next move.

The text support was fine, paper-thin hotel stationary, measuring 15-cm × 21-cm (approximating the current A5 size in the EU), with visible chain and laid lines, and coloured a very vivid dull grey. It bore the address of the Hôtel du forum. It was undated, but from internal evidence seems to be from around 1905. The text is (was) in black ink. Missing letters are indicated by "/," enclosed in angled brackets.

Figure 2 — Camille Flammarion at work, 1906. Could this be the man to whom the document is addressed? The image shows Flammarion employing his customary technique for seeing the canals on Mars. The companion portrait of Percival Lowell remains unpublished. Drawing by R.A. Rosenfeld, after Gordon Ross.

> Dearest Camill<//>[3]
> </>pril 1 <////>
>
> <apparently some three paragraphs are missing from the beginning>&, this trip does indeed remind me of earlier occasions, some twenty years ago, when Vincent worked here—but I also saw the painting at Theo's in Paris afterwards. Since Vincent observed, and gave heavenly phenomena a place on his canvases, then why not? The naked eye stars of Ursa majoris are in their approximate places, so it makes sense to look, does it not?[4] & he ~~he~~ could have found them readily enough in any copy of the supplement to *Astronomie populaire*, or Admiral Smyth, had this last been translated into your tongue (which it has not).[5] How to discover, then, whether Bode's nebula & its close companion are in the painting?[6] We are men of science, and Kapteyn & Gill have shewn the way.[7] The setting up of carefully mounted powerful optical apparatus of the best quality at the focal distance from which the painting was made will enable one to see the sky ~~as~~ Vincent saw and recorded, but in a greatly enhanced way, in the small field which will be visible. It will then be the simplest matter to detect whether M81 & M82 are present, and how accurately they have been depicted, and cleverly hidden in a painterly fashion. I would like to employ the Great Theodolite of Ramsden in the keeping of the Board of Ordnance, as it is not presently employed for the Great Trigonometrical Survey.[8] You recall the comparison spectra Huggins et al. introduced into the optical train for nebular chemical identification, as well as the screens others have used for planetary work.[9] To further increase the chance of success, I propose to introduce at the focus of the eyepiece a special screen, with the images of M81 & M82 as seen by Rosse or Lassell painted delicately on the glass.[10] That way we can be sure that what our mind and perceptions ~~s~~suggest to our sight is indeed what we have taken pains to see. The Lalande medal is in our grasp![11] (Could the Ear Nebula be similarly reveal<///>[12]

The rest of the letter was missing, which is doubly unfortunate, as it would doubtless have been as enlightening as the foregoing, and have contained the name of the writer.

What we do know, even without access to the missing portion, or indeed the original at the present time, is that no publication resulted from this project, nor was any prize awarded for the work. That at least doesn't stretch credulity. ✶

This research has not made use of NASA's Astrophysics Data System.

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Websites

NOAO, Ear Nebula
https://www.noao.edu/image_gallery/html/im1169.html
(consulted 2017 February 6)

Vincent Van Gogh, La nuit étoilée en 1888, Arles, Musée d'Orsay
www.musee-orsay.fr/en/collections/index-of-works/notice.html?no_cache=1&nnumid=78696
(consulted 2017 February 6)

Endnotes

1 See the website Vincent Van Gogh, La nuit étoilée en 1888, Arles, Musée d'Orsay listed at the end of this paper.

2 The source was an anonymous tip to the Archives' hot-line. The attempt at disguise was poor.

3 This could be Camille Flammarion (1842-1925); see de La Cotardière & Fuentes 1994; Flammarion 1998.

4 Interesting accounts of the astronomy in van Gogh's astronomy paintings are: Boime 1984; Whitney 1986; Wolfschmidt 2007; & Olson 2014, 35–66. The first two are considered seminal. The astronomy of the 1888 *La nuit étoilée* has been much less written about than that of the 1889 *La nuit étoilée.*

5 This is Flammarion 1882, an observational supplement to Flammarion 1880. Admiral Smyth refers to Smyth 1844.

6 M81 & M82.

7 Jacobus Cornelius Kapteyn (1851–1922), Professor of Astronomy at the Rijksuniversiteit Groningen, and Sir David Gill (1843–1914), Her Majesty's Astronomer at the Cape of Good Hope. They collaborated on the *Cape Photographic Durchmusterung*, 1896–1900; van der Kruit 2015, 153–204. What follows in this letter is a fool's misapplication born of a misunderstanding of Kapteyn's technical setup and procedures for measuring Gill's plates.

8 On the history of this instrument, see McConnell 2007, 200–207, 223–230.

9 On Huggins see Becker 2011. Screens were a 19th- and early 20th-century term for filters.

10 William Parsons, Third Earl of Rosse (1800–1867), and William Lassell (1799–1880). Their nebular discoveries are conveniently discussed in Steinicke 2010.

11 The Prix Lalande (1802–1970) was one of the most important awards for astronomical work. Unfortunately, in its latest manifestation as the Grande Médaille of the Académie des sciences, it is no longer awarded solely for astronomical work.

12 If this is a reference to the "Ear Nebula," IPHASX J205013.7+465518, it is a preternaturally prescient reference to a planetary nebula otherwise unknown in 1905, and, in the present context, a reference of remarkably tactless cheek. This may be a clue as to the nature of this document. For an image of this object, see NOAO, Ear Nebula (in the websites listed at the end of this paper).

Second Light

The Localization of a Fast Radio Burst

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

Last year I wrote about the localization of a Fast Radio Burst (*JRASC, Vol. 110, No. 2*, p. 93). To remind readers, FRBs are bursts of radio energy lasting a millisecond or two, thought to originate in the relatively distant Universe, at redshifts up to about 0.5. The ink was barely dry on the story before the claim had been called into question. More about that later. Just after that, a repeating Fast Radio Burst was found, using the Arecibo Telescope in Puerto Rico. So far, this is the only fast burst known to repeat, but it provided a great opportunity for Shami Chatterjee of Cornell University, and a group of collaborators around the world, to make another attempt at localizing the burst. With a lot of patience, and some luck, they were able to use the Karl G. Jansky Very Large Array in New Mexico to pinpoint the location (right ascension of 5h 31m 58.7s, declination of +33d 8′ 52.5″, in the constellation of Auriga) of the bursts (see the 2017 January 5 issue of *Nature*). A faint, unresolved optical source was found in archival data from the Keck Telescope. Chatterjee and his collaborators obtained new images of the area, using the Gemini North Telescope on Mauna Kea. The optical counterpart is a very small, faint galaxy. It turns out that there is also a faint, persistent radio source near the same location, which Chatterjee concludes might be the signature of a weak active galactic nucleus (a supermassive black hole accreting a small amount of gas). Alternatively, it could be an unusually bright supernova remnant or pulsar wind nebula. The most straightforward explanation is that the persistent radio source is associated with the burst source inside the dwarf host galaxy.

Chatterjee estimates that the burst lies at a redshift about 0.3 (a luminosity distance of 1.7 Gpc), though follow-up work indicates it is somewhat closer, at z=0.2 (a luminosity distance of 1 Gpc). The host galaxy shows no evidence of dust emission (they used the Atacama Large Millimetre/submillimetre Array in Chile to look). There are no archival detections of X-rays or infrared emission from the galaxy, but I am sure that there will some follow-up observations to probe these wavelengths further. A faint AGN, though, would probably require several million seconds of time to get a detection or a meaningful upper limit. Converting the observed optical magnitude (25) with the distance gives a luminosity similar to that of the Small Magellanic Cloud.

The burst source and the persistent radio source are separated by <500 pc. If they are closer to each other, there is a possibility that they interact with each other. Or they may be completely unrelated to each other. Or they may be the same source. The position of the burst is not as accurately determined as that of the persistent source. Which brings me back to the story about Evan Keane's localization a year ago. Shortly after that work was published, a couple of researchers at Harvard made the case that Keane was actually looking at a faint AGN. The source subsequently brightened and faded again several times, seeming to support that view, although the pattern of variability was unlike any AGN previously seen. But the fact that a second burst appears at some level to be associated with an AGN has raised the possibility that Keane was right after all. Time and further study will tell.

For now, let's assume that the burst and the AGN are not associated with each other. What could provide the energy for the burst? In order for a burst to be coherent, the source must be much smaller that the distance light could travel during the length of the burst. For a length of 0.001 that means that it must be <300 km across (0.001 × 3×10^5 km/s). For a radio flux of 0.1 Jy-ms at a distance of 1.0 Gpc, that implies an isotropic energy of 10^{38} erg. Of course, the burst may be very highly beamed, meaning the energy involved would be much less.

At this point, Chatterjee thinks that there is no conventional known type of source that has the properties of this burst, with or without the persistent emission. He also cautions that this is the only fast radio burst known to repeat, so it is not at all clear that it is representative of the "class." But this is what keeps astronomy fun—we keep finding ever weirder stuff! ✶

Leslie J. Sage is Senior Editor, Physical Sciences, for Nature Magazine *and a Research Associate 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.*

Dish on the Cosmos

Things that Go Blip in the Night

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

Astronomers are closing in on answering one of the major questions that has vexed the community for the past decade, namely what are the Fast Radio Bursts (FRBs). In the infinite poetry that is astrophysics, FRBs are (1) *Fast* because they transpire over milliseconds, (2) *Radio* because they are seen in the radio part of the electromagnetic spectrum, and (3) *Bursts* because they are rare eruptions of radio waves. An FRB is observed for a few milliseconds and then shuts off abruptly.

It was a long time after their original discovery before the research community was even convinced these were real objects. Finding these signals is incredibly difficult for two reasons. First, a huge number of circumstances have to align to detect an FRB. The telescope must be tuned to the right frequency, looking in the right direction, and the data must be recorded fast enough to see the burst. Most radio astronomy is studying faint objects, so the telescopes stare in one direction for a relatively long time: seconds to days. The data are averaged into a single set of measurements and any FRB signals that appear end up washed out into the rest of the signal.

The other major barrier to finding FRBs is plasma dispersion. Most of space is filled with a diffuse plasma, namely a gas of hydrogen where the electrons have been separated from their protons. The loose electrical charges respond to the passage of an electromagnetic wave, and the wave shakes the charges up and down. This shaking slows the passage of the electromagnetic wave and the magnitude of slowing depends on the frequency of the signal. Higher-frequency signals are slowed less by the plasma, so in a burst of radiation, they will arrive at Earth first. The situation is similar to how glass slows the passage of visible light, so we can create lenses and prisms. This refraction also depends on the frequency of the light, but in the case of visible light passing through glass, the high frequency radiation (blue light) is slowed more. Plasma dispersion presents a problem: not only are the signals very short in duration, but the signals at high frequency arrive earlier than those at low frequency (Figure 1). To find the signals, the radio telescope hardware must delay the high-frequency signals to align with the low-frequency signals that arrive later. The amount of delay depends on how much plasma is between the emitter and the telescope. In looking for bursts, the telescope hardware tries many different amounts of plasma to "de-disperse" the signal and hope that the burst signal pops out after accounting for a specific amount of plasma.

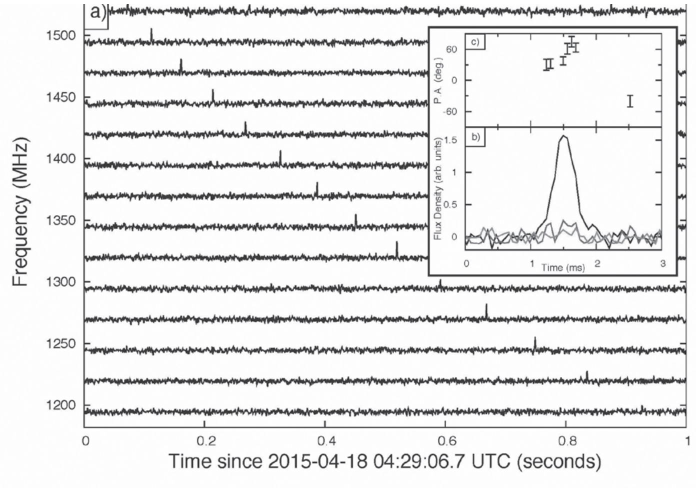


Figure 1 — A Fast Radio Burst seen in radio data shown as radio emission intensity plotted vs time of arrival for different frequencies. The small spike in each of the time series shows the FRB arrival times, which vary with frequency due to plasma between the emitter and the observatory. The inset panel shows the burst signal after it has been corrected for plasma dispersion. Image Credit: E. F. Keane (SKA Observatory).

The June *Journal* deadline for submissions is 2017 April 1.

See the published schedule at
www.rasc.ca/sites/default/files/jrascschedule2017.pdf

Finding FRBs would have been an impossible task were it not for astronomers already searching for pulsars. Pulsar hunts face many of the same challenges as the search for FRBs, namely having to correct for plasma dispersion to find a weak signal that changes in time. With the hardware and techniques that the pulsar astronomers use already in place, the first FRB was found in 2007 by Duncan Lorimer and colleagues using data originally collected in 2001 by the 64-m Parkes Radio Telescope in Australia. The signal was mysterious because it was so bright and short-lived. In addition, the signal implied a relatively large amount of plasma between the observatory and whatever made the burst. Since the telescope was looking away from the galactic plane and into the large amount of plasma, the signal was speculated to be from an extragalactic source.

This isolated event puzzled astronomers, and the community began hunting for the source of the bursts. The trail had many false leads. All the early FRBs were found exclusively in data from the Parkes Telescope, which made people wonder if it was actually something wrong with the telescope. To further obscure the nature of FRBs, several similar signals, dubbed perytons, were found at Parkes. Some great detective work

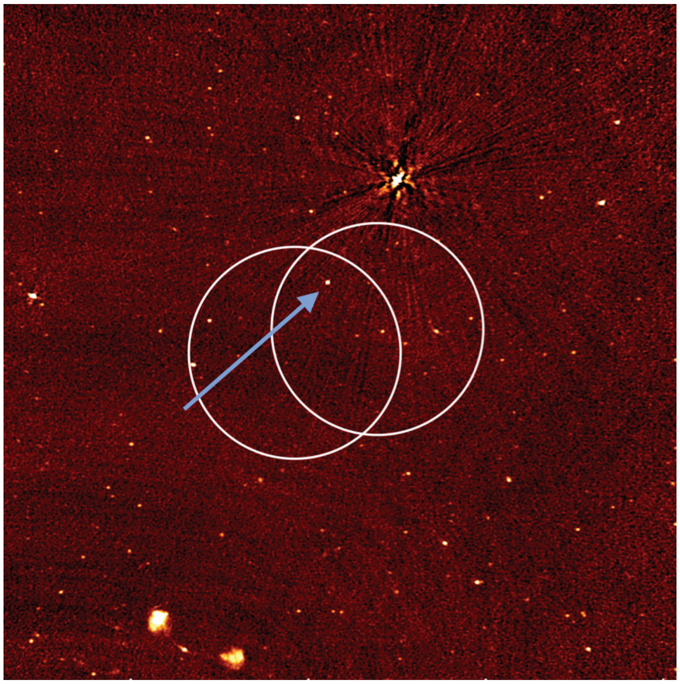


Figure 2 — Radio image of the repeating Fast Radio Burst during outburst. The location of the burst is indicated with the light blue arrow. The two white circles indicate previous detection locations from other telescopes. The other features in the image are galaxies and foreground objects. The spiky artifacts of some of these objects arises from the interferometric imaging method. Image Credit: S. Chatterjee (Cornell)

found that perytons were typically found at lunchtime, and usually when the telescope was pointed toward the canteen. Later, a few good experiments revealed that perytons were created by opening the microwave oven before the power was shut off. Some of the main FRB signals still appeared to be real and other telescopes began to detect these bursts. There were enough of the bursts to lead astronomers to conclude that they were happening all over the sky.

The random distribution in all directions helps in understanding the FRB nature. If the FRBs were created by ordinary galactic objects, they would be seen near the plane of our galaxy. Similarly, if the burst locations were aligned with the ecliptic, astronomers would suspect Solar System objects. Seeing FRBs all over the sky could only mean they occurred at the distances of nearby stars (which appear all over the sky) or out at the distances of other galaxies. The large plasma dispersions combined with the sky positions argued that FRBs were extragalactic in origin. However, if objects are far away, they must give off a huge amount of radio power to be detected here on Earth, across a sizeable fraction of the visible Universe.

When astronomers need to explain how to generate a lot of power in a short burst, they turn to supernova explosions and related "cataclysmic" phenomena. Exploding stars are a natural fit to explain things like Gamma Ray Bursts, which are also short bursts of radiation seen all over the sky, just in gamma rays not in radio waves. The energy budget of a supernova is clearly large enough to power an FRB, and "exotic supernova" was a good hypothesis for a while.

Then, Paul Scholz, a PhD student at McGill University working with other astronomers, found that one of the FRBs repeated, which shattered the cataclysmic hypothesis. Stars cannot explode more than once. It would be rare to see a supernova in the exact same direction as a previous explosion, much less eight times in one day. Whatever explained this FRB had to be repeatable. Additionally, repeatable events can be explored in more detail. Generally, single-dish radio telescopes find FRBs, but the resolution of these facilities is poor (arcminute scales). A single detection can span thousands of galaxies along the line of sight. By monitoring the repeating FRB with other facilities, it becomes possible to localize the burst source and learn more about it. First, radio astronomers used interferometers to dramatically improve the resolution (sub-arcsecond scales) and find where the repeating bursts were coming from (Figure 2). With a good position, teams could then ask other telescopes to start exploring the sky and find out what else lies in that direction.

The most recent results in this chase have just started to come in, where optical telescopes have found a small dwarf galaxy lined up with the location of the radio burst. This result does not immediately answer what the origin of burst could be, but it does rule out some of the options. Neutron stars remain a great candidate to explain the bursts, potentially the subclass known as magnetars. Magnetars have the largest known magnetic fields in the Universe and changing field structure on their surface could power bursts. Alternatively, it could be winds blown by neutron-star pulsars into the surrounding plasma, prompting bursts of emission. Or FRBs could result from matter falling onto supermassive black holes, driving jets of particles out in a straight line toward us.

The hard work of tracking down one source is bringing us closer to understand this FRB. However, questions linger, such as whether this single FRB is typical: no other FRBs have been shown to repeat. The only answer to these questions is to keep looking. An ever-larger number of events will eventually force answers out into the open where we can understand what is happening. New facilities, such as the Canadian HI Mapping Experiment (CHIME; see this column from April 2016) in Penticton promise to detect 1 to 10 FRBs every day instead of the 18 FRBs discovered to date. The mystery will unravel under the sheer pressure of larger numbers and improved statistics. Chasing a new phenomenon is always exciting. It shows the Universe always has something new to teach us. ✶

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 Matrix

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

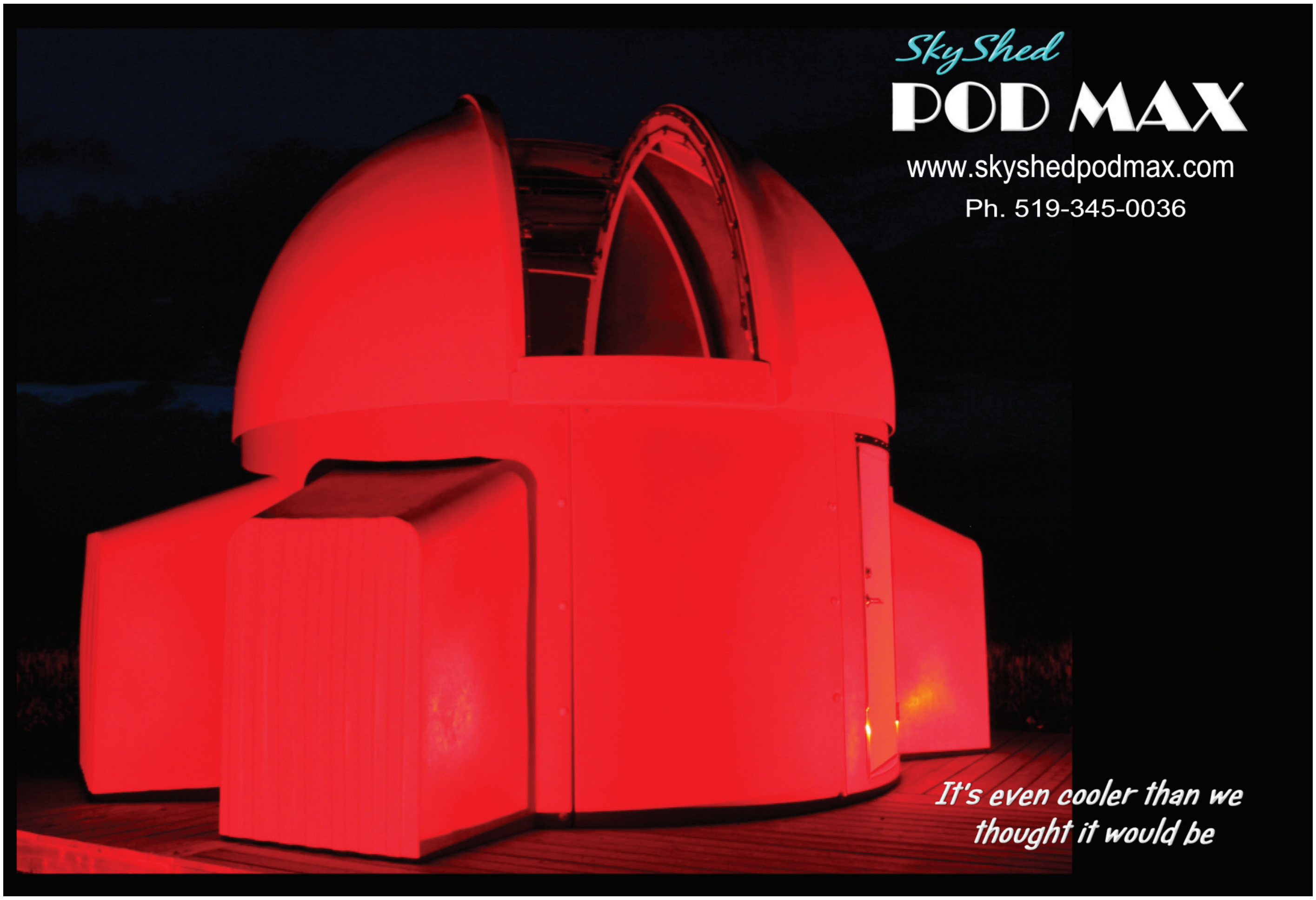
This is not strictly an astronomy app but you can do astronomy and cosmology with it. Armchair research, that is.

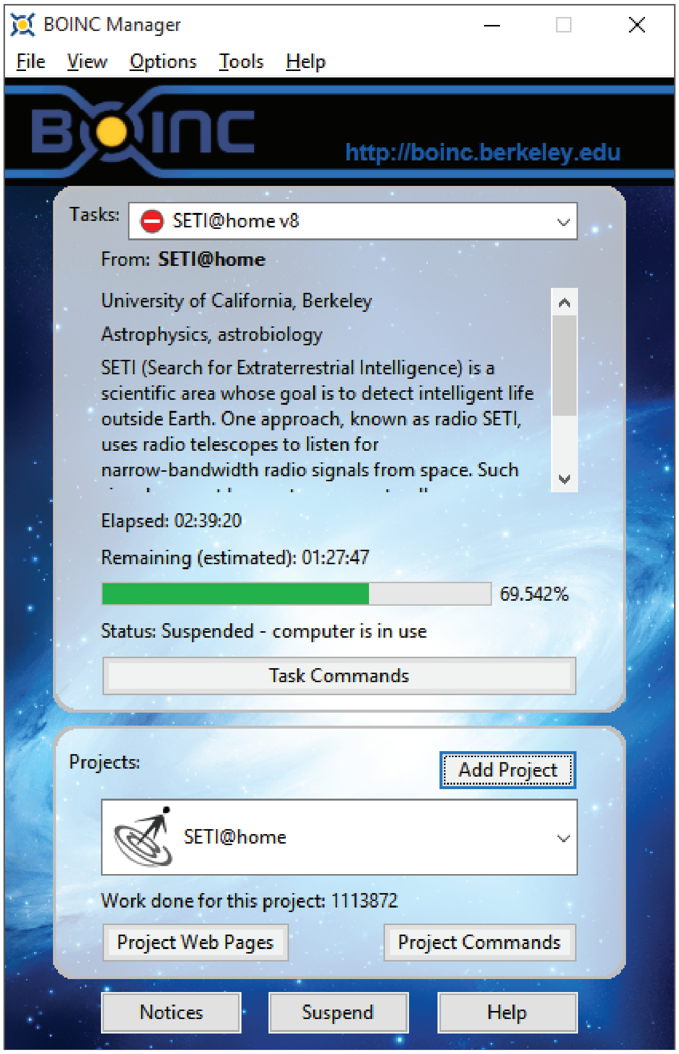
Built by the University of California, the Berkeley Open Infrastructure for Network Computing (BOINC) tool is one that uses a computing device's idle time. Participants offer their computers or devices so the unused computing power may be utilized for grid-based projects. There are over 250,000 volunteers helping with more than 665,000 computers and devices in use. It's fascinating when you think about it. From all over the world, over a half-million devices, at companies, schools, in individual homes, connected via Internet pathways, are crunching data for science, medicine, and research. You can easily get involved.

You can assist with volunteer computing projects like Cosmology@Home, SETI@Home, Asteroids@Home, etc. There are a couple of projects associated with CERN's Large Hadron Collider*. You can help search for spinning neutron stars with Einstein@Home. There are projects to cure diseases, fight cancer, study global warming, and do other types of scientific research. I've been working with the Search for Extraterrestrial Intelligence project for over a decade (pre-dating BOINC proper). I got involved in the data analyses because I was leaving my computer on all the time and I knew I had "extra cycles."

A computer, laptop, or tablet goes idle or into a passive state after a short time when you leave it unattended. Say you come home from work, turn on the home computer to check some emails and review some web pages, but then head to the kitchen when dinner's ready. The computer, still running, connected to the Internet, while periodically downloading new emails, is essentially doing nothing. The central processor unit is likely working at two percent or three percent of its total capacity. An hour or so after dinner, you send out some emails, work on a spreadsheet, and then settle into the living room to watch a movie. A bit more computer work before bed. So, in what might be a typical evening, the home computer might be on for five or six hours and only actively used for one or two.

If you have an Android tablet or a Kindle reader, it goes into an idle state as well, normally, any time you put it down and stop using it and the screen goes off, or you directly turn off





Tasks: SETI@home v8

From: SETI@home

University of California, Berkeley

Astrophysics, astrobiology

SETI (Search for Extraterrestrial Intelligence) is a scientific area whose goal is to detect intelligent life outside Earth. One approach, known as radio SETI, uses radio telescopes to listen for narrow-bandwidth radio signals from space. Such

Elapsed: 02:39:20

Remaining (estimated): 01:27:47

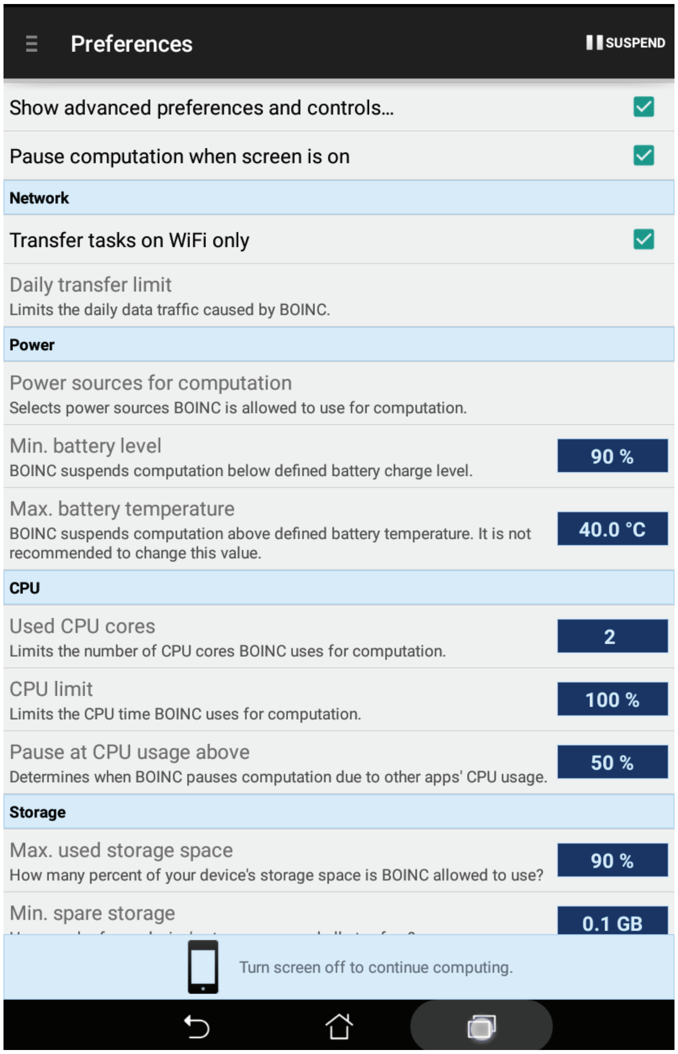
69.542%

Status: Suspended - computer is in use

SETI@home

Work done for this project: 1113872

Figure 1 — Simple interface in Windows.



Show advanced preferences and controls... ☑

Pause computation when screen is on ☑

Transfer tasks on WiFi only ☑

Daily transfer limit
Limits the daily data traffic caused by BOINC.

Power sources for computation
Selects power sources BOINC is allowed to use for computation.

Min. battery level: 90 %
BOINC suspends computation below defined battery charge level.

Max. battery temperature: 40.0 °C
BOINC suspends computation above defined battery temperature. It is not recommended to change this value.

Used CPU cores: 2
Limits the number of CPU cores BOINC uses for computation.

CPU limit: 100 %
Limits the CPU time BOINC uses for computation.

Pause at CPU usage above: 50 %
Determines when BOINC pauses computation due to other apps' CPU usage.

Max. used storage space: 90 %
How many percent of your device's storage space is BOINC allowed to use?

Min. spare storage: 0.1 GB

Turn screen off to continue computing.

Figure 2 — Manager controls for Android.

the screen. The device is still running, still connected to the network, by telephone carrier service or by home networking Wi-Fi, checking for notifications, checking for new messages, but, again, working at a fraction of its normal capacity.

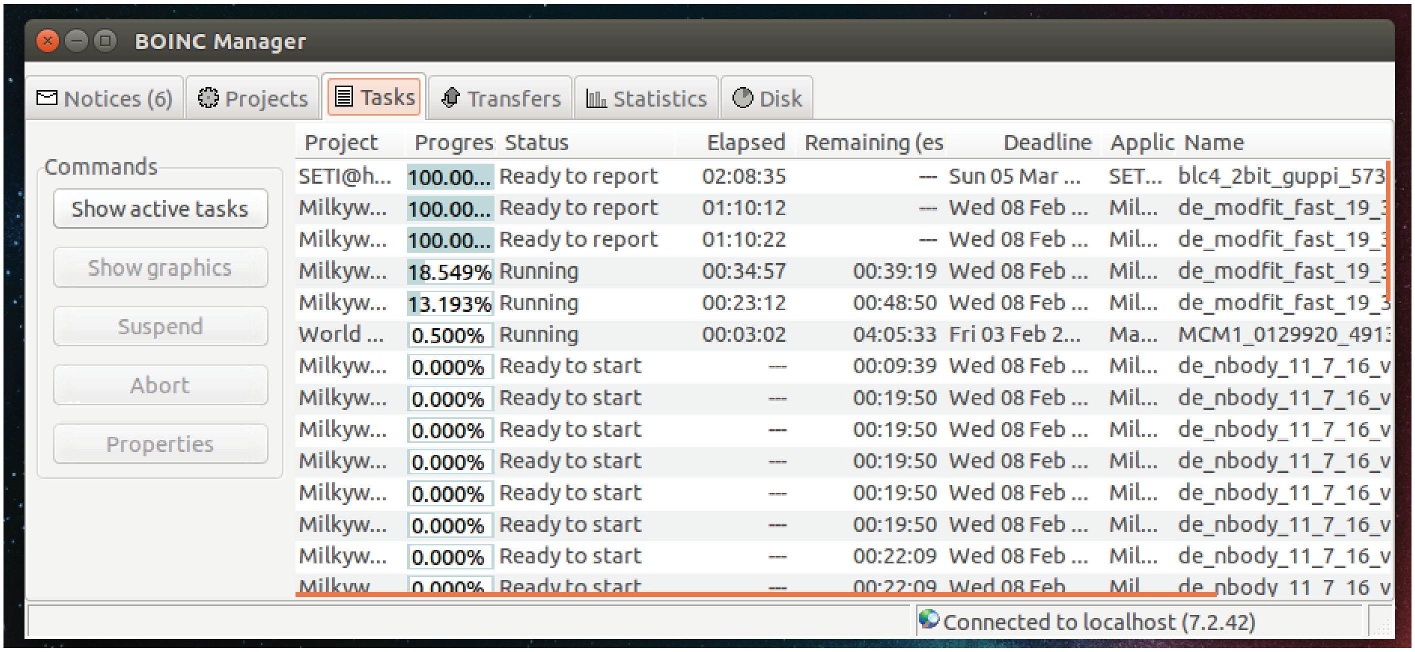
Typically, I have more than one computer running all the time, continuously. As I write this article on my Windows 10 tower computer, I have a Ubuntu workstation running (I was recently reviewing some Linux astronomy software), along with my Android tablet (playing streaming music). My Windows computer truly runs continuously. I never turn it off at night nor when I leave home. Maybe, on average, I use the Windows box 10 hours a day. The Linux machine I do little active work on so it's probably fair to say I use it one or two hours a month. I use my tablet on and off through waking hours. Add that all up and these three computing devices have 45 hours of unused idle time per day.

I have BOINC running on these active machines. The BOINC Manager software runs on Windows, Mac, Linux, and Android.

Getting started is pretty easy. The first step is to download an appropriate copy of the BOINC manager software to the preferred device. If using a Windows or Mac computer, surf into http://boinc.berkeley.edu and click the Download button. Got a Kindle? Check the Amazon App Store. If using an Android device, search in the Google Play Store. I noticed in Google Play similar products; I use the official one from the Space Sciences Laboratory. Next: install the software.

Then you choose the project or projects you want to help with. The simple user interface (Figure 1) makes it easy to add a new project with the handy button. In the advanced or full interface, one uses the Tools menu. Projects have specific hardware requirements so one needs to consider this when reviewing projects to support.

Once you obtain the software and register for a project, a packet of work is automatically sent to your computer, your computer (when available) processes the data, and the completed packet is then transferred back to the project site. It's quite painless and unobtrusive. That is, in general, the



Project	Progres	Status	Elapsed	Remaining (es	Deadline	Applic	Name
SETI@h...	100.00...	Ready to report	02:08:35	—	Sun 05 Mar ...	SET...	blc4_2bit_guppi_573
Milkyw...	100.00...	Ready to report	01:10:12	—	Wed 08 Feb ...	Mil...	de_modfit_fast_19_
Milkyw...	100.00...	Ready to report	01:10:22	—	Wed 08 Feb ...	Mil...	de_modfit_fast_19_
Milkyw...	18.549%	Running	00:34:57	00:39:19	Wed 08 Feb ...	Mil...	de_modfit_fast_19_
Milkyw...	13.193%	Running	00:23:12	00:48:50	Wed 08 Feb ...	Mil...	de_modfit_fast_19_
World ...	0.500%	Running	00:03:02	04:05:33	Fri 03 Feb 2...	Ma...	MCM1_0129920_491
Milkyw...	0.000%	Ready to start	—	00:09:39	Wed 08 Feb ...	Mil...	de_nbody_11_7_16_v
Milkyw...	0.000%	Ready to start	—	00:19:50	Wed 08 Feb ...	Mil...	de_nbody_11_7_16_v
Milkyw...	0.000%	Ready to start	—	00:19:50	Wed 08 Feb ...	Mil...	de_nbody_11_7_16_v
Milkyw...	0.000%	Ready to start	—	00:19:50	Wed 08 Feb ...	Mil...	de_nbody_11_7_16_v
Milkyw...	0.000%	Ready to start	—	00:19:50	Wed 08 Feb ...	Mil...	de_nbody_11_7_16_v
Milkyw...	0.000%	Ready to start	—	00:19:50	Wed 08 Feb ...	Mil...	de_nbody_11_7_16_v
Milkyw...	0.000%	Ready to start	—	00:22:09	Wed 08 Feb ...	Mil...	de_nbody_11_7_16_v
Milkyw	0.000%	Ready to start	—	00:22:09	Wed 08 Feb	Mil	de_nbody_11_7_16_v

Figure 3 — Data being processed on a Linux workstation.

processing is normally only done when you're not actively using the computer or device.

The Manager app is smart. It lets you easily control options for CPU and storage space utilization. I've configured my Windows and Linux instances to run in Advanced mode so I can access the full user interface. On Linux, I've set the app to run continuously, all the time, even if I'm using the computer. The Android version (Figure 2) even has controls for battery temperature so to avoid unwanted overheating scenarios. Android BOINC lets you transfer data via Wi-Fi only, to avoid extra data charges.

The BOINC Manager offers a number of other features. Occasionally, I'll review my statistics.

I don't remember exactly when I first starting offering idle time of my home office computers but by late May 2004, I had processed 132 work units. Actually, back then, BOINC was not yet developed; rather, there were unique applications for a handful of projects. In July 2006, I switched to the BOINC system. As of today, I've completed over 1 million work units for SETI. I also help on the World Community Grid humanitarian and Milky Way 3D modelling projects (Figure 3).

I took screen snapshots from Windows BOINC Manager 7.6.9 (32 bit) and Ubuntu 7.2.42 (64 bit). I recently updated to the most current client version, 7.6.33. On my ASUS MemoPad tablet, I run version 7.4.43. When I let my Android auto-update the BOINC one day, it stopped functioning, perhaps an issue with Marshmallow. So I rolled back to a good working version and suppressed the automatic updating.

I'm not suggesting you leave your computers or devices on, if you are not doing so already. There's obviously a cost associated with keeping electronics on, all hours of the day. If you have devices that are heat-sensitive, something like this might not be good for it—heat kills electronics. And if you have a classic desktop or tower or laptop computer with "platter" hard disk and fans, these moving parts will experience additional wear.

But if you have computers on already, you can share your unused "cycles." You can easily participate in grid computing and there's no additional cost to you. You can help in a variety of astronomical and related fields. If you run your machines for many hours in a day but turn them off at night or when you go on trips, you can still volunteer—a portion of the computer time will be idle. And every little bit helps (no pun intended).

* BOINC was in the news recently. The Einstein@home project announced the discovery of the most massive double neutron-star system ever observed.

Update Bits

Stellarium released a new version on Christmas day, version 0.15.1. I have 0.15.0 installed on my Windows home computer and it has a number of new and exciting features, like the ability to show Digital Sky Survey images. ✶

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

John Percy's Universe

Women in Astronomy (or Not)

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

It's a bit presumptuous of me, as a male, to write this article, but I do so in January 2017, motivated by two events in December 2016: the publication of Dava Sobel's (2016) award-winning book *The Glass Universe: How the Ladies of the Harvard Observatory Took the Measure of the Stars*, and the death of Vera Rubin on Christmas Day. I was familiar with much of the content of Sobel's book, but she brings the material and the characters to life so well, as she did in her previous bestsellers such as *Longitude* and *Galileo's Daughter.* Rubin was a pioneer female astronomer who, with her colleague Kent Ford, established that 90 percent of the matter in the universe was unseen "dark matter," which did not emit or absorb radiation. We still don't know what it is.

Pickering's Women

Before 1900, there were very few notable women in astronomy, though Hypatia of Alexandria (ca 360–415), Caroline Herschel (1750–1848), Mary Somerville (1780–1872), and Maria Mitchell (1818–1889) would qualify. Sobel's book begins with another remarkable woman: Anna Palmer Draper, heiress and widow of a doctor and amateur astronomer and pioneer in stellar photography, Henry Draper. Upon his untimely death, she briefly considered carrying on his work herself, as she had been his assistant, but wisely decided to partner with Edward Pickering, director of Harvard College Observatory (HCO). He would provide the expertise and resources; she would provide the funding.

HCO quickly developed techniques for wide-field photography, including objective-prism spectroscopy, generating a flood of data. Pickering needed research assistants or "computers" to help. Initially, these came from among family and friends. Williamina Fleming (1857–1911), the Pickerings's maid, turned out to have a flair for astronomy; she laid the groundwork for our present system of stellar spectral classification. Annie Cannon (1863–1941) refined this system, and used it to classify 225,300 stars for the monumental Henry Draper (HD) Catalogue, and 350,000 stars in total. Her many honours included the first honorary degree to be awarded by Oxford University to a woman. Antonia Maury (1866–1952), niece of Henry Draper, made important contributions to stellar spectral luminosity classification. Henrietta Leavitt (1868–1921) discovered the period-luminosity relationship for Cepheid pulsating variable stars, one of the most important tools for cosmic distance determination. As of 2008, the 100th anniversary of her discovery, this relationship bears her name.

After Pickering's death in 1919, Harlow Shapley (1885–1972) became HCO Director. Adelaide Ames (1900–1932) was the first student to earn a graduate degree from HCO. Her name lives on in the Shapley-Ames Catalogue of Bright Galaxies. Cecilia Payne (1900–1979) was the most outstanding of the HCO women. Her doctoral thesis (submitted through Radcliffe College, since Harvard didn't admit women) was described by one astronomer as "the most brilliant PhD thesis in astronomy." It showed, for the first time, that the Sun and stars consist mostly of hydrogen. She eventually became chair of the astronomy department at Harvard. Helen Sawyer (1905–1993) was another of Shapley's students. She married fellow graduate student Frank Hogg, a Canadian. She and Frank joined the University of Toronto in 1935, and Helen became Canada's best-known and most beloved astronomer. She wrote a weekly astronomy column in the *Toronto Star* for more than 30 years, served as President of the RASC, and much, much more. She was appointed a Companion of the Order of Canada in 1976.

In the middle of the 20th century, life was certainly not easy for female scientists, especially in the physical sciences. Helen Sawyer Hogg's path was difficult, and filled with uncertainty, but she persisted and opened many doors that had previously been firmly shut.

Vera Rubin (1928–2016)

Vera Cooper Rubin received her B.A. from Vassar College in 1948, her M.A. from Cornell in 1951, and her Ph.D. from Georgetown University in 1954. Her research was on motions of galaxies, and of stars within galaxies. She then embarked on her academic career, at perhaps the low point for women in the physical sciences, despite the influx of science funding resulting from the Space Race. After 11 years in an assortment of academic positions, she joined the Department of Terrestrial Magnetism of the Carnegie Institute of Washington, where she remained for the rest of her career. There, she teamed up with instrument specialist Kent Ford to study the orbital motions of stars in nearby galaxies. Using a new and efficient electronic detector—an image tube—they were able to use spectroscopy and the Doppler effect to record the stellar orbital motions in the faint outer regions of these galaxies. These velocities were much larger than predicted, assuming that the masses of the galaxies were those of the visible stars and interstellar matter. Either Newton's and Einstein's laws of gravity were wrong, or there was ten times more mass in the galaxies than was visible. Rubin's and Ford's results were confirmed for dozens of galaxies since then, both by them and by others. These results, together with other galactic and cosmological observations, show conclusively that 90 percent

Figure 1 — The staff of the Harvard College Observatory in 1918. If most or all of the staff had been male, would this "daisy-chain" photograph have been taken?

of the mass of the Universe is invisible dark matter. This is one of the great mysteries of modern astrophysics.

Like Sawyer Hogg, Rubin faced numerous challenges, as a woman in a male-dominated field. She was the first authorized female user of the Mount Palomar Observatory, but there was only one washroom, marked "Male." This was perhaps the least of the barriers she faced. Motivated by these challenges, she worked actively, throughout her career, to champion women in science, and to encourage girls to pursue their dreams of becoming an astronomer.

She was the recipient of numerous prestigious awards and honours, including the Gruber Prize, the "Nobel Prize of Cosmology." She enjoyed a long marriage to Robert Rubin. All four of her children received Ph.D.s in the sciences—one of them a female astronomer.

The Modern Era

Coincident with Rubin's hard-won rise to fame, issues of equity and diversity began to be addressed in the scientific community in the U.S. The American Astronomical Society established a Committee on the Status of Women in Astronomy in 1972. Its website (https://cswa.aas.org/) contains a wealth of information and statistics, including CSWA's history, activities, and achievements. These include a series of conferences, in 1992, 2003, and 2009; the next is in 2017. The first conference gave rise to a statement of the problem—the Baltimore Charter for Women in Astronomy (http://cswa.aas.org/bc.html), the second to the Pasadena Recommendations on how to proceed.

In Canada, progress was slower. Michael Reid and Brenda Matthews (2005) carried out an important ten-year survey of the status of women in Canadian astronomy, concluding that "Between 1991 and 2000, women were significantly under-represented in astronomy at all levels, but that the trend is toward greater equality." They extended the survey for an additional five years (Reid and Matthews 2007), and found that the under-representation had decreased at lower academic levels, but persisted at the highest level, such as full professor.

Helen Sawyer Hogg was the founding president of the Canadian Astronomical Society (CASCA) in 1971–1972, but it was over three decades before CASCA had its next woman president: Gretchen Harris in 2002–2004. Laura Ferrarese was president in 2012–2014, and Christine Wilson in 2014–2016. A few weeks ago, McGill astronomer Vicki Kaspi was appointed a Companion of the Order of Canada—the highest rank. CASCA now has a Diversity and Inclusivity Committee (http://casca.ca/?page_id=6648) to foster and monitor further progress. And progress needs to be made. In my own department, women made up about half of the graduate students and post-docs, but less than 20 percent of the faculty (though it didn't help that two women faculty members recently left for positions elsewhere). We have never had a woman as department chair. Of the other mathematical and physical science departments, only Statistics has had a woman as chair.

The situation has been improved, somewhat, by government urgings and policies. The federal government created University Faculty Awards, "to enhance the recruitment, retention, and early career progression of women and Aboriginal people in tenure-track faculty positions in the natural sciences and engineering…." Non-profit organizations such as the Canadian Association for Women in Science (CAWIS) have also played a role. CAWIS was formed in 1981, an off-shoot of the U.S.-based AWIS; among the CAWIS founders were my astronomer colleague Nancy Remage Evans and my wife Maire Percy. The Canadian Association for Girls in Science (CAGIS: www.cagis.ca) was inspired by 9-year-old Larissa Vingilis–Jaremko. Two of my undergraduate (women) research students have recently benefitted from the annual Canadian Conference for Undergraduate Women in Physics, which, among other things, provides important opportunities for mentorship and networking, in addition to its academic content. But the most important factor has been consciousness raising among scientists and administrators of all genders. On the negative side: when the federal government created a Canada Excellence Research Chairs program in 2010 to attract science superstars, all 19 recipients were male.

Women in Amateur Astronomy

A look through the history of the RASC shows that women have not been well represented among amateur members, especially at the leadership level. Mary Lou Whitehorne is the only woman amateur to have served as National President (2010–2012). At a 1999 joint conference of the RASC, ASP, and AAVSO, she addressed the topic of involving more women in amateur astronomy (Whitehorne 2000). It's challenging to combine employment and family responsibilities with a demanding hobby like astronomy. Observing, beyond the backyard, introduces other challenges (she mentioned the lack of washrooms). And amateur astronomy, being dominated by older, experienced males, can be intimidating for some women. This problem could be lessened if we get more women involved in amateur astronomy. Right now, the percentage probably ranges between 10 and 20 percent. Let's try to improve that number.

Causes and Cures

For both men and women, the "pipeline" from childhood to astronomerhood is leaky at all stages. Many elementary-school teachers are uncomfortable teaching science and math. Some parents do not consider astronomy prestigious and lucrative, compared with medicine, law, or business, especially for the most able students. There is still some outright bias against women in science, and other traditionally male occupations, such as a belief that health-care professions are "more appropriate" for women. By the crucial teenage years, many young women do not consider it "cool" to be good at science and math. Misguided teachers and counsellors may tell young women that "women are not good at science and math," or "math and science are not good for women." In the physical sciences, there is still a lack of role models.

Beyond that, the pipeline continues to leak. Ivie et al. (2016) have recently published a comprehensive longitudinal study and discussion of women's and men's career paths in astronomy beyond graduate school. The study found that, although gender was not directly responsible for women leaving astronomy, there were two indirect effects: women received less-than-satisfactory advising and mentoring, and they were more affected by the "two-body problem"—the need for many couples to find two satisfactory professional positions in the same location. Another interesting phenomenon, which I had not heard of until relatively recently, is the "impostor syndrome"—the belief, by apparently successful individuals, that their achievements were due to hard work alone, or to luck, rather than genuine ability. According to Wikipedia, some studies suggest that the impostor syndrome is especially common among high-achieving women. Ivie et al. (2016) found an indirect effect of the impostor syndrome: "Higher scores on the impostor syndrome scale were not directly related to actually leaving (astronomy). There is an indirect effect because a high impostor score increased the likelihood of changing advisors, which in turn increased the odds of working outside (astronomy)."

The conclusion? We must work to repair the leaks in the pipeline at every stage, for men and especially for women—a worthwhile objective in this Sesquicentennial year. ✶

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The Royal Astronomical Society of Canada

Vision

To be Canada's premier organization of amateur and professional astronomers, promoting astronomy to all.

Mission

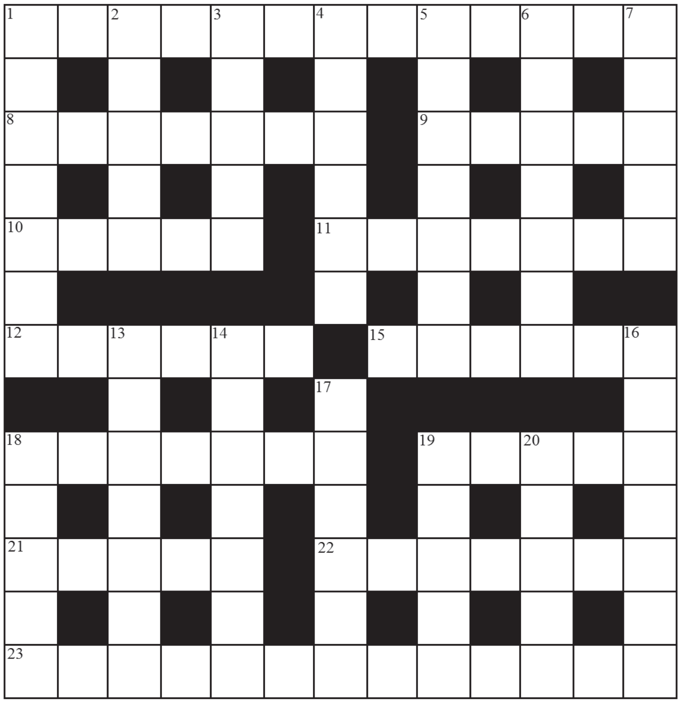
To enhance understanding of and inspire curiosity about the Universe, through public outreach, education, and support for astronomical research.

Values

- Sharing knowledge and experience
- Collaboration and fellowship
- Enrichment of our community through diversity
- Discovery through the scientific method

Astrocryptic

by Curt Nason



ACROSS

1. Curling first end odder with scope accessories (3,3,7)
8. Santa ate six at the lunar base 16 years ago (7)
9. Atlas, for example, about Saturn (5)
10. Eyepiece had fluorite put in before (5)
11. Other eyepieces had argon in an odd locus (7)
12. China setting in the Milky Way (6)
15. SETI desire when aliens turn switch, e.g. (6)
18. Star pointer mysteriously agitates without electron (7)
19. Short fly by night prefaces Index Catalogue of tunes (5)
21. Physicist circulated air in a current (5)
22. Unattractive point for star cluster aging (7)
23. Return lab file about the observing aid (7,6)

DOWN

1. In Germany I take a break around a wide-field telescope (7)
2. Dopey like Pluto (5)
3. I'd follow Babe to the east, like rust (5)
4. Stellar reaction creates universal silicate, all in fun (6)
5. Bull's hoof has gold when I turn around (2,5)
6. Hop the caboose or get trapped in the jet stream (7)
7. Bay at the Moon, often stuffy with cold (5)
13. Global warmer's stomach muscle soundly beats in the crow's wing (7)
14. Coal pit mined for scope-quality glass (7)
16. Morning Venus rotates, if cruel (7)
17. Twin played by alternate actors (6)
18. Sedna rotates in the closed vehicle (5)
19. One dram put back on Mars day at Mont Mégantic (5)
20. Gamma wavelengths stop between second and third (5)

Answers to February's puzzle

ACROSS

1 ANTLIAE (anag); **4** A BAND (hid); **7** NEMEA (men (rev)+EA); **8** WHIPPLE (whi(pp)le); **9** BROCCHI (2 def, coathanger); **10** OWENS (2 def); **11** A SPIRAL GALAXY (anag); **14** RADON (2 def); **16** OLYMPUS (2 def); **19** RENEWAL (re(new)al); **20** ARIEL (2 def); **21** LOBBY (l(OBB)y); **22** MATADOR (anag)

DOWN

1 ARNEB (Arne+B); **2** TOM BOPP (tom+bop+p); **3** ISAAC (is+a+ac);**4** ARIZONA (Ari+an oz (rev)); **5** APPLE (app+le); **6** DEEP SKY (speed (rev)+Ky); **8** WHIRLPOOL (whirl+loop (rev)); **11** AURORAL (Aur+oral); **12** RUNAWAY (2 def); **13** APPLIED (app+lied); **15** DENEB (D(ENE)B); **17** YEAST (y+east); **19** SOLAR (sol+a+r)

It's Not All Sirius

by Ted Dunphy

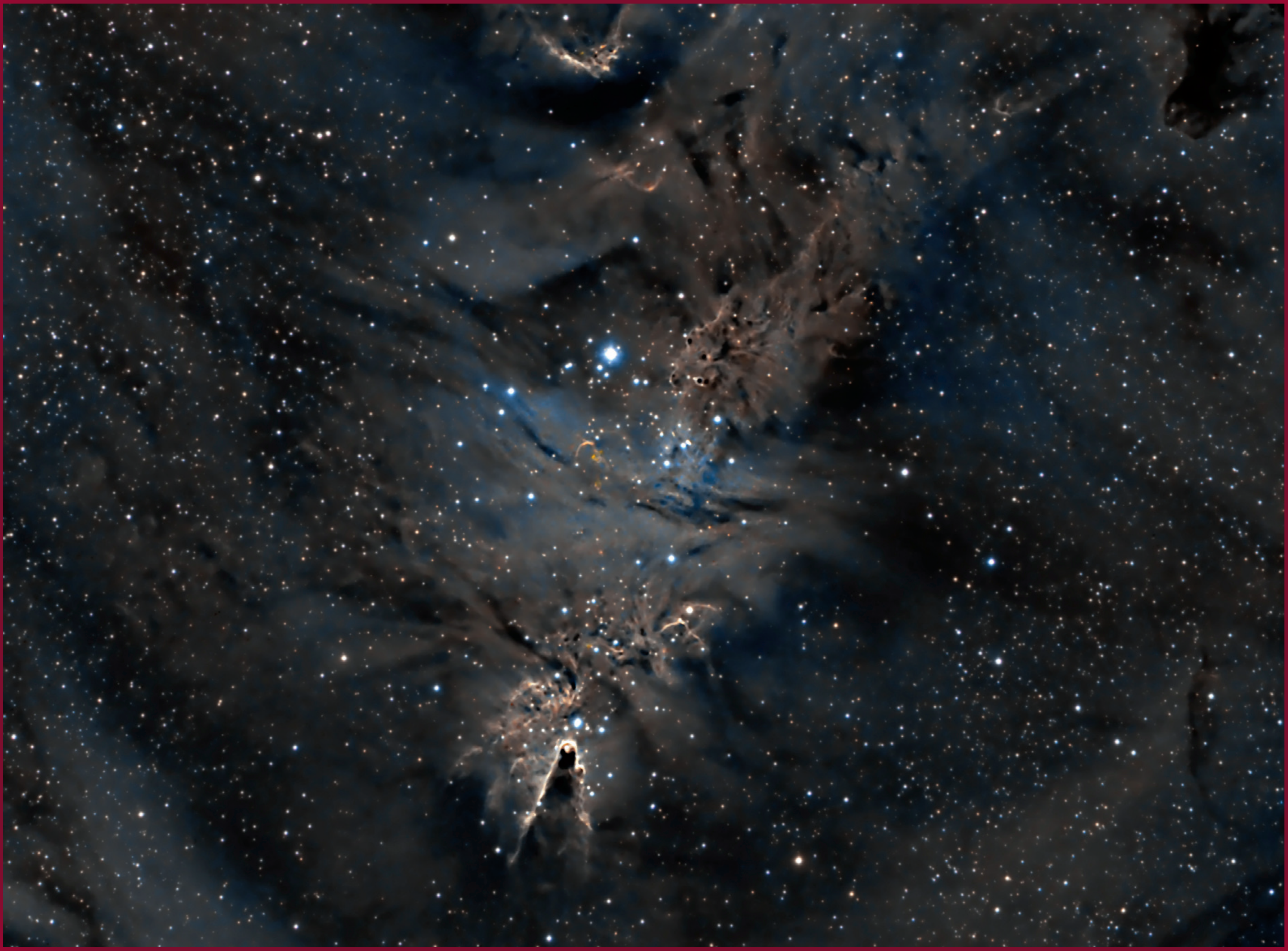
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

Board of Directors and appointed officers for 2016/2017 | Conseil d’administration et membres attitrés pour 2016/2017

Great Images

by Dave Newbury

M13 from recent Astroimaging Certificate winner, Dave Newbury of St. John’s, Newfoundland & Labrador. Taken from Terra Nova National Park on 2015 June 30. The Moon was 99% full. 11 subs @ 60 s each, ISO 1600, using a Canon T1i unmodified and a Celestron C11@ ƒ/7 on an EQ8 mount. Guiding w/ QHY5Lii, C80, PHD2. Stacked and Processed in PixInsight.



Journal

Great Images

The image is an 8.5-hour exposure of NGC 2264 taken by Dan Meek. He used a Tele Vue NP127is and QSI583wsg CCD camera. M27 Planetary Nebula in Vulpecula. Taken from Mount Pearl, NL, 2015 Sept 25. 29 subs – 60s – 6400iso, DGM NPB filter, Canon 6D modified, Celestron C11@ F7 on EQ8 mount, Guiding w/QHY5Lii, C80, PHD2, Stacked and Processed in PixInsight