The Journal of The Royal Astronomical Society of Canada

Journal

Le Journal de la Société royale d'astronomie du Canada

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IN CANADA

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The Best of Monochrome.

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

This image of the Christmas Tree Cluster and the Cone Nebula was taken by Dan Meek from Calgary. The Hα image was captured using a Tele Vue 127 and a QSI583wsg CCD camera over three nights for a total of four hours.

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Royal Astronomical Society of Canada

Société Royale d'Astronomie du Canada

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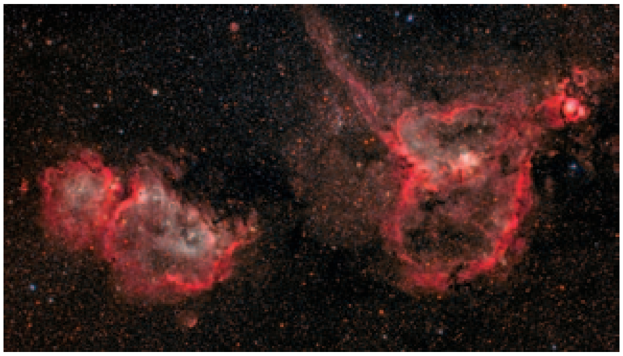

Lynn Hilborn took this beautiful image of the Heart and Soul nebulae from his Whistlestop Observatory in Grafton, Ontario. Hilborn used a TS71 f/5 telescope with a modified full-frame Canon 6D camera and a 12nm Hα filter. Exposure time was Hα 6×30m 3200 ISO, RGB 25×10m 1600 ISO.

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

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Canada

President's Corner

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

I sometimes wonder how many of us in the Society know about the work that goes on in the background helping to create and distribute our printed publications. It's time we recognized all those people. I'm pleasantly surprised at the numbers involved and the varied firms that help us fulfill our outreach and education mandate.

I'll begin with the printers in Dartmouth, Nova Scotia. When we first started doing business there, the name was Maritime Digital Colour, which morphed to Cansel/MDC, and is now just **Cansel**. The firm is headquartered in Vancouver, with offices and outlets all across the country. www.cansel.ca

The people we deal with on a regular basis are Jim Murphy, Lynn Adams, and Brenda Innocent. In the actual plant are the people who put the paper and ink in the machines, collate, staple, package, and distribute the final product out the door. They are, in no particular order,

Brian Blenkhorn, Carolyn Wilkinson, Chris Pacey, Dave Wiley, Dennis Hearn, Earl Hearn, Glenn Cribby, Randy Cornelius, and Stewart Martin.

Cansel prints this *Journal*, plus the *Observer's Calendar*, our Star Finders, Moon Gazer's Guides, and various brochures. Most products except the *Journal* and the *Observer's Calendar* are packaged and shipped right from Cansel.

The finished *Journal* goes out the door to **Russell House**, a distribution firm, also in Dartmouth. www.russellhouse.ca They process our mail—which includes addressing, inserting, sealing, and delivering to a postal outlet. We seldom have any contact with these people, but we rely on them to provide a timely, reliable service. They are: Kevin Cooper, Shawn Cooper, Pat Judd, who make sure all RASC addresses are "cleaned" and accurate to Canada Post's standards. They format addresses, correct invalid / changing postal codes, then sort the mail to maximize postage discounts and keep postage costs down. Finally, they prepare files directly onto the address whitespace area. Wanda Robinson makes sure all mail processing instructions are up-to-date for Canadian, USA, and International destinations, as well as scheduling production and preparing the paperwork required at Canada Post. Ben Judd, Linda McIntyre, Vivian Horton, Elaine Mountain, Peggy Aulenback, Georg-Ann Brooks, and Larry Robinson handle all production, which includes addressing and final mail preparation. Erika Richards is the receptionist, and Stuart Inglis is the Vice-President Marketing and Sales, Eastern Canada.

The *Observer's Handbook* is printed in Toronto by **Webcom**, mainly because the Handbook has a specialized binding.

www.webcomlink.com We have a great rapport with the people there, and they do their utmost to fulfill our printing needs for this complicated book. One only has to leaf through the latest edition to realize the pride they take in doing a great job. Our contacts at Webcom are Dennis Soler, Project Manager, and Ayhan Angelo, Account Executive.

Finally, the mail fulfillment centre handling all of our Handbooks, *Observer's Calendar*, *Skyways*, and such, as bulk orders to Canadian addresses, to the US, and overseas, is **Harrison Mailing Limited**. www.harrisonmailing.on.ca Situated in Pickering, on the eastern outskirts of Toronto, the employees there respond to requests from the Society Office, packaging and mailing orders large and small. The people there are far too numerous to mention individually, so Linda Penwarden, Client Service Manager, says we should simply mention the Harrison Mailing Team. And, that we shall.

Clear skies! (And, don't forget to order your electronic 2016 Observer's Handbook, available again for a mere $10 at www.drmz.net/rasc/DRMZ/OH2016.drmz. Call the Society Office for payment and activation details.)

Clear skies! ✶

News Notes / En manchettes

Compiled by Jay Anderson

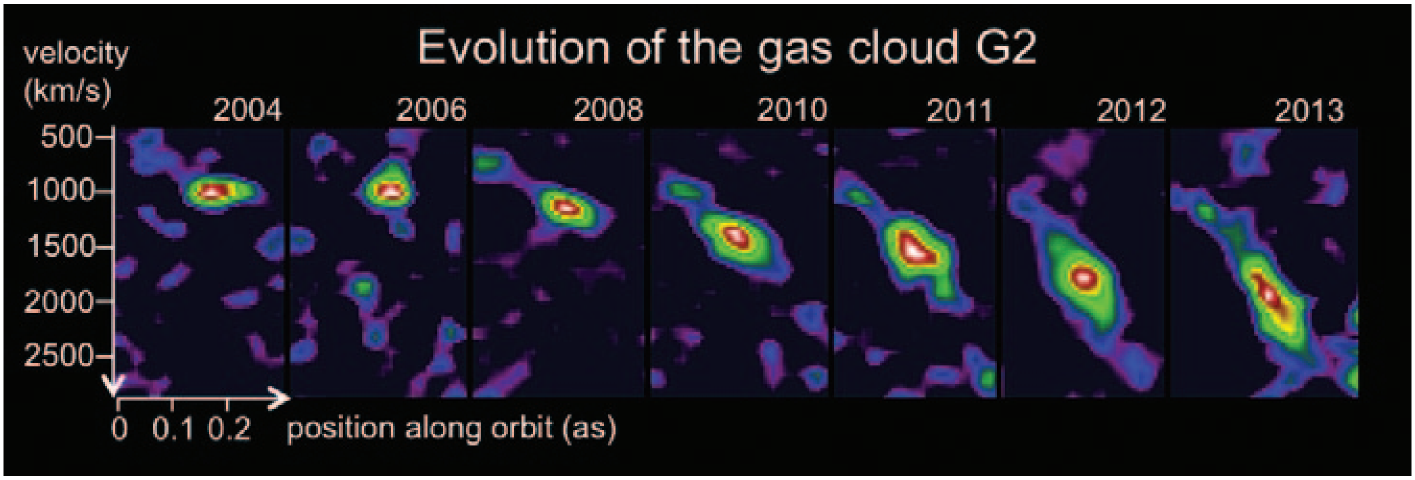

Figure 1 — This series of images show the evolution of G2 between 2004 and 2013 as it stretched out while approaching the black hole at the centre of the Milky Way. Credit: Max Planck Institute for Extraterrestrial Physics.

G2 identity revealed

Since 2002, astronomers have been watching what appeared to be a large cloud of hydrogen gas (which came to be known as G2) approaching the black hole at the centre of the Milky Way (Figure 1). At the time, and in the intervening years, the cloud appeared to be stretching and elongating as it moved into the intensifying gravitation field around the galactic core. Closest approach was awaited with considerable anticipation, as the cloud was expected to be captured by the black hole and cause an eruption of high-energy particles and photons.

Closest approach was in the summer of 2014 and to the surprise of most researchers, the cloud passed the black hole with almost no effect (Figure 2), demonstrating that G2 could not have been a hydrogen cloud. Now, a team of researchers at the W.M. Keck Observatory led by Andrea Ghez, UCLA professor of physics and astronomy, has identified G2 as a pair of binary stars that had been orbiting the black hole and had merged into an extremely large star, shrouded in dust and gas. Ghez, who studies thousands of stars in the neighbourhood of the supermassive black hole, said G2 appears to be just one of an emerging class of stars near the black hole that are created because the black hole's powerful gravity drives binary stars to

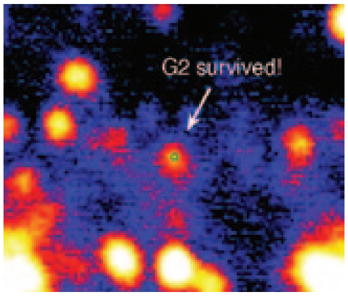

Figure 2 — An image from W.M. Keck Observatory near-infrared data shows that G2 survived its closest approach to the black hole in 2014. The green circle just to its right depicts the location of the invisible supermassive black hole.

Figure 3 — Liftoff of Vega VV06 carrying LISA Pathfinder *on 2015 December 3 from Europe's Spaceport, French Guiana. Image: European Space Agency.*

merge into one. When the two stars merge, the resulting single star expands for a million years before it settles down. The body has fascinated many astronomers in recent years, particularly during the year leading up to its approach to the black hole. "It was one of the most watched events in astronomy in my career," Ghez said.

According to Ghez, "This may be happening more than we thought; the stars at the centre of the galaxy are massive and mostly binaries. It's possible that many of the stars we've been watching and not understanding may be the end product of a merger that are calm now." She also said that G2 had suffered an abrasion of its outer layers, but had otherwise survived, though G2 appears to be in an inflated stage now. Ghez also noted that G2 is undergoing what she calls a "spaghettification"—a common phenomenon near black holes in which large objects become elongated. At the same time, the gas at G2's surface is being heated by stars around it, creating an enormous cloud of gas and dust that has shrouded most of the massive star.

Compiled with material provided by W.M. Keck Observatory and UCLA.

LISA Pathfinder heads for gravity-wave demonstration

The European Space Agency's *LISA Pathfinder* lifted off December 3 on a Vega rocket from Europe's spaceport in Kourou, French Guiana, on its way to demonstrate technology for observing gravitational waves from space. Einstein's general theory of relativity predicts that these waves should be universal, generated by accelerating massive objects. They have not been directly detected to date because they are so tiny—the ripples emitted by a pair of orbiting black holes would stretch a million kilometre-long ruler by less than the size of an atom.

LISA Pathfinder will test the extraordinary technology needed to observe gravitational waves from space. At its core is a pair of identical 46-mm gold–platinum cubes separated by 38 cm, which will be isolated from all external and internal forces acting on them except one: gravity. The mission will put these cubes in the purest free-fall ever produced in space and monitor their relative positions to astonishing precision, laying the foundations for gravitational-wave observatories in space. Such future missions will be key partners to the ground sites already searching for these elusive cosmic messengers. Space and ground experiments are sensitive to different sources of gravitational waves, both opening up new possibilities to study some of the most powerful phenomena in the Universe.

The spacecraft will be parked at a stable virtual point in space called L1, some 1.5 million kilometres from Earth towards the Sun, a position it is expected to reach in mid-February. Once in orbit around L1, the final mechanisms will be unlocked and the cubes will no longer be in mechanical contact with the spacecraft. A complex system of laser beams bouncing between the two cubes will measure how close to true free-fall they are to within a billionth of a millimetre—never previously achieved in space.

The spacecraft itself will be an active part of the experiment, firing tiny thrusters about 10 times a second to adjust its position and avoid making contact with the cubes, thus shielding them from any forces that would prevent them from moving under the effect of gravity alone. If these extraordinarily high-precision measurements and operations can be achieved by *LISA Pathfinder*, the door will be open to building a future space observatory, capable of detecting the minute disturbances in spacetime produced by gravitational waves.

"Gravitational waves are the next frontier for astronomers. We have been looking at the Universe in visible light for millennia and across the whole electromagnetic spectrum in just the past century," says Alvaro Giménez Cañete, ESA's Director of Science and Robotic Exploration.

Compiled using information provided by the European Space Agency.

Milky Way central black hole has magnetic field

The supermassive black holes at the centres of galaxies are like cosmic engines, converting energy from infalling matter into intense radiation that can outshine the combined light from all surrounding stars. If the black hole is spinning, it can generate strong jets that blast across thousands of light-years and shape entire galaxies. These black-hole engines are thought to be powered by magnetic fields. Now, for the first time, astronomers have detected magnetic fields just outside the event horizon of the black hole at the centre of our Milky Way Galaxy.

"Understanding these magnetic fields is critical. Nobody has been able to resolve magnetic fields near the event horizon until now," says lead author Michael Johnson of the Harvard-Smithsonian Center for Astrophysics (CfA). "These magnetic fields have been predicted to exist, but no one has seen them before. Our data puts decades of theoretical work on solid observational ground," adds principal investigator Shep Doeleman (CfA/MIT), who is assistant director of MIT's Haystack Observatory.

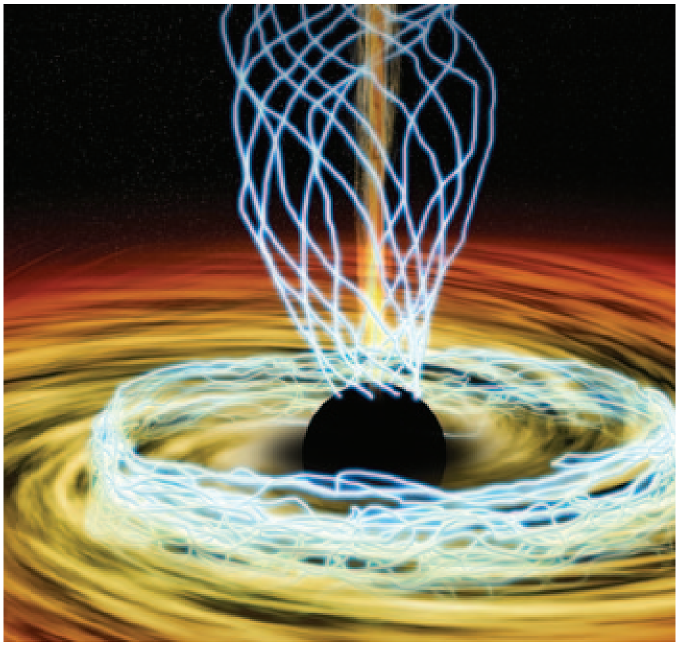

Figure 4 — In this artist's conception, the black hole at the centre of our galaxy is surrounded by a hot disk of accreting material. Blue lines trace magnetic fields. The **Event Horizon Telescope** *has measured those magnetic fields for the first time with a resolution six times the size of the event horizon (6 Schwarzschild radii). It found the fields in the disk to be disorderly, with jumbled loops and whorls resembling intertwined spaghetti. In contrast, other regions showed a much more organized pattern, possibly in the region where jets (shown by the narrow yellow streamer) would be generated. Image: M. Weiss/CfA.*

This feat was achieved using the Event Horizon Telescope (EHT)—a global network of radio telescopes that link together to function as one giant telescope the size of Earth. Since larger telescopes can resolve finer details, the EHT ultimately will distinguish features as small as 15 micro-arcseconds. (15 micro-arcseconds is the angular equivalent of seeing a golf ball on the Moon.)

The Milky Way's central black hole, Sgr A* (Sagittarius A-star), weighs about 4 million times as much as our Sun, yet its event horizon spans only 8 million miles—smaller than the orbit of Mercury. At the black hole's distance of 25,000 light-years, this size corresponds to an incredibly small 10 micro-arcseconds across. Fortunately, the intense gravity of the black hole warps light and magnifies the event horizon so that it appears larger on the sky—about 50 micro-arcseconds, a region that the EHT can easily resolve.

The Event Horizon Telescope team made observations at a wavelength of 1.3 mm, measuring the linear polarization at

Figure 5 — A screen capture of one frame from one of Miloslav Druckmüller's video clips constructed from observations by the ***Solar Dynamics Observatory***. *The image shows a filament eruption on 2014 December 14. Image: Miloslav Druckmüller.*

that wavelength. In Sgr A*, polarized light is emitted by electrons spiraling around magnetic field lines. As a result, this light directly traces the structure of the magnetic field. Sgr A* is also surrounded by an accretion disk of material that orbits the black hole. The team found that magnetic fields in some regions near the black hole are disorderly, with jumbled loops and whorls resembling intertwined spaghetti. In contrast, other regions showed a much more organized pattern, possibly in the region where jets are generated. They also found that the magnetic fields fluctuated on short time scales of only 15 minutes or so.

"Once again, the galactic centre is proving to be a more dynamic place than we might have guessed," says Johnson. "Those magnetic fields are dancing all over the place."

These observations used astronomical facilities in three geographic locations: the Submillimeter Array and the James Clerk Maxwell Telescope (both on Mauna Kea in Hawaii), the Submillimeter Telescope on Mt. Graham in Arizona, and the Combined Array for Research in Millimeter-wave Astronomy (CARMA) near Bishop, California. As the EHT adds more radio dishes around the world and gathers more data, it will achieve greater resolution with the goal of directly imaging a black hole's event horizon for the first time.

New high-resolution video of solar eruptions from the *Solar Dynamics Observatory* Atmospheric Imaging Assembly (SDO AIA)

Miloslav Druckmüller of the Institute of Mathematics, Faculty of Mechanical Engineering, at the Brno University of Technology, Czech Republic has released reprocessed high-resolution video clips of solar flares, filament eruptions, and even the destruction of Comet Lovejoy on his website at www.zam.fme.vutbr.cz/~druck/Sdo/Pm-nafe/0-info.htm. Druckmüller is well known in eclipse-chasing circles for his unique and spectacular images of the solar corona, created using techniques of his own development that emphasize fine detail and noise suppression without loss of image information.

From the SDO AIA images, Druckmüller has combined the 211-, 171-, and 304-Å bands into a false-colour image by defining a characteristic temperature for each wavelength and then mapping the result into a lower blackbody temperature where radiation is in visible wavelengths. The new colours are then processed to achieve a precise colour balance and saturation in a manner similar to that used in digital cameras for automatic white balance.

The video clips are presented in .avi format to avoid artifacts, making the files very large—typically 200-400 MB. High-resolution monitors are required to show the movies at their best.

More high-res images from *New Horizons*

The *New Horizons* flypast of Pluto is the gift that continues giving, as the slow playback of stored images and science data continues to surprise and delight planetary astronomers and the public alike. Images released on December 4 showed scenes from the spacecraft's closest approach on July 4, adding new layers of mystery to those already accumulated over the previous five months.

Figure 6 — In this highest-resolution image from ***New Horizons****, great blocks of Pluto's water-ice crust appear jammed together in the informally named al-Idrisi Mountains. Some mountainsides appear coated in dark material, while other sides are bright. Several sheer faces appear to show crustal layering, perhaps related to the layers seen in some of Pluto's crater walls. Other materials appear crushed between the mountains, as if these great blocks of water ice, some standing as much as 2.4 km high, were jostled back and forth. The mountains end abruptly at the shoreline of the informally named Sputnik Planum, where the soft, nitrogen-rich ices of the plain form a nearly level surface, broken only by the fine tracework of striking, cellular boundaries and the textured surface of the plain's ices (which is possibly related to sunlight-driven ice sublimation). This view is about 80-km wide. The top of the image is to Pluto's northwest. Credit: NASA/JHUAPL/SwRI*

John Grunsfeld, former astronaut and associate administrator for NASA's Science Mission Directorate marvelled that "New Horizons thrilled us during the July flyby with the first close images of Pluto, and as the spacecraft transmits the treasure trove of images in its onboard memory back to us, we continue to be amazed by what we see."

The latest images form a strip 80 kilometres wide on a world 4.8 billion km away. The pictures trend from Pluto's jagged horizon about 800 kilometres northwest of the informally named Sputnik Planum, across the al-Idrisi mountains, over the shoreline of Sputnik, and across its icy plains. The image from this sequence (Figure 6) that shows the region along the al-Idrisi Mountains-Sputnik boundary is almost Earth-like, showing lines of dune-like features that will be difficult to explain in the tenuous atmosphere surrounding the ex-planet. The dune field is broken into large pan-like blocks that might be floating on flows of frozen nitrogen.

"Seeing dunes on Pluto—if that is what they are—would be completely wild, because Pluto's atmosphere today is so thin," said astronomer William B. McKinnon from Washington University in St. Louis. "Either Pluto had a thicker atmosphere in the past, or some process we haven't figured out is at work. It's a head-scratcher."

The mountain terrain that surrounds the dune fields of Sputnik are enormous—comparable to the Rocky Mountains in scope. The height of the mountains may be an indication of the presence of water on Pluto, as the other constituents of the ex-planet's surface—carbon-dioxide ice, nitrogen ice, and methane ice—are too soft to support the steep mountain slopes seen in the new images. The possible presence of water on such a distant planet has not yet fuelled speculation about life on the outer reaches of the Solar System, an oversight that will probably be rectified at some future date. ✶

Compiled from data provided by NASA

North American Noctilucent Cloud Observations in 1964–77 and 1988–2014: Analysis and Comparisons

by Mark S. Zalcik[1], Todd W. Lohvinenko[2], P. Dalin[3,4], W.F. Denig[5]

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Abstract

North American observations of noctilucent clouds (NLC) in the periods 1964–1977 and 1988–2014 are compared. Between the two study periods there has been no change in the activity profile of the NLC season; nor has there been any trend in NLC incidence. When comparing individual sites, it was determined that at Broadview, Sask. (50.4N 102.6W) and The Pas, Man. (54.0N 101.1W), there were no significant trends in incidence nor brightness. However, in the case of Baker Lake, Nun. (64.3N 96.0W), in 2003–2009 there was marked increase in NLC incidence, but also a decrease in average brightness in 1993–2009 compared with 1967–1977. Brightness data from 1967–1977 indicate that average and maximum NLC brightness increases with increasing latitude. A study of observer detection of NLC of different brightnesses confirms that a significant number of displays are missed because they are too faint for some observers to see; consequently, when comparing NLC incidence between two periods, it may be preferable to compare only numbers of bright displays.

Introduction

Noctilucent clouds (NLC) are a beautiful nighttime phenomenon visible at mid-northern latitudes in the late spring and into summer (Figure 1). They appear in twilight as cirrus-like formations occupying the blue twilight arch, sometimes visible all night at those latitudes, poleward of the 52nd parallel, that have perpetual twilight near the Summer Solstice. NLC remain illuminated by the Sun much later into twilight than tropospheric clouds because these thin clouds are much higher, at 80–85 km, residing in the upper reaches of Earth's mesosphere. A bright, extensive display of NLC hanging eerily in the northern sky, sometimes so bright that the clouds cast shadows, can be a truly memorable sight.

Curiously, NLC have been known only since 1885 when they were first sighted in the United Kingdom, Germany, Czech Republic, Estonia, and Russia (Gadsden and Schröder, 1989, Dalin et al., 2012), and only since 1933 in North America, when they were observed and photographed by Ernest Vestine, who at the time was studying the aurora in northern Alberta. His historically significant account was documented in JRASC (Vestine, 1934). As NLC have not been known for a long time, their emergence may be due to changes in the upper atmosphere, such as increasing terrestrial levels of the greenhouse gas methane, which breaks down into water vapour among

Figure 1 — Photo of the noctilucent cloud display of 2014 June 17/18, about 0030 MDT from Edmonton, Alta. Photo by Bruce McCurdy.

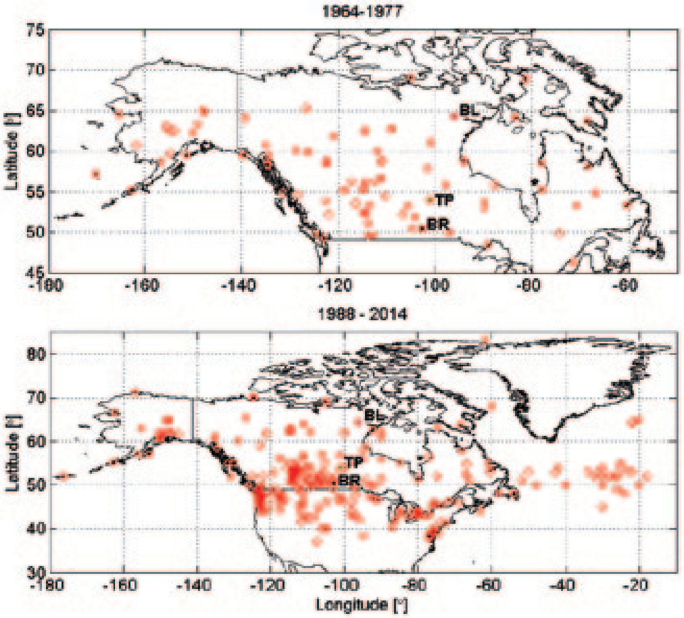

Figure 2 — Maps showing locations of NLC observers during the periods 1964–77 and with the NLC CAN AM surveillance network in 1988–2014. On both maps, the following letters indicate sites whose data are compared between both periods: BR-Broadview, Sask.; TP-The Pas, Man.; BL-Baker Lake, Nun.

other products in the stratosphere (Thomas et al., 1989). The water vapour then diffuses upward to the mesosphere where it accretes on meteor dust and large hydrated ions. Efforts to monitor NLC have intensified with each decade and now include data collection by the Aeronomy of Ice in the Mesosphere (AIM) satellite, which was launched in 2007 (Russell et al., 2009).

Continuous ground-based monitoring of NLC has been conducted since 1962 in Moscow (Romejko et al., 2003), 1973 in Lithuania (Dubietis et al., 2010), and 1983 in Denmark (Dalin et al., 2006, Kirkwood et al., 2008), as well as in the UK and Sweden (Gadsden and Schröder, 1989, Kirkwood et al., 2008). In North America, subsequent to the Vestine sighting, there was a gap of 23 years with no sightings (Fogle, 1966) until 1956, when there were three consecutive active nights from Edmonton, Alberta (Fogle, 1966). A handful of sightings were recorded through the rest of the 1950s and early 1960s (Fogle, 1966). In 1962, an ambitious effort was organized by Benson Fogle of the University of Alaska, who enlisted the help of weather agencies in the US and Canada to commence synoptic monitoring of the summer skies. The number of North American NLC sightings consequently climbed remarkably as observations were expanded through 1965, and in his extensive summary, Fogle concluded that "NLC occur as frequently over North America as over Europe and the USSR and that the previous scarcity of observations was probably due to the lack of interested and informed observers here" (Fogle, 1966).

As of 1967, Fogle's extensive observing program remained in place in Canada, Alaska, Iceland, and Greenland, with many weather stations and airports continuing to look for NLC until 1977. A large volume of data was logged and archived, but to our knowledge, this trove up until now has never been analyzed. This paper presents the data and compares it with visual data compiled by our NLC CAN AM network data, which we started collecting in 1988.

Figure 2 shows the locations of sites with NLC sightings in both periods, 1964–1977, and 1988 –2014, hereafter referred to as the 1960s–1970s period and the NLC CAN AM period, respectively. We use 1964 as the starting year for the 1960s–1970s period, as it was in that year that the number of observers ramped up to obtain a wider coverage of the entire North American continent. The NLC CAN AM sites include a small number of observers who did not see NLC. Note the good coverage in Alaska in the 1960s–1970s period and the extensive coverage continent-wide in the NLC CAN AM period.

Data and Discussion

In a typical NLC season, activity begins in mid May, peaks from mid June to mid July, and drops off in mid August (Zalcik, 1998). Has there been any marked change in this profile between the 1960s–1970s and NLC CAN AM periods? The comparison in activity profiles of 1964–1977 and 1988–1995 is illustrated in Figure 3 by plotting the sites' latitude vs the median night of each site's sightings during the study period. A similar graph has been composed for the 1988–1989 NLC CAN AM seasons (Lohvinenko and Zalcik, 1990). Note from both graphs that, as one travels north of roughly the 55th parallel, the median date quickly becomes later and later through July and into August. There are two reasons: a) north of about 61N the local skies are too bright to see NLC around the Summer Solstice; as we get later into July and August, more areas progressively northward can see NLC as their skies get darker; b) in August, the mass of parent clouds of NLC, those being polar mesospheric clouds (PMC) that form over the summertime poles, begins to diminish until it completely disappears by month's end, thereby ending the NLC season. Some of those parent clouds are gradually transported southward (like icebergs) due to the meridional summertime wind circulation directed from north to south, enabling visibility of PMC as NLC at mid- and subpolar latitudes throughout the summer. The similarity of the 1960s–1970s and NLC CAN AM curves suggests that the NLC season remained framed in the same three-month window, with the seasons in 1988–1995 not starting any earlier nor ending later than with the 1964–1977 seasons. Gadsden (1998) also noted that in the last half of the 20th century there had been no change in the profile of the NLC season.

In Figure 4, we compare the network-wide activity levels in the 60s–70s and NLC CAN AM periods. The solar activity cycle is represented by the Lyman-alpha flux averaged for June and July of each year from 1964 to 2014 (green line, right y-axis). The best NLC-years in both periods experienced total active nights in the 50–60 range. On the other hand, during some seasons the totals were in the 20s or lower. Note that in 1964, there were already over 50 active nights, only 8 years after the aforementioned "resurgence" of North American NLC in 1956.

Many researchers have sought to correlate NLC activity with the solar sunspot cycle. The NLC-hindering mechanism as such is thought to be the solar maximum increase in UV flux, which reduces upper-atmosphere water vapour and hence NLC activity. Romejko et al. (2003), Dalin et al. (2006), and Dubietis et al. (2010) have indicated that there is a marked decrease in NLC activity two years after sunspot maximum. In the 1960s–1970s period, ground-based data agree well. The high NLC active-night totals in 1964 through 1968 reflect the low sunspot period underway since 1963 (Denig, 2015). Conversely, the low NLC activity in 1969–1973 corresponds with the broad sunspot maximum of 1967–1971. Going to the next cycle, the strong NLC years of 1976–1977 correspond well with the start of the next sunspot low point in 1974.

During the NLC CAN AM period, the lower NLC activity anticipated after the 1990 solar maximum was manifested by the ultra-low total of 12 active nights in 1992. The depth of this low may have been due to atmospheric changes brought about by the Mt. Pinatubo eruption in the Philippines in 1991 (Zalcik et al., 2014). Already in 1995 we see a marked increase in NLC activity. The situation with the next cycle is however not as clear-cut. NLC activity two years after the 2002 sunspot maximum was at a high point and remained high until the end of the decade. Moreover, the precipitous dip in activity in 2010 does not correspond well with 2008 solar activity, which was actually near minimum. In this regard, it is important to mention that the NLC cycle is significantly shorter (8.6–9.5 years) than the solar cycle (10.4–10.6 years) (Dalin et al., 2006). That is why the quasi two-year lag varies between 0 and 3 years, thus partly explaining the "unusual" behaviour between the last NLC and solar cycles.

In a good NLC year, the seasonal total can be much higher at a particular site, topping 20 active nights, and continuous nightly viewing with use of a digital camera and mobility to find clear skies has yielded 30 active nights (Zalcik et al., 2014). With regard to weather and airport-based flight service stations, there are three such sites that participated in both the 1960s–1970s program and the NLC CAN AM campaign: Broadview, Sask. (50.4N, 102.6W, 1968–1977 and 1988–1994); The Pas, Man. (54.0N, 101.1W, 1967 –77 and 1988 –95 [no data in 1992]); Baker Lake, Nun. (64.3N, 96.0W, 1967–1977 and 1993–2009 [no data in 1999, 2001, and 2008]). Figure 5 shows the seasonal NLC totals for the sites in both intervals, and average values are listed in Appendix A. Included in each graph is the corrected sighting totals taking into consideration weather conditions; a weather-correction system was introduced by Zalcik et al. (2014) and applied to the NLC CAN AM data, and a similar treatment is applied here to the 1960s–1970s data based on more generalized weather cloud estimations with the 1960s–1970s reports. From the graphs it looks like activity in both periods at The Pas was similar, and activity was about 25% higher at Broadview during the NLC CAN AM period.

As for Baker Lake, the situation is much more conspicuous. Not only was average seasonal incidence over three times higher in the NLC CAN AM period up to 2009, 4.8 active nights per season compared with 1.3 active nights per season in 1967 –77, but the corrected sightings totals in some of the seasons during the new millennium were anomalously high. The 2003 season was particularly robust, with 12 active nights despite poor tropospheric weather, boosting the corrected total to nearly 30. Recall that this was at around the time of solar maximum, when NLC activity would be expected to be much lower. Based on the Baker Lake data, one may contend that NLC activity at high latitudes seems to have increased substantially since the turn of the century. Russell et al. (2014), simulating PMC using SABER data from the TIMED satellite, indicated that there was a marked increase in PMC in 2003 in the latitude range of 45–70N and that, for the most part, levels remained high for the rest of the decade. They also noted that the 2003 season exhibited a marked drop in mesospheric temperature in the 60–85N latitude range in

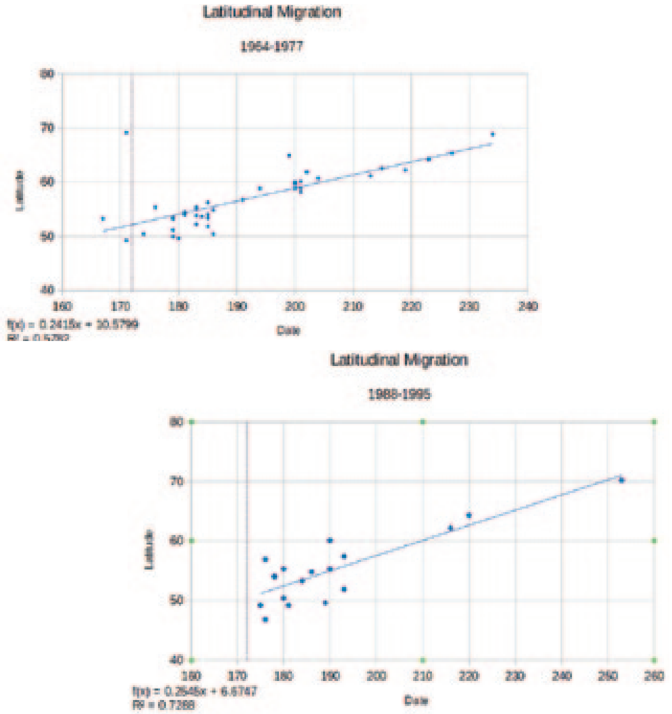

Figure 3 — Graphs showing site latitude as a function of median night in: a) 1964–77, and b) 1988–95. The vertical black dashed line corresponds to the night of the Summer Solstice, Jun 21/22, night 172.

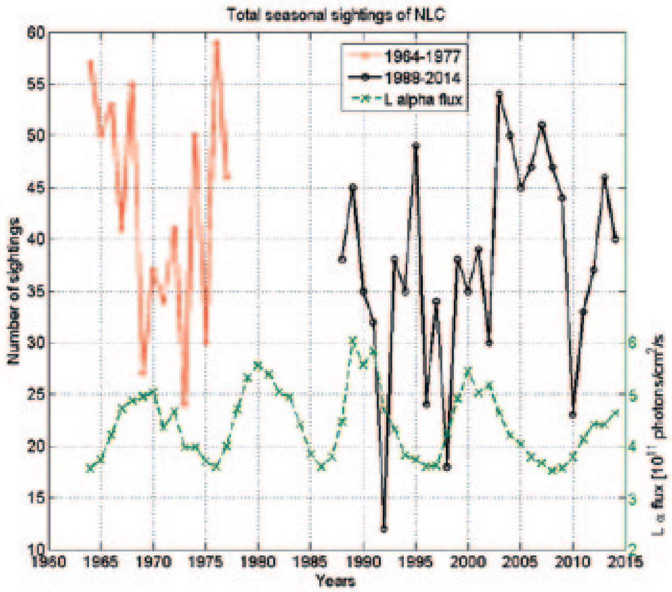

Figure 4 — Graphs showing seasonal network-wide totals of NLC-active nights in 1964–77 and 1988 –2014. The low points in 1969–73 and 1992 correspond with the 2-year lag in NLC incidence as a result of sunspot maxima. The green dashed line is the Lyman alpha flux (right y-axis).

comparison with the 2002 and 2004 seasons, which would suggest that the increase in occurrence of PMC, and thus NLC, in 2003 were temperature-caused.

Regarding Baker Lake, it should be noted that there is a problem with utilizing this site as an indicator of NLC activity as a whole during a particular season. The reason is that the site's high latitude allows observers there to see NLC only starting in the third week of July, clearly later than the peak period experienced by observers in the upper 50s of latitude. Thus, Baker Lake samples only one quarter or so of the total of any one season.

Another aspect of NLC that can be compared between the early and later periods is brightness of a display. The faintest NLC are barely visible to the naked eye, though at such times using a digital camera assists detection, because visually feeble NLC will be more obvious in a camera image thanks to the sensitivity of today's digital cameras. Indeed, with the advent of digital photography, we are now able to detect more displays, as we have reached further into what was previously a sub-visible range of NLC brightness (Dalin et al., 2008). On the other end of the scale, the brightest NLC can be so bright as to permit one to read by their luminance.

The brightness scale in the 60s–70s program had five categories:

(1) very weak NLC, barely visible

(2) NLC easily detected, but with low brightness

(3) NLC clearly visible

(4) NLC very bright

(5) NLC extremely bright, illuminating objects facing them.

The NLC CAN AM program has 3 categories: 1–faint; 2–moderate; 3–bright. Figure 6 shows three images of NLC that represent the three levels of brightness. This 3-point scale corresponds fairly well to the above 5-point scale in that the "4" and "5" categories were essentially further measures of already bright NLC. From the 1960s–1970s observer reports there were far more designations of "3" compared with "4" and "5."

The North American program, specifically in the years 1967–1977, had as part of their reporting regimen the estimation of NLC brightness for each observation on the above 1- to 5-point scale. We have taken the brightness data from these 11 years and determined the average brightness of NLC from a site as a function of latitude, and the results (Figure 7) indicate that average brightness significantly increases with increasing latitude. The same result is valid for maximum NLC brightness. This tendency has been detected by *Solar Backscatter Ultraviolet* satellite instruments and by AIM satellite data (DeLand et al. [2007], Rong et al. [2014]).

The Broadview, The Pas, and Baker Lake sites during both periods recorded NLC brightness estimations and the comparisons are shown in Figure 8, with average values listed in Appendix A. The precise years of surveillance for all sites are the same as those mentioned earlier; note that the NLC CAN AM period extends to 2009 as only Baker Lake observed past 1995. The 3–point scale is used, with any 1967–1977 values of "4" or "5" placed in the "3" brightness bin, hence the denotation "3+". At The Pas, the average brightness percentages for the 3 categories were similar to one another and this profile

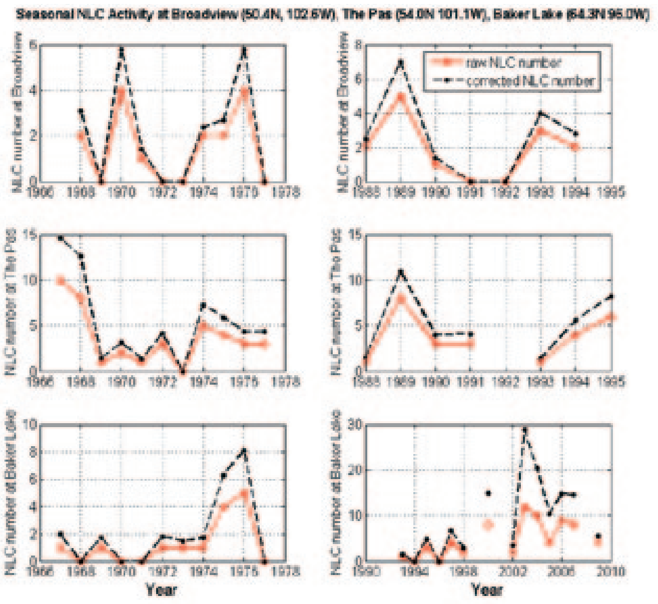

Figure 5 — NLC incidence at Broadview, The Pas, and Baker Lake in the 60s–70s period and the NLC CAN AM period. The red curves show actual sighting numbers, and the black curves corrected numbers based on weather interference. Note the difference in y-axis scales at Baker Lake between the two periods, and the higher numbers of both actual and corrected sightings there starting in 2003.

can be seen in both periods. At Broadview, the NLC CAN AM period had a higher percentage of brightness "3" observations. At Baker Lake, the 1960s–1970s period had more such observations; in fact, over half had a value of "3" or more, and there were very few faint NLC. Hence, in 1988–2009 vs 1967–77, there are no similar trends in brightness with all three sites.

A brilliant display of NLC would be obvious so as to alert many people to its presence. On the other hand, many faint NLC displays will go unnoticed except for those who know about NLC and who are actually looking for them (see Figure 6). Somewhere in between these brightness extremes is what could be termed an average detection threshold. But at what brightness level does such a threshold lie? The large volume of multi-site brightness data from the 1967–1977 Canada–US NLC program allows us to delve further into the matter. To see how easily NLC of a brightness of 1, 2, and 3 are detected, we conducted a study employing tandems of sites near to one another, using one as the observation site, where NLC were unequivocally seen with a certain recorded brightness, and a test site where observing was concurrently done. In total there are 260 test cases from 9 tandems of sites, with distances between the sites ranging from 135 km to 260 km, with an average of 183 km. Results are shown in Figure 9, with panel (a) using maximum brightness values for a particular site on a particular night, and (b) showing the average brightness of all

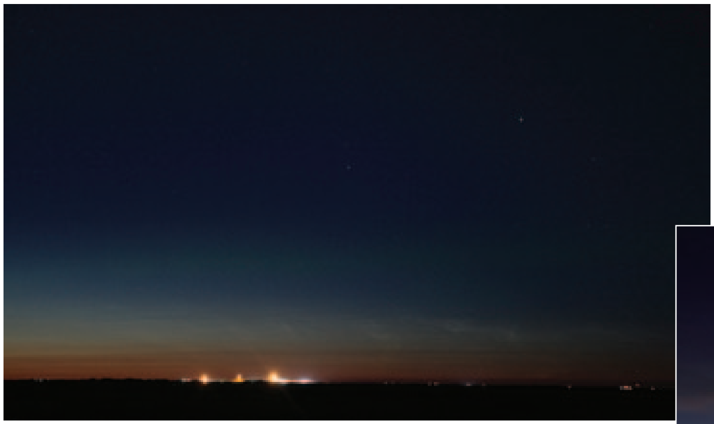

Figure 6a, 6b, 6c — Photos of NLC showing the 3 main categories of brightness: (a, left) brightness of 1, faint NLC, display of 2012 Jul 19/20, 0006 MDT, Villeneuve, Alta., photo by Mike Noble, note the faint auroral arch above the NLC;

(b, above) brightness of 2, moderate brightness, display of 2014 Jun 22/23, 0016 MDT, Edmonton, Alta., photo by Ross Sinclair;

(c, left) brightness of 3, bright NLC, 2005 Jul 2/3, 0012 MDT, Devon, Alta., photo by Doug Hube.

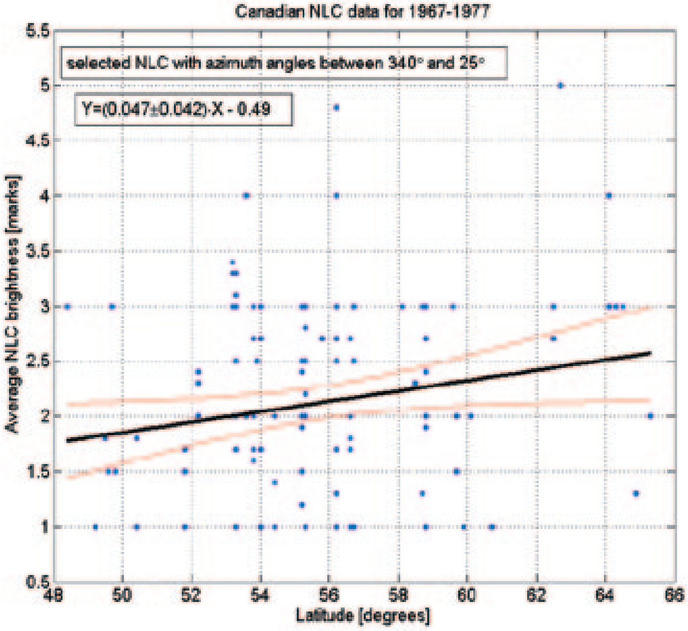

Figure 7 — Relationship between site latitude and average brightness of NLC, the data originating from the North American 60s–70s observing program.

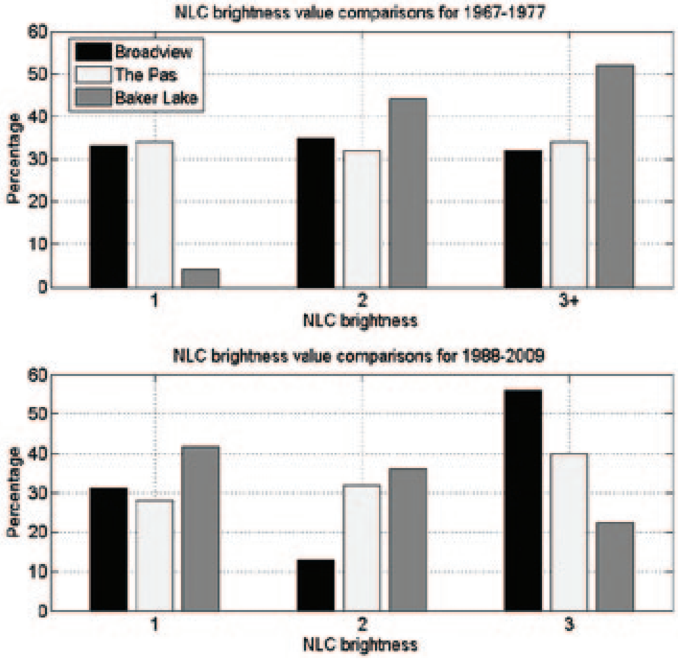

Figure 8 — The percentage of observations with a brightness of 1, 2, and 3 at Broadview, The Pas, and Baker Lake in both the 60s-70s and NLC CAN AM study periods. In the second panel, only Baker Lake observed as late as 2009; Broadview and The Pas observed in the late 80s through to the mid 90s. The "3+" designation in the first panel includes brightness estimates of 4 and 5 which were additional choices pertaining to very bright NLC in the 60s-70s program.

positive sky checks on a particular night. The data are statistically significant, and indicate, with a maximum brightness of 1 at the observation site, NLC were seen only 36% of the time. With a brightness of 3, fully three-quarters of the observation site sightings were corroborated at the test site. Perhaps this percentage would be even higher if the average distance between the observation and test sites were less; Zalcik et al. (2014) have indicated that the patchy nature of NLC can prevent sites close to one another from seeing the same display.

Our data suggest that even with experienced observers staffing weather stations, it takes a bright display of NLC to be noticed. We need to caution here that no matter who the observer, a brightness estimate is a subjective value, and that the brightness estimation value for an NLC display will no doubt vary from observer to observer. In any event, if a significant majority of observers notice only the brighter NLC displays, perhaps, when comparing NLC activity in different epochs, we should only be utilizing the numbers of bright displays. It should be noted that in the aforementioned study of Lithuanian NLC observations (Dubietis et al., 2010), there was a statistically significant trend noticed in bright NLC from the years 1973 –2009.

The problems associated with observer subjectivity and varying detection thresholds from observer to observer can be eliminated with the use of continuous monitoring for NLC by automated digital cameras such as those in the global camera network currently in place (Dalin et al., 2008).

Keeping the above results in mind, let us return to the incidence and brightness comparisons at Baker Lake in the periods 1967–1977 and 1993–2009. Though the 2000s part of the latter period experienced much higher NLC occurrence than the 1990s part and the entire 1967–1977 period, note that in general this most recent period had a much higher percentage of brightness 1 NLC, over 40% compared with <5%. Perhaps the higher occurrence in the latter period starting around 2003 was partly due to a better ability of the observers to detect faint NLC, thereby boosting their sighting totals. Nevertheless, the much higher NLC occurrence at Baker Lake starting in 2003 is conspicuous, and it would be a good idea to have NLC observations resume there to look for a continuation of the early millennium high-incidence trend.

Conclusions

1) There has been no statistically significant trend in NLC incidence between the periods 1964–1977 and 1988–2014.

2) There was no change in the seasonal profile of NLC activity from May through August between the periods 1964–1977 and 1988–1995.

3) At Broadview, Sask., and The Pas, Man., there was no trend in NLC incidence between the periods 1967–1977 and 1988–1995. However, at Baker Lake, Nun., there appeared to be a significant increase in NLC incidence in 2003–2009 when compared with 1967–1977 and 1993–1998.

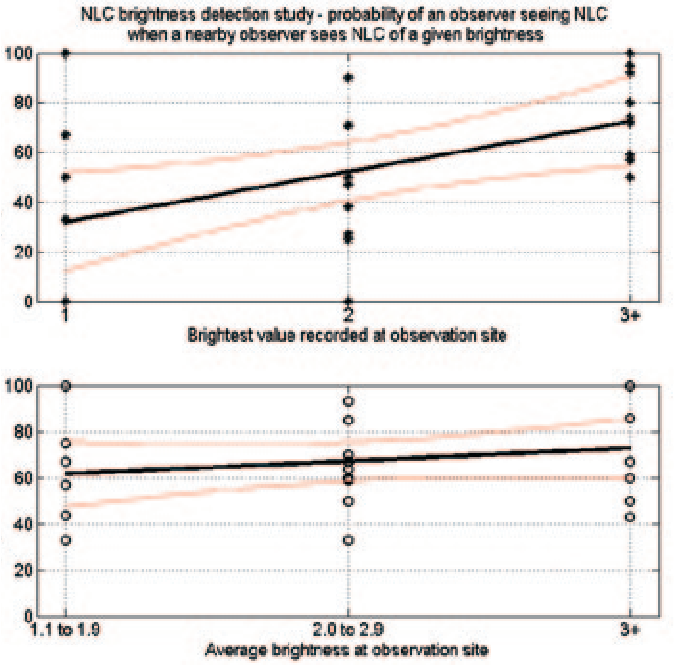

Figure 9 — Results of the brightness detection study using NLC data from 1967-77. a) uses the brightest value estimated for a site on a particular night, and b) the average values of all NLC readings on the same night. The y-axis shows the percentage of those displays that were concurrently seen at the observation site's corresponding test site.

4) Average NLC brightness between the periods 1967–1977 and 1988–1995 at Broadview, Sask. and The Pas, Man. has changed little, but average NLC brightness at Baker Lake, Nun. was lower in 1993–2009 as there was a higher proportion of faint displays.

(5) As shown by brightness data from 1967–1977, average and maximum NLC brightness increases with increasing latitude.

(6) A significant number of NLC displays are missed by some observers because they are faint (brightness value of 1).

(7) Taking into consideration (6.), it may be preferable to compare only numbers of bright displays when evaluating trends in NLC brightness because bright displays are noticeable to a broader population of observers.

(8) The significance of the higher incidence at Baker Lake since 2003 is perhaps lessened considering the high proportion of faint displays, which may be the result of higher observer acuity and/or interest.

(9) The problems of an observer's NLC detection ability and brightness evaluation is solved by incorporating automated digital photography such as the current global digital-camera network. ✶

Acknowledgements

We thank the hundreds of observers at weather stations in Canada, the US, Iceland, and Greenland who contributed NLC data to the monitoring programs set up in 1963–77. Thanks to Benson Fogle, the architect of the extensive continental effort, and to Oliver Ashford, Karl Andersen, J. Bessemoulin, Mac Emerson, G. McDowell, G. McMurray, J. Noble, B. Pedersen, Charles Roberts, R. Savory, and H. Sigtryggson, who helped organize the program through the years of the study period. Thanks to the hundreds more observers in the NLC CAN AM program, both weather/flight service station personnel (participation facilitated by Don White and Ed Hartery, respectively) as well as amateur observers, who have contributed observations since 1988.

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	Years of study	Total Years	Active nights	Average	Corrected Active Nights	Average	Total Brightness Readings	Average
Broadview	60s–70s	10	15	1.5	21	2.1	88	2
NLC CAN AM		7	13	1.9	18	2.6	16	2.3
The Pas	60s–70s	11	40	3.7	59	5.4	223	2
NLC CAN AM		7	26	3.7	36	5.1	50	2.1
Baker Lake	60s–70s	11	14	1.3	23	2.1	27	2.5
NLC CAN AM		14	67	4.8	129	9.2	116	1.8

Appendix A — Incidence and Brightness Comparisons at Broadview, The Pas, and Baker Lake during the 60s–70s and NLC CAN AM Periods

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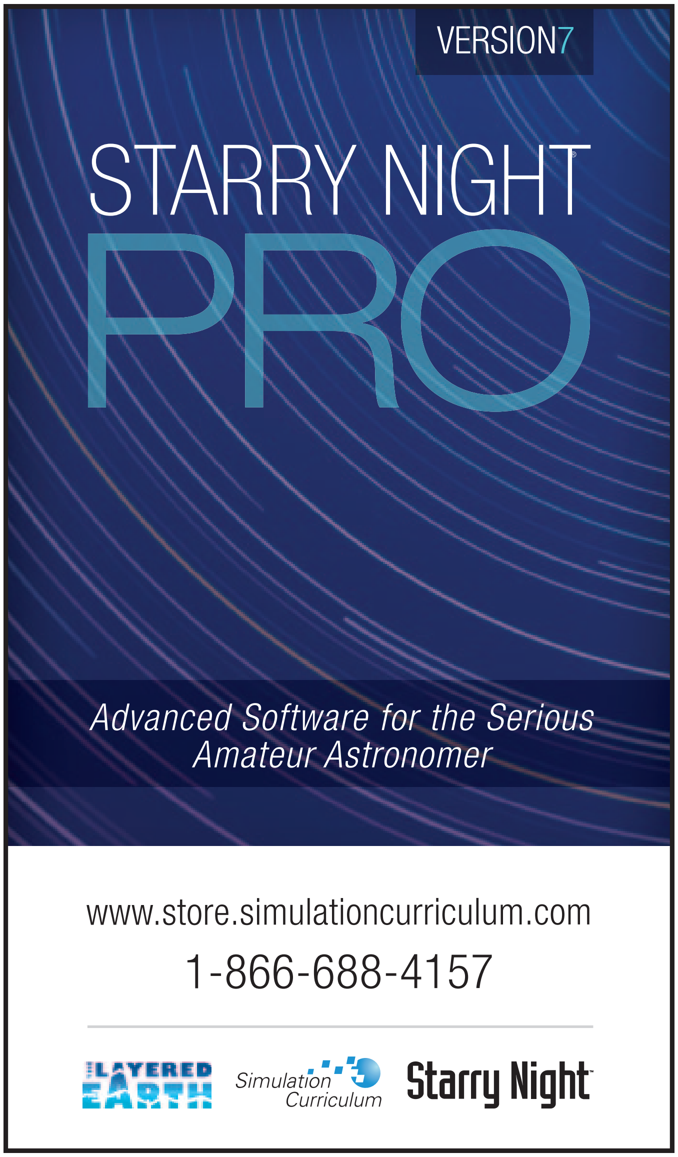


Investigating Exoplanets Using a Ground-Based Telescope

by Mélanie and Emma Seabrook
Toronto Centre

Abstract

There has always been a wishful belief that other planets exist out there, just waiting to be found. However, it was not until 1992 that the first exoplanet was confirmed to exist by Aleksander Wolszezan and Dale Frail. Many methods of detection have arisen since then, such as the transit photometry method. This method is used by spacecraft, but is also possible for astronomers to use on Earth. The depth of the drop in brightness of the parent star during a transit is determined by several factors, such as the parent star's size and magnitude. We have investigated whether or not the size ratio of the exoplanet to the parent star affects its transit depth, and hypothesized that the closer the planet and parent star are in size, the larger the dip in brightness. We collected data on exoplanet transits, and our results do support our hypothesis. However, when we compared our data to the Exoplanet Archive's data, we found that it was slightly different. This shows the importance of experiments like this one; knowledge of the Universe is still limited, and the more information collected about exoplanets, the more exact knowledge of them will be, and the more can be figured out about the conditions on these planets. All of these are steps toward finding habitable planets, and extraterrestrial life.

Question/Proposal

While doing research on exoplanets, we came across an article explaining how scientists can calculate the size of an exoplanet from the dip in brightness that occurs during a transit. We started wondering about how the size of exoplanets in relation to their parent stars might affect the dip in brightness that occurs during a planetary transit. From this, we hypothesized that if the exoplanet is closer in size to its parent star, then the dip in brightness will be larger. To prove our hypothesis, we decided to record planetary transits of four different exoplanets using a 16-inch telescope located in the Sierra Remote Observatories in California. We made sure that the exoplanets had different size ratios so that we could find the trend, if there is one. The size ratios of our exoplanets are 6.6, 9.08, 9.35, and 62.14. If the percentage dip is the largest in the transit of the planet with ratio 6.6 and then gets smaller as the ratios get larger, then our hypothesis will be proven correct. Answering this question would build on other astronomers' research and help develop new techniques of research on exoplanets from Earth.

Research

In 1992, one discovery changed the world of astronomy forever. The first planet outside our Solar System was discovered. Astronomers Aleksander Wolszezan and Dale Frail detected this gas giant orbiting a pulsar using a method called *radial velocity*. Three years later, the first exoplanet orbiting a Sun-like star was discovered by Michel Mayor and Didier Queloz, again using the radial-velocity method. Many new methods have been innovated since then, measuring different aspects of stars to determine whether they host exoplanets, such as gravitational microlensing, direct imaging, and pulsar timing. One method innovated by astronomer Otto Struve in 1952 (40 years before the first exoplanet was even discovered), is called the transit photometry method. At first it was meant to measure variable stars, but it was soon found that stars with regular drops in brightness may be hosting an exoplanet. By measuring these drops in brightness through pictures taken by spacecraft, scientists can determine whether an exoplanet is orbiting the star or not. The method is now used by spacecraft in orbit such as *Kepler*, *CoRoT*, and *Super WASP*. To date, 1,918 exoplanets have been confirmed, many of which were detected by *Kepler*. Thousands more still need to be confirmed. *Kepler* was programmed to take numerous pictures of the same specific area in the constellation Cygnus. Scientists would then collect and analyze the data to identify stars hosting exoplanets. *Kepler* collected so much data that even today astronomers are still looking through it to find new exoplanet candidates.

If so much data can be collected by spacecraft, why collect data from Earth? In order to confirm the accuracy of data, it should be backed up by several different sources, and more specifically several different types of sources (e.g. from space and from Earth). Comparing data from different sources both helps certify the information known about exoplanets, and helps astronomers develop newer, better methods of detection that can be used by both spacecraft and astronomers on Earth.

Information on the four exoplanets we chose to study is found in Table 1.

Facts about the Exoplanets:

HAT-P-36b was discovered in early 2012 through the ground-based HAT-Net project. It was one of the first four exoplanets discovered that year.

WASP-43b is a tidally locked exoplanet. One side is hot enough to melt iron, and the other side is the polar opposite. It was also found that there may be a large amount of water on the planet.

WASP-12b is an exoplanet that is so massive and so close to its parent star that the gravitational pull on the planet coming from its parent star is causing the planet to slowly deteriorate. The deteriorated material is forming a disk around WASP-12 leaving the planet in the shape of a football.

	WASP-43b	WASP-12b	HAT-P-36b	CoRoT-7b
Constellation	Sextans	Auriga	Canis Venatici	Monoceros
Orbit (in days)	0.813	1.09	1.3	0.8
Magnitude of parent star	12.4	11.69	12.26	11.7
Transit Length (in hours)	1.16	2.9	2.2	1.05
Mass (in Jupiter masses)	2.03	1.404	1.832	0.0151
Radius (in Jupiter radii)	1.036	1.736	1.2	0.14
Transit Depth	2.43%	1.189%	1.34%	0.03%

Table 1

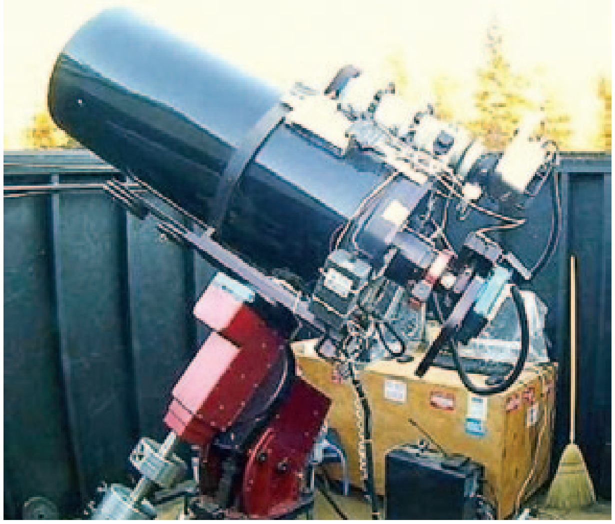


Figure 1 — The RC Optical Systems telescope

CoRoT-7b is a rocky planet that is likely the remains of a gas giant. The planet is tidally locked. Because of this, one side of the planet is so hot that it vapourizes rock, that later condenses causing a rocky rainfall onto the molten lava below.

Methods

Our project is based on measuring how the dip in brightness changes when the variables (exoplanet's and parent star's size) and the difference between the variables change. To ensure that our process was fair, we executed the same procedure for each exoplanet; to remove any bias, we chose exoplanets with a range of size ratios (6.6 to 62.14). This way, we also get a clear and more accurate answer.

Materials

Telescope: RC Optical Systems 0.4m *f*/8.9 (16-inch reflector)

Camera: Santa Barbara Instruments Group STL11000M

Mount: Bisque Paramount ME

Filter: Astrodon NIR (Near infrared)

Location: Sierra Remote Observatories, Auberry, California, USA (http://Sierra-Remote.com)

This is the telescope/camera set-up we used, remotely located at the Sierra Remote Observatories, California.

Software

Maxim-DL (V4): camera control, image calibration, photometric reduction

CCD Commander: automated data acquisition via programmed script

TheSky6: telescope pointing and tracking

Programs

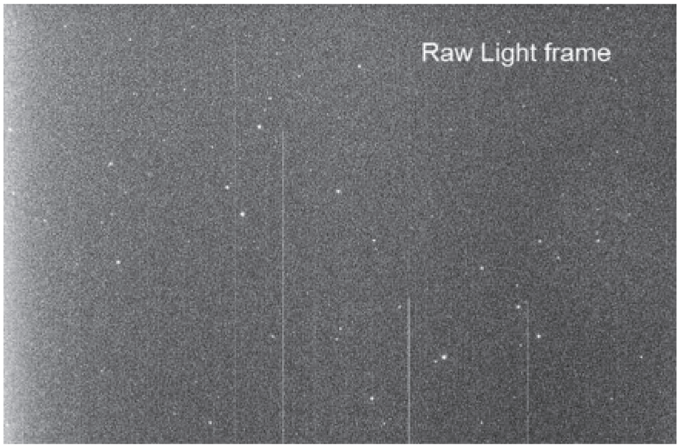
Microsoft Office Excel, NASA Exoplanet Archive, Stellarium

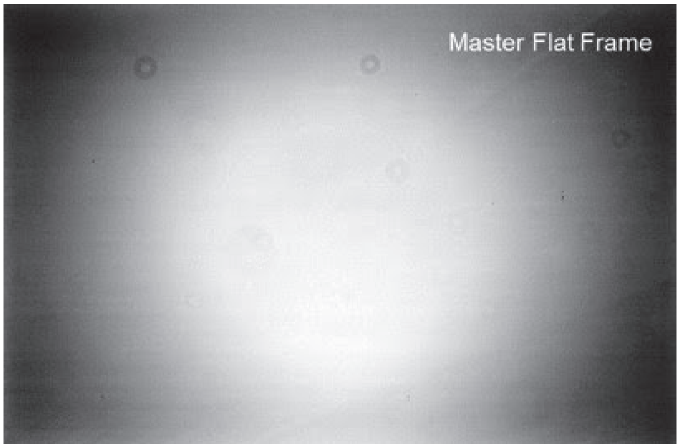
Procedure

1. Set requirements for exoplanets:
   - Minimum 1% transit depth required for the camera to pick up the dip in brightness (except for CoRoT-7b which was the control);
   - Minimum star magnitude of 13 required for the camera to pick up the dip in brightness;
   - Time of start of transit between 3 UT and 7 UT so that it will be dark throughout the transit;
   - Minimum two good transit dates so that (a) if the first transit night is overcast the next one can be used to collect data, and (b) the data can be duplicated.
2. Using Exoplanetarchive.com, create an ephemeris of confirmed exoplanet transits for the specific location (Sierra Remote Observatories, California), and period of time to be able to select exoplanets that meet the previously set requirements.
3. Select exoplanets that meet all requirements and check altitudes in all transits to make sure the stars remain above the horizon throughout each transit.
4. Check that it's clear during the transit night, (no clouds, no dew, low humidity).
5. On the transit night, set the telescope to point and track the selected parent star.
6. Collect images of the star during a four- to six-hour period, (corresponding to the transit).
7. Calibrate the raw light images using Maxim-DL (V4) software, with dark and flat frames.

Dark and flat frames are used to calibrate the raw light frames to correct dust, "column defects," and "hot pixels" from the images.

8. Transfer data to an Excel file to create scatter plots. Reduce data noise using a running average (of 3–6 points).
9. Size all scatter plots to the same scale and compare the transit depths versus size ratios.





Results

For our research project, we selected the following four exoplanets: WASP-43b, WASP-12b, HAT-P-36b and CoRoT-7b, whose transits fulfilled the criteria detailed in the Methods section. CoRoT-7b was used as the control because its transit depth was too small for our telescope to detect. WASP-43b's data was duplicated and showed the same results (data not shown).

After the remote image acquisition and the data processing, we compared the four transits' scatter plots (shown on next page). The x-axis shows the time during the transit, and the y-axis shows the intensity of the star.

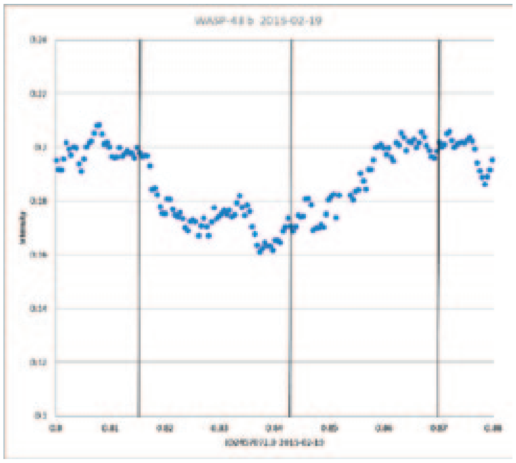
Our results calculated from the data are shown in the table below as well as the star-planet radius ratio and the NASA exoplanet archive data, for each exoplanet:

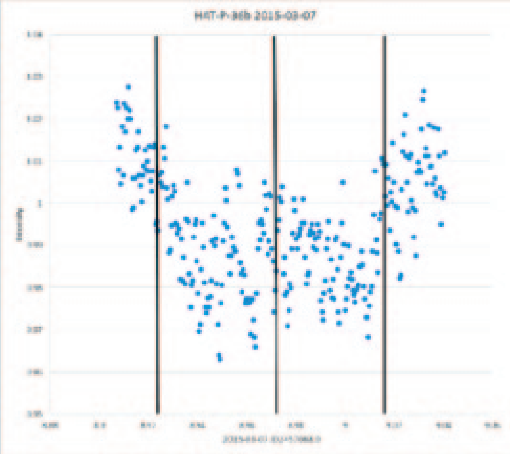
	WASP-12b	**HAT-P-36b**	**WASP-43b**	**CoRoT-7b**
Star-planet Radius Ratio	9.35	9.08	6.6	62.14
Our Data (percentage drop)	2.59%	2.92%	4.9%	no transit detected
NASA Exoplanet Archive Data (percentage drop)	1.189%	1.34%	2.43%	0.03%

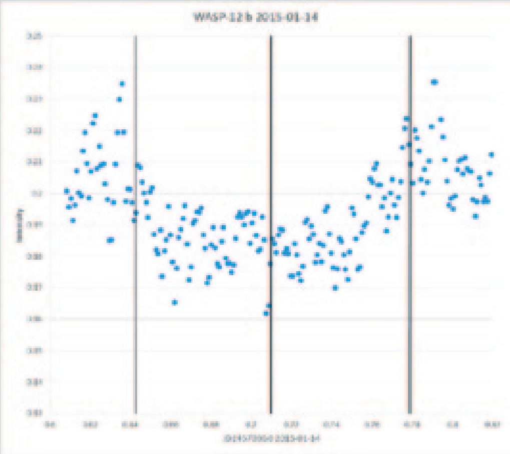
Table 2

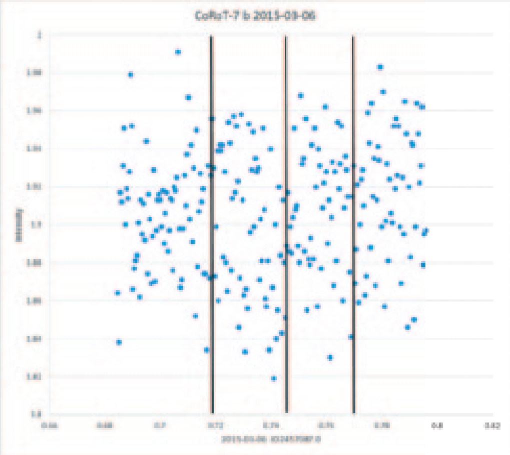
Our results show that WASP-43b has the largest dip (4.9%) while WASP-12b and HAT-P-36b, with close star-planet ratios, have similar dips (2.59% and 2.92% respectively). As expected, CoRoT-7b did not show a measurable dip, since its large star-planet ratio (62.14) renders the dip in brightness too small to be detected by our telescope. However, NASA spacecraft was able to detect a dip of 0.03%.

In the table, we show the NASA Exoplanet Archive's transit depth values of our selected exoplanets. Although there is a difference between our collected data and the data in the archive for the drop percentage, both sets of data are consistent with our hypothesis. In fact, our values differ by a factor of approximately 2.12 for each exoplanet transit depth, which means that our data is consistent. As can be seen in the above table, CoRoT-7b has the greatest ratio and the smallest dip in









brightness. When looking at the other exoplanets, as the ratio gets smaller, the dip in the brightness of the star gets larger, which is coherent with our hypothesis.

Discussion

We were able to collect data and analyze the transits of four exoplanets. Our results show that the size ratio of the parent star to the planet does in fact affect the size of the dip. We proved our hypothesis correct as the exoplanet with the smallest planet-star radius ratio had the largest dip in brightness, and the dips decreased as the ratios increased.

When comparing our data to the NASA Exoplanet Archive's data, we noticed a difference between our drop percentages and theirs. The drop percentages differ by approximately a factor of 2.12 for each transit depth. The difference in values could be due to the following reasons:

1. Since we are measuring a very small dip in the brightness of a star, the error on the values is larger. We could reduce the error by recording more transits of each exoplanet.
2. NASA uses pictures of the star taken from outer space, whereas we are taking pictures from the surface of Earth. On Earth, we have weather and atmospheric conditions that affect our data.

However, this comparison did spark a question that could be turned into a new project: How does the atmosphere affect our images, and is it a consistent factor? Answering this question could help astronomers make corrections to their data, if necessary.

When creating the scatter plots, we noticed that WASP-43b's transit ended earlier than predicted on the exoplanet database. Further investigations might reveal why this occurred. It is possible that there is an unknown exoplanet in the system affecting the orbit of WASP-43b since the data was collected by NASA. There were also spikes right at the bottom of WASP-43b and HAT-P-36b's drops. Further research would be necessary to reveal what caused these spikes. They may be caused by moons orbiting these planets or even something in their atmospheres that could block out light from their parent stars. However, we would first need to duplicate our measurements to make sure they are recurring before being able to determine what is causing them.

In future, we may also record the transits for a more varied range of exoplanets, such as ones that have larger orbits. This would allow us to compare the effect that the orbit size has on the dip in brightness of the parent star to the effect of the size ratio that we investigated in this project.

Conclusion

The fact that we were able to record exoplanet transits using a relatively small telescope (16-inch) from Earth, really shows the advances that have taken place in astronomy (camera and telescope) in recent years. The amateur astronomical community is growing rapidly and can perform more and more astronomical research using relatively inexpensive equipment from their own backyards. ✶

Mélanie is in Grade 11 and Emma, her sister, is in Grade 9, both in the Advanced Placement Program at Thornlea Secondary School in Thornhill, Ontario.

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Acknowledgements

We would like to thank our mentor, Paul Mortfield, for supporting us throughout the duration of this project and for allowing us to make use of his telescope in California to compile our research. Thank you to our Mom for her encouragements.

On the Rightful Identity of a Well-known Solar System Object

by Andrew Oakes
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With the close flyby of Pluto in July 2015, the public's attention refocused for a short period on NASA's *New Horizons* probe as it flew past a most distant Solar System world, recoding information of the until-then uncharted object. The data collected from the probe will provide Solar System experts with years of useful telemetry that will help reveal the true nature of *New Horizon*'s main scientific target.

As the timing would have it, the probe's flyby brought to mind a previous incident where Pluto had become a centre of worldwide attention. This earlier event, as a result, has provided historians of science with a thought-provoking episode to study in astronomy—in this case the recent dispute concerning the rapid demotion of Pluto. From its secure, multi-decade status as a full-fledged planet within our home Solar System, the International Astronomical Union (IAU) in 2006 withdrew that security and redefined Pluto as dwarf planet 134340 Pluto[1]. This action was not a sudden one. It was built on a combination of events (or pressure-points) that accumulated over time. What came to a head in this specific episode was the convergence of several key elements: the steady progression of the ancient-to-modern history of astronomy; the advancement of observational technologies; the making of new knowledge resulting from Solar System discoveries; the need to challenge established tradition to secure terminological accuracy, irrespective of the short-term impact on public or scientific community sentimental preferences; and an acceptance of the steady evolution of scientific reality regarding what is known about our Sun's expanded family of objects found within its gravitational sphere of influence. An additional pressure, which would not have been present before the mid-1990s, was the emerging existence of extra-solar planets within other distant star systems.

Change—scientific and otherwise—is with us constantly, whether we like it or not. It is unavoidable as the march of science brings with it new conceptions requiring, from time to time, the discarding of old notions whenever they are found to no longer apply to the observed reality. In a sense, here we see the playing out of a well-known truism that Thomas Kuhn[2] referred to in 1959: "…a scientific discovery must fit the times, or the time must be ripe."[3] In this case, the appropriate time was the summer of 2006, which was indeed ripe to redefine Pluto's planetary status. Ongoing scientific discovery in the late 20th and early 21st centuries now demanded an adjustment in Solar System nomenclature as it applied to Pluto and a series of new trans-Neptunian objects. In the end, observational truth backed by hard scientific data trumped public sympathies and tradition when it came to Pluto.

Let us now briefly look at some of the developments in astronomy that led to what can only be concluded as a logical decision, despite public outrage and some scientific community disagreement in the demotion of Pluto's status from being the Sun's ninth planet.

First, since early antiquity, moving celestial bodies were considered wanderers in our celestial sphere. Not surprisingly, the specific set of attributes applied to these wanderers "has changed several times over recorded history."[4] With time the wanderer concept was refined specifically to categorize the then-five visible planets—Mercury, Venus, Mars, Jupiter, and Saturn. Once a heliocentric model was adopted as our Solar System's structure, the Earth joined the ranks as planet number six. Uranus (discovered in 1781) became number seven; Neptune (discovered in 1846), number eight. It should be noted parenthetically that the Sun and the Moon were themselves removed from the very original list of seven wanderers (planets) in antiquity. Therefore, the nomenclature adjustments and reconfiguration of the Solar System have been well underway over the many centuries before Pluto's demise in 2006.

Second, in the 19th and 20th centuries, the human psyche was predisposed to look for more planets, given that "the orbital motion of Uranus was not totally explained by the presence of Neptune."[5] The story of Neptune's discovery was now repeating itself due to the perceived anomaly. The belief that a Planet X (the name Lowell gave the unknown member of the Solar System[6]) existed beyond Neptune was strong and resulted in four extended search attempts. These were conducted beginning in 1905, 1909, 1914, and 1929 at the privately built Lowell Observatory near Flagstaff, Arizona. Furthermore, other astronomers had commented over a span of 35 years on the possible existence of a trans-Neptunian planet. These included S. Newcomb in 1874, Camille Flammarion in 1879, G. Forbes in 1880, D.C. Todd in 1880, and later M.A. Gaillot in 1909[7], and W.H. Pickering in 1909. As fate would have it, the discovery of Pluto was left to the Lowell Observatory with Clyde Tombaugh at the telescope and operating the Zeiss Blink Comparator. David Levy, of Comet Shoemaker-Levy 9 fame and the biographer of Clyde Tombaugh, described the Lowell Observatory's success as follows: "The discovery [of Pluto] was the climax of their long search sired by [Percival] Lowell, encouraged by [Roger Lowell] Putnam, organized by V.M. Slipher, assisted by E.C. Slipher and Carl Lampland, and concluded by Tombaugh."[8] The point being made here is that sympathetic astronomers and fellow travellers expected to hear of a new planet beyond Neptune, given their experience with Uranus and its orbital idiosyncrasies. As well, the Lowell Observatory search programs had deeply set in its goals the finding of a new planet. When Tombaugh discovered Pluto in early 1930, it was easily declared a planet, despite being seen at 15th magnitude, or "unexpectedly faint,"[9] rather than the predicted 12th magnitude. It would be almost five decades before the actual size of Pluto could be confirmed, a critical point in concluding how it fit among the family of planets. Determination of size required the discovery of Pluto's moon, Charon, in 1978, which was not good news for Pluto.

Third, since the 16th century, the making of new knowledge concerning our Solar System had been slowly progressing with the improvement of non-optical instrumentation in Tycho Brahe's time and, later, the introduction of the telescope, starting with Galileo in 1609. Subsequently, significant leaps took place in the 18th, 19th, and 20th centuries, resulting in Solar System discoveries of an unprecedented nature. Telescopic designs, both refractor and reflector, were improved; lens apertures and mirror sizes were pushed to the limit; photographic plates were replaced by fast light-gathering digital cameras; spectroscopic instrumentation was brought into use; radio telescopes were introduced and space telescopes were launched into orbit; robotic space missions were sent throughout the Solar System to visit our closest neighbours, whether planet, comet, asteroid, or planetary satellite in nature. We are currently in the Golden Age of Solar System exploration, which began in 1959 with Luna 2 impacting the Moon, and continues to this day with the soft landing of Rosetta/Philae on comet 67P/Churyumov-Gerasimenko on 2014 November 12.[10] It is therefore not surprising, when astronomers look at our much expanded Solar System family, that classification adjustments are needed of discovered objects. And this is where the reclassification episode of Pluto has come into play.

With the discovery of the Kuiper belt in 1992, astronomers have now located more than 100,000 Kuiper-belt objects over 100 km in diameter. This region of the Solar System extends from the orbit of Neptune at 30 astronomical units (AU) outward to about 50 AU from the Sun. The significance cannot be missed that Pluto is located in the Kuiper Belt. Pluto is 2390 km in diameter, only twice that of its largest moon, Charon, at 1212 km.[11]

As early as the mid-1990s, planetary astronomers began to question Pluto's status seriously. Brian Marsden, the

Continues on page 24

Pen & Pixel

Figure 1 — Klaus Brasch took this mosaic of 16 separate one-minute exposures with a 135-mm ƒ/4 lens shooting at ISO 6400 with a Canon 6D full-frame DSLR and an IDAS LPS-V4 filter. Frames were stacked and processed in Adobe Photoshop CS6. Brasch says, "Sky conditions were exceptionally clear and transparent from my backyard observatory in Flagstaff, Arizona."

Figure 2 — Ron Brecher took this image of the Spider Nebula (IC 417) using SBIG STL-11000M camera, Baader Hα, R, G, and B filters, 10″ ASA astrograph operating at ƒ/6.8, and a Paramount MX. It was guided with QHY5 guider and 80-mm ƒ/6 Stellar-Vue refractor. The image was processed using DBE and ColorCalibration, along with PixelMath.

Figure 3 — The International Space Station photobombed Malcolm Park's shot of the aurora borealis. Park took the photograph at the RASC North Frontenac Dark Sky observing area.

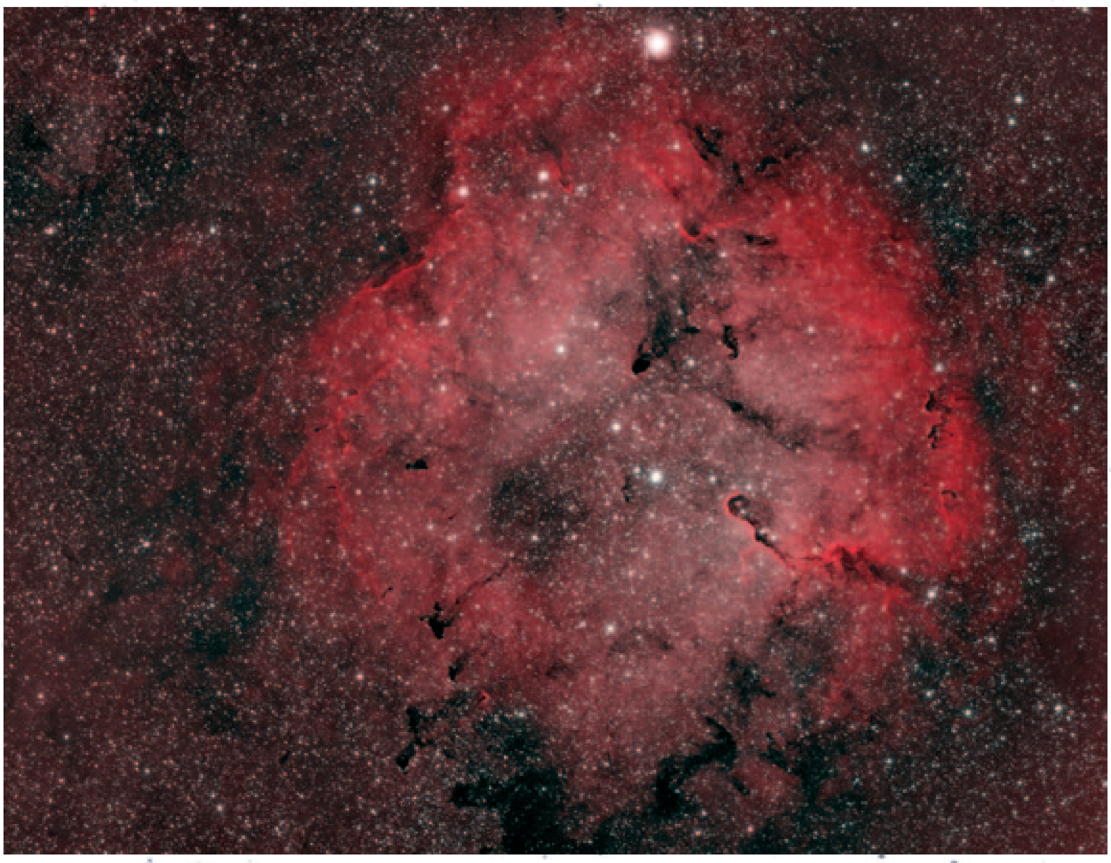

Figure 4 — Dalton Wilson took this image of Sh 2-131 (IC 1396), commonly referred to as the Elephant Trunk Nebula from Didsbury, Alberta. Wilson used an Atik 460exm and a Canon 200mm on a Mesu 200 mount. Exposure was 9×900 sec. in Hα/OIII.

Continued from page 21

then-director of the IAU's Central Bureau for Astronomical Telegrams and the Minor Planet Center, proposed a dual designation for Pluto in 1998. He suggested Pluto be viewed as both a planet and a minor planet. At the time, Marsden noted: "If Pluto were discovered today instead of 70 years ago, it would be considered a minor planet and given a minor planet number."[12] This idea of dual designation was not popular. However, Solar System astronomers increasingly believed it was incorrect to classify Pluto as a planet, as it fit better with the description of other Kuiper-belt objects. To correct this misnaming, the IAU after review and discussion moved forward to reclassify Pluto as a dwarf planet—134340 Pluto now joins such Solar System bodies as dwarf planets 1 Ceres, 136199 Eris, 136108 Haumea, and 136472 Makemake[13], the latter three within the Kuiper belt.

The Pluto episode shows that Earthlings must not become too attached to scientific nomenclature, as advancements in Solar System research may bring surprises that will require redefinitions of already known objects. In the pursuit of accuracy and data integrity, such classification refinements are an ongoing process that is good for science generally and Solar System astronomy specifically. ✶

Andrew Oakes is a Contributing Editor to the Journal.

Endnotes

[1] David M.F. Chapman (Editor). *Observer's Handbook 2015*. The Royal Astronomical Society of Canada, Webcom Inc., p. 241.

[2] An American physicist, historian and philosopher of science (1922–1996).

[3] Thomas Kuhn. "Energy Conservation as an Example of Simultaneous Discovery." Marshall Clagett, Editor. (1959) *Critical Problems in the History of Science*. University of Wisconsin Press, Madison, Wisconsin, p. 312.

[4] Barrie Jones (2010). Pluto–*Sentinel of the Outer Solar System*. Cambridge University Press, Cambridge, UK, p. 171.

[5] David H. Levy. (1991). *Clyde Tombaugh – Discoverer of Planet Pluto*. University of Arizona Press, Tucson, p. 35.

[6] A.J. Whyte. (1980). *The Planet Pluto*. Pergamon Press, Willowdale, Ontario, p. 25.

[7] Ibid, p. 19-23.

[8] Levy, p. 63.

[9] Helen Sawyer Hogg. (1976). *The Stars Belong To Everyone – How to Enjoy Astronomy*. Doubleday Canada Limited, Toronto, Ontario, p. 145.

[10] Chapman, p. 36-37.

[11] Ibid., p. 242,

[12] Steven J.D. Dick. (2013). *Discovery and Classification in Astronomy Controversy and Consensus*. Cambridge University Press, Cambridge, UK, p. 18.

[13] Chapman, p. 241.

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The Royal Astronomical Society of Canada

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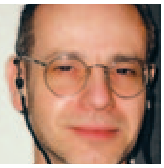

by R.A. Rosenfeld, RASC Archivist
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Abstract

The popularity of practices in amateur astronomy is variable. One such practice, the making of amateur astronomical poetry, was very much part of the amateur landscape in North America a century ago. Now it is largely forgotten. What were the characteristics of this material?

Verse can be respectable…

Poetry has provided a medium of communication for astronomical matter for a very long time. In Greco-Roman antiquity it was neither aberrant, nor strange to clothe technical matter in poetry—quite the opposite, in fact. Eratosthenes of Cyrene (*ca.* 274 BC–194 BC), Hyginus (late first BC?), and Aratus of Soli (late 4th-century BC–pre-240 BC), among others, laid out celestial maps in poetry, which are key sources for ancient topographies of the heavens, and their transmission (Ératosthène de Cyrène 2013; Hygin 1983; Aratos 2002). The option of conveying science through poetry endured in the republic of letters, of which astronomy was an integral part. The latest significant astronomical work in verse by a prominent astronomer of which I am aware is the virtuoso *tour de force* on eclipses by fr. Roger Boscovich, s.j. (1711–1787), an up-to-date exposition of the phenomena in thousands of Latin hexameters (Boscovich 1760). It has been acknowledged for centuries that casting technical material in poetic form can improve the efficiency of its recall.[1]

The epochs in our "culture" during which important astronomers and natural philosophers wrote poetry, and notable poets handled the stuff of science are of greater duration than the episodes in which poetry and science were seen as immiscible. This should cause little surprise, for the educated received instruction in the trivial arts of communication, as well the quadrivial arts of quantification, at least up to the time of Charles Darwin, and John Herschel.[2]

It seems that there have always been serious, technically assured, and inventive poets willing to write about astronomy. Maurice Riordan and Dame Jocelyn Bell Burnell have produced an attractive anthology of some of that work (2008), as has David Levy (2001).

Amateurs' night out, and not in a good way...

Reckoned by the quantity of surviving poetry in the "western" tradition, the interval spanning the advent of Romanticism in the latter eighteenth century up to World War II dominates elite cultural production as found in more conservative canons of English poetry.[3] The period from the RASC's origin up to World War I, and the following period to *ca.* 1950, overlapped with a particular efflorescence of popular poetry, inspired in part by the work of celebrated major poets. A subset of the production of popular poetry was devoted to astronomical themes, and most of it would now be considered sentimental, amateurish, and technically inept. It was largely written by amateur astronomers. Read now, the poetry can provide much unintended entertainment at the expense of its creators, and their art. Popular astronomical publications of the time were quite willing to publish that poetry, conferring on its authors a degree of undeserved immortality, which might seem a wonder of that age viewed in retrospect.

Space does not permit a thorough examination of the phenomenon, but it can be explored a little in two publications.

Popular Astronomy (*PA*), issued from 1893–1951 out of the Carleton College Department of Astronomy and the Goodsell Observatory (MN), was arguably the most significant popular astronomy journal ever to have arisen in North America. In addition to its function informing (and forming) the amateur community, it served as a "trade journal" for the nascent American professional community, and an "unofficial journal" of the American Astronomical Society (Marché 2005). *Sky and Telescope*, its one-time younger rival (1941–), while it moved into the vacuum created by *PA*'s demise, never entirely succeeded in filling the space it had occupied.

The earliest substantial poem did not appear in the pages of *PA* till over a decade after its founding. The verse was published in a note by Eugene Fairfield McPike, the notable editor of 17th-century astronomical texts, and is entitled "On Halley's Comet, in 1835" (McPike 1904). It was written in Haworth by one "P. Bronte", that is, by either the Rev'd Patrick Brontë (1777–1861), or his son, Patrick Branwell Brontë (1817–1848). Astonishingly, McPike does not acknowledge that the poet was either Charlotte Brontë's father, or brother:

> Our blazing guest, long have you been,
> To us, and many more, unseen;
> Full seventy years have pass'd away
> Since last we saw you, fresh and gay– [571, ls. 1–4]

And so it continues without any sign of improvement for over 100 lines, showing nothing more than clichéd engagement with the celestial event.

Praise and awe was also directed to those who studied the stars. At a 1905 post-retirement event for the dean of

American solar physicists, Charles Young (1834–1908) of Princeton, a poem in his honour, *Stars and the Soul*, was read:

> "Two things," the wise man said, "fill me with awe:
> "The starry heavens and the moral law."
> Nay add another marvel to thy scroll,–
> The living marvel of the human soul.
>
> Born in the dust and cradled in the dark,
> It feels the fire of an immortal spark,
> And learns to read, with patent, fearless eyes,
> The splendid secret of the unconscious skies…
> [Poor 1908, 220–221]

The author was Henry Van Dyke (1852–1933), one of Young's colleagues at Princeton. He was professor of English literature at the time.

Charles Skeele Palmer (1858–1939), mining chemist and sometime meteoriticist, wrote "Master of Machines" in praise of the amateur astronomer, mechanical engineer, and premier designer of OTAs, mounts, and enclosures, Ambrose Swasey (1846–1937):

> As man has slowly risen from the soil
> To gaze at stars and all of Heaven's host,
> And turns from daily struggle with his toil
> To guess how great the Whole in which Earth's lost;
> As history shows ancient worthies' worth
> And justly honors all their ways and means,
> So modern heroes claim our loyal faith
> In poets, statesmen, masters of machines.
> With Alvan Clark, and "Uncle John" Brashear,
> And Worcester Warner's art celestial,
> Join Ambrose Swasey,—an immortal group—,
> "Trapezium" of stars terrestrial.
> All honor to the eyes that watch the skies;
> But doubly honor those who help those eyes.
> [Palmer 1935]

Can honour truly be paid with false rhymes (host/lost, worth/faith), clumsy assonance ("worthies' worth"), and uncalculated puns ("To guess how great the W**hole** in which Earth's lost")?

A short poem by RASC honorary member Edward Emerson Barnard (1857–1923) is an exception. *True Greatness* dates from 1880, when Barnard was still a developing amateur, and predates his first comet discovery:

> See yon star of silv'ry ray;
> How at dawn it fades away!
> But the night will bring anew
> All its light of silver hue.
>
> Thus may deeds of greatness cease
> At the dawn of gentle peace,
> But the nights of strife and pain
> Brings their lustre back again! [Barnard 1918]

It works because it has a single unifying literary conceit, that for the person who critically observes clear nights bring work (observational "deeds of greatness" achieved through "strife and pain"), but that for the observer purposeful seeing also conceptually gives the stars their "lustre." The poem avoids sentimentality, presents a truth about the observing process in the slightly archaizing poetic diction of the period but avoids all excess, and the implied relationship of observer and objects is unusual enough to be memorable. Surprisingly little of the astronomical poetry produced during the period reflects real observing experiences.

Other poems appear *in memoriam*, or as the mildest of satires, or as light treatments of physical constants or dimensions (e.g. Meeser 1932; W.W. 1948; Farwell 1951). And the poems continue, right up to the unexpected demise of the magazine.

What of the RASC?

Somewhat against expectation, the *Transactions of the Astronomical and Physical Society of Toronto* (1890–1899), and the *Transactions of the Toronto Astronomical Society* (1900–1901) contain no poetry written by amateur astronomers. That distinction had to await the transformation of the *TAPST* and *TTAS* into the present *Journal*.

Dr. Albert D. Watson (1859–1926), a Toronto medical practitioner and amateur astronomer, succeeded J.S. Plaskett to become the 12th RASC President, in 1916–1917. He was also the worst serial offender among the RASC poets. Watson clearly considered himself a significant poet who could publicly exercise the craft, and practice criticism (Watson 1922a; Watson 1922b).

In his *Copernicus: a Monologue*, we find Watson's Copernicus boasting:

> So shall the key that I shall give to men
> Unlock the golden gateway of the skies,
> And make my word a pilot through the deep,
> So that in coming days a child shall know
> The seas of light that float above the world
> [Watson 1913, 37]

It is hard to imagine Copernicus envisioning *De revolutionibus* as an apposite text for teaching children anything about photons.

Watson's last contribution to the *Journal* is, not surprisingly, a poem. The *Dawn of Night (on Mount Hamilton)* is fairly representative:

> Now swings our mighty circle up the sky—
> The great equator climbing to the Sun
> That shrills in voice of flame: "The day is done!"
> Across yon darkening sea—vapours that lie

> O'er Santa Clara's vale—our Pisgah eye
> Discerns the day's eclipse. [Watson 1923, ls. 1–7]

Can the Sun ever be heard metaphorically as a body which "shrills in voice of flame," and what has a biblical mountain to do with any of this?

The year after his RASC Presidency, Watson turned more of his energies to his séances and other psychical "research," becoming in time President of the Association for Psychical Research of Canada. Perhaps it was for the best.

Assigning merit to poetry is often seen as a matter of personal taste mediated through experience. There is another way to look at popular poetry—it can be considered not as good or bad, to be admitted into a canon or not, but rather as particular practices manifesting a culture, operating as a means of communication, and facilitating social discourse (Chasar 2007). Used to reconstruct, or explore networks of individuals or communities, or to discover their views or reveal their attitudes, even the most trite and dire expressions can have value for writing the histories of social things, like astronomy groups and their reactions to celestial phenomena. Yet another aspect to weigh is that the technically poor, overly sentimental, and cliché ridden astronomical poetry of a century ago presumably meant something to its authors, and their audiences. Truly discovering the range of significances might prove challenging.

Poetry now rarely appears in the *Journal*, or elsewhere in print in the astronomical world, even in more popular publications. Are the successors of the amateurs who at one time would have written astronomy poems now submitting digital astrophotos in their stead? ✶

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Endnotes

1 As Kozodoy 2011, 217–219, 224 observes when discussing medical poems, including the astronomical poem "Be-šem 'el 'ašer 'amar" by Abraham Ibn Ezra (*ca*. 1089– *ca*.1167), 238–241.

2 Elshtain 2010 has interesting things to say about Darwin's use of poetry in his scientific notebooks, and Higgins 2011 traces the mutual influence of geology on poetry and poetry on geology in the formative period 1790–1860. It becomes clear that many serious natural philosophers, naturalists, and later scientists, found poetic techniques and poetic expression useful and necessary in their work, and that the best poets were considered capable of conveying the truth of science at that time.

3 Even in the more "enlightened" current edition of the Norton Anthology—affirmatively including varieties of modern post-Romanticism, and giving voice to those who do not fit the profile of the majority of RASC members— the 1770–1950 period outruns all periods but 1950–*ca*. 2000 in page count, and poets represented; Ferguson et al. 2004.

Binary Universe

Where are We Now?

by Blake Nancarrow, Toronto Centre
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Where are we? Where are we in space? In our galaxy? In the Universe? I wondered these things at a young age and tried to figure things out. I remember in the late 1970s trying to visually represent where we were in space. With my Texas Instruments calculator and architectural rulers, I tried making a drawing of the nearby stars but quickly discovered I'd need a bigger piece of paper. I altered the scale and still was only able to fit a handful of stars.

I also grew disappointed with the limitations of a two-dimensional illustration at representing the local group of galaxies. I knew they must be above and below, all around us. Of course, then, we did not have ready access to microcomputers and inexpensive three-dimensional rendering software.

Maybe that is why I like the little application called Where is M13? so much. WIM is a simple, free, and fun app. It allows the user to select and plot an object on the graphical display, showing where the object is in relation to the Sun. This gives a strong sense of where we are and where the designated object is in 3-dimensional space.

On starting the application for the first time, we are presented with the Galaxy View and the sortable list of objects in the Messier catalogue. The zoomable dual-pane Galaxy View shows a top-down rendering of the Milky Way in the left panel and side view in the right panel (see Figure 1). The "you are here" marker is the orange circle. With M13 (or NGC 6205) selected in the bottom panel, we see the globular cluster visually shown at the 2 o'clock position (relative to our Sun) as we fly over the galaxy (or at galactic longitude 59°) and above the plane of the galaxy (galactic latitude 41°).

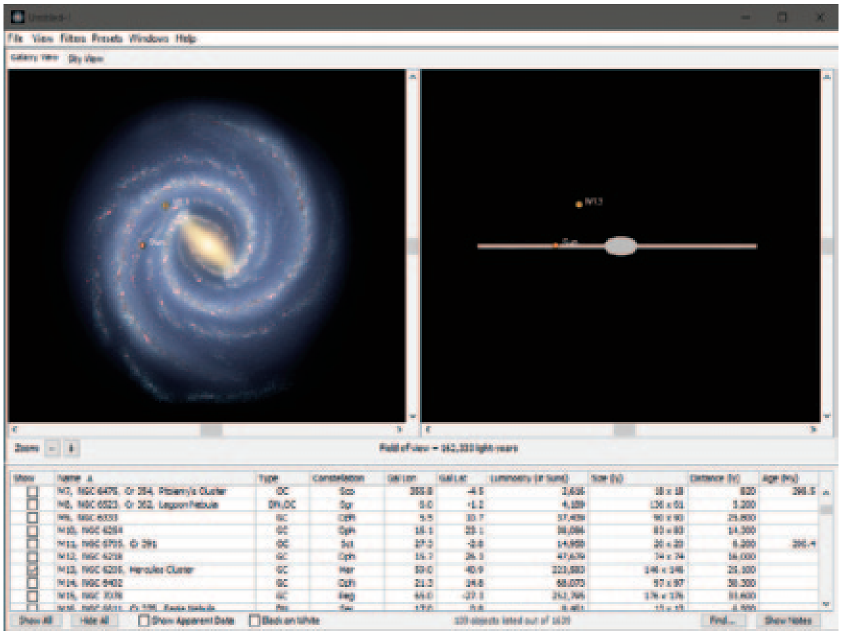


Figure — 1 Galaxy View, with two perspectives of the Milky Way, Messier 13 selected.

Clicking an object in the list circles the target in the visual display. Alternatively, you can click on a marker in the display and it will highlight the object in the list below.

If you select an object that does not fit in the panel at the current zoom level, a line will appear in the dual displays pointing the way.

Another view is available in the program (see Figure 2). It displays objects in a way that we're familiar with: a classic chart, reminding us of the constellation that hosts the objects. Of course, given the cylindrical projection, there is significant distortion at the top and bottom edges. Regardless, it is helpful when considering targets on a particular evening or to get a sense of the distribution of items in a particular catalogue. Look closely: the grid is galactic, not equatorial.

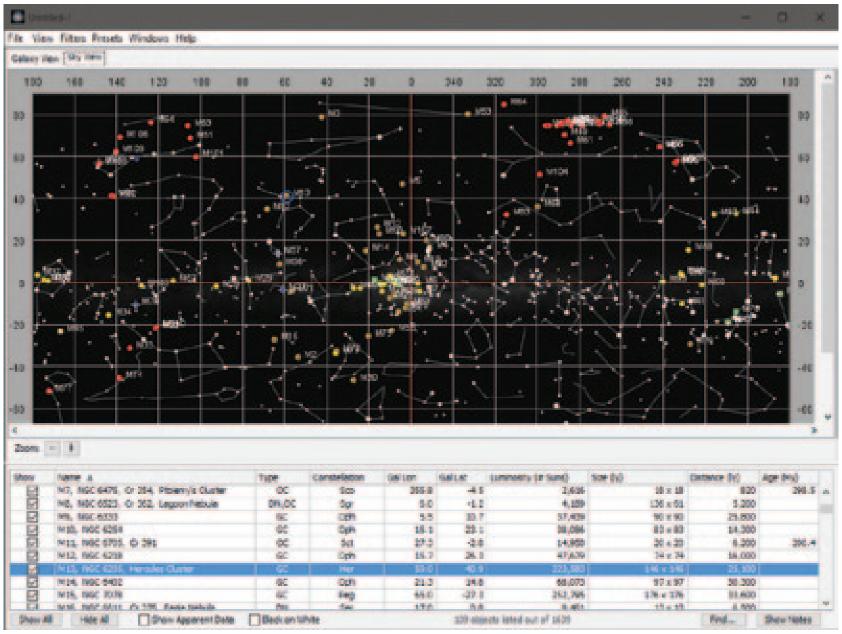


Figure 2 — Sky View, galactic grid enabled, with all the Messier catalogue objects selected.

The searchable tabular pane at the bottom of the screen shows detailed information for objects. In the "galaxy" mode, it lists objects by name with a type, the host constellation, the distance and actual size, if applicable. The Apparent Data mode reveals the RA and Dec, magnitude, and apparent angular size.

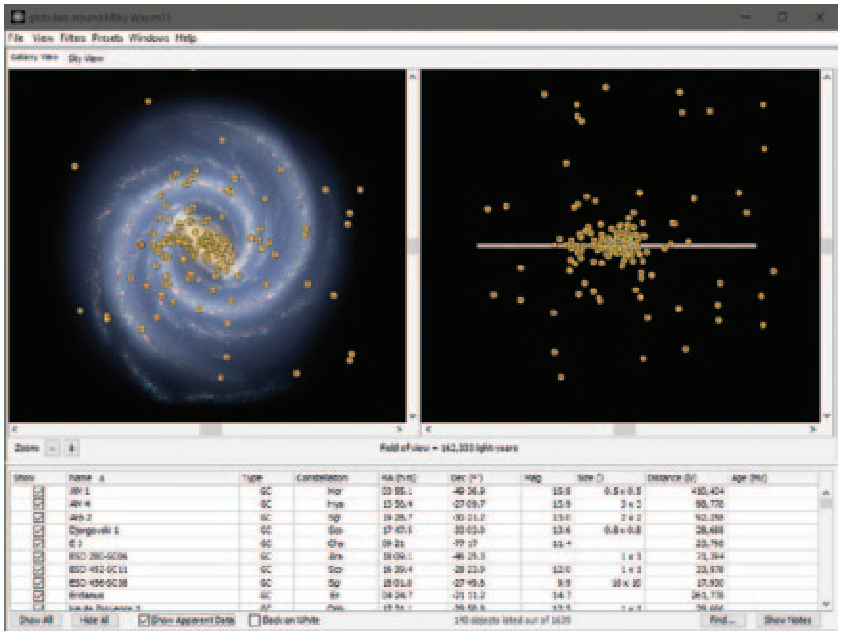
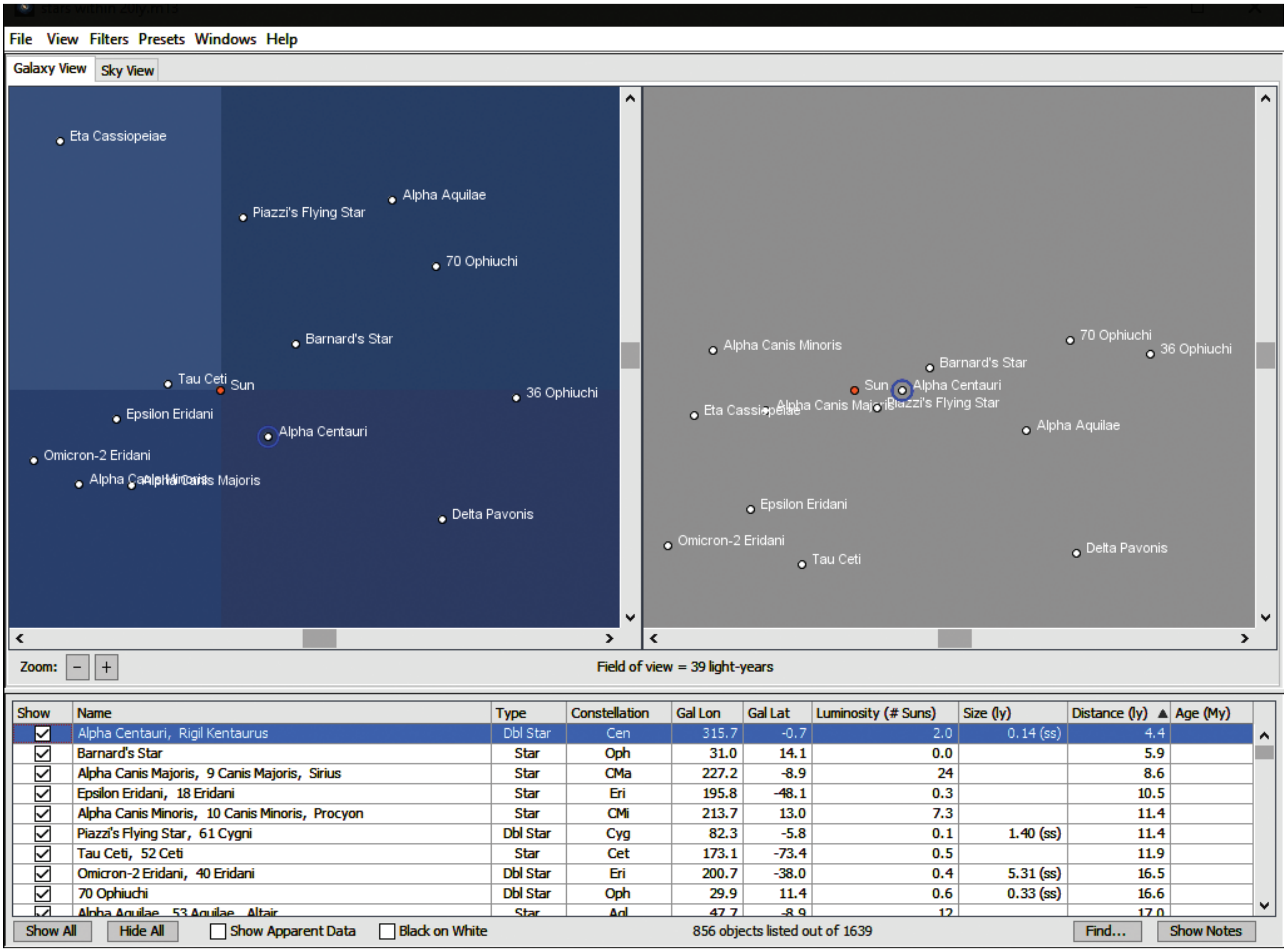


Figure 3 — Globular clusters buzzing around the galaxy, apparent data listed.

The software tool is not limited to the Messier catalogue; it has deep-sky objects from the NGC (and IC), Caldwell, and Collinder catalogues. WIM has over 1600 objects in its database. That's not a lot compared to other astronomy apps but it contains objects for which we have good distance data. The Filters menu allows one to select the preferred catalogue and then to further restrict the type of object.

During a summer evening while at the Carr Astronomical Observatory, a discussion began on globular clusters. One person was unclear where the globulars were, in general. I stated most were outside the disk of the galaxy, either above or below, but still members of our galaxy. That brief verbal description did not click for them. So I launched WIM, set the filters, and showed them. Like bees about the hive (see Figure 3), the edge-on view clearly showed that globulars lie within the sphere or halo of our galaxy. You too might find WIM very useful at star parties and outreach events.



Field of view = 39 light-years

Show	Name	Type	Constellation	Gal Lon	Gal Lat	Luminosity (# Suns)	Size (ly)	Distance (ly) ▲	Age (My)
☑	Alpha Centauri, Rigil Kentaurus	Dbl Star	Cen	315.7	-0.7	2.0	0.14 (ss)	4.4	
☑	Barnard's Star	Star	Oph	31.0	14.1	0.0		5.9	
☑	Alpha Canis Majoris, 9 Canis Majoris, Sirius	Star	CMa	227.2	-8.9	24		8.6	
☑	Epsilon Eridani, 18 Eridani	Star	Eri	195.8	-48.1	0.3		10.5	
☑	Alpha Canis Minoris, 10 Canis Minoris, Procyon	Star	CMi	213.7	13.0	7.3		11.4	
☑	Piazzi's Flying Star, 61 Cygni	Dbl Star	Cyg	82.3	-5.8	0.1	1.40 (ss)	11.4	
☑	Tau Ceti, 52 Ceti	Star	Cet	173.1	-73.4	0.5		11.9	
☑	Omicron-2 Eridani, 40 Eridani	Dbl Star	Eri	200.7	-38.0	0.4	5.31 (ss)	16.5	
☑	70 Ophiuchi	Dbl Star	Oph	29.9	11.4	0.6	0.33 (ss)	16.6	
☑	Alpha Aquilae, 53 Aquilae, Altair	Star	Aql	47.7	-8.9	12		17.0	

☐ Show Apparent Data ☐ Black on White

856 objects listed out of 1639

Figure 4 — Galaxy View zoomed in tight to 20 light-years showing neighbouring star systems.

The Filters menu also has two stellar catalogues. With this, we can label nearby or distant stars. Of course, we need to zoom in considerably to see stars in our neighbourhood (see Figure 4). The proper names of stars can be shown using a setting in the View menu. It is easy now to have a sense of our notable neighbour planetary systems in 3D, without struggling with a paper diagram. It also gives a greater sense of stellar luminosity. We know Rigel and Betelgeuse appear equally bright. WIM reminds us that Rigel is over twice the distance but makes up for those light-years with the brightness of 48,000 Suns.

Preset filtered views exist in the application, including the Local Group of galaxies (see Figure 5) with little red ovals, young or old open clusters with yellow dots, and our galaxy with the spiral arms labelled. The constellation presets are rather interesting in that they show some of the single and double stars that make up the stick-figure pattern in the sky, reminding us that stars are proximal or distal, some are in the foreground while some form the background. Where are diffuse nebulae (green squares)? Happily, the user of the program can create custom views, with comments, and save them for future reference. I made one (see Figure 6) for the planetary nebulae (blue dots). Wow. Look at all those old, tired stars. Presets automatically open in a separate window. In fact, the separate windows feature is useful in various ways.

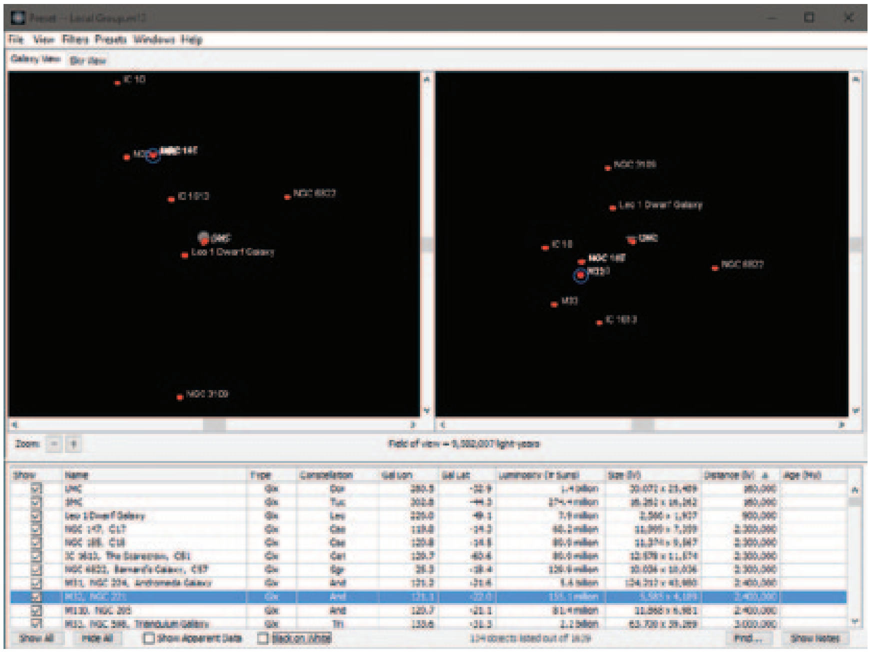


Figure 5 — A Galaxies preset showing members of The Local Group, including M31 and M33.

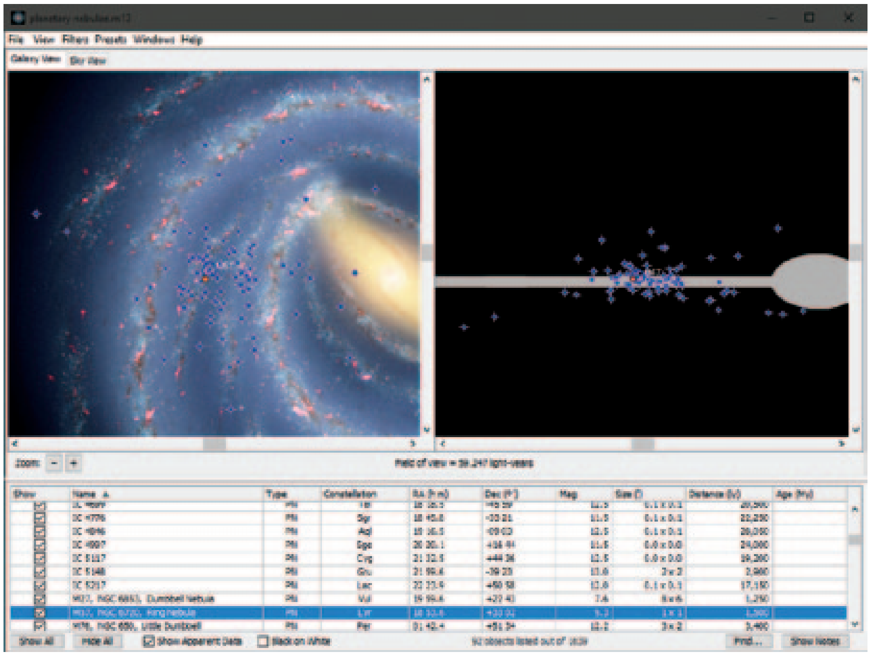


Figure 6 — A custom list emphasizing the extraordinary number of nearby planetary nebulae.

I have one complaint: I cannot display a galactic coordinate grid in the Galaxy View. And there are a couple of minor issues: first, the program does not offer a red-light mode (although it does have a Dark Theme); second,an image or photograph can be displayed, but they are not high quality or zoomable.

It's easy to forget that space is not flat. The celestial sphere that we use, on software displays or paper charts, are constructs, ways of representing what we see. But space is not two-dimensional. "The map is not the territory," a friend would regularly remind me. The stars and galaxies and planetary nebulae and open clusters and globulars and Magellanic Clouds are not painted on the inside of a sphere that spins around the Earth. We live in an open, vast, deep Universe, and at this precise moment there are celestial objects (whichever way you are currently facing) in front of you, behind you, above, below, left, right, every which way.

Where is M13? was made by Bill Tschumy, an amateur astronomer, and is available from the Think Astronomy web site (www.thinkastronomy.com/). This software runs on Windows, Mac, and Linux computer, with a current version of Java installed. Consider again Where is M13? if you regularly help at star parties: it will help you quickly answer many of the common questions and perhaps, in a profound way, help people understand that stars and deep-sky objects are truly all around us. Download it just for yourself, for fun, to explore our little corner of Universe. You are here. ✶

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

Second Light

The *Dawn* Spacecraft at Ceres

by Leslie J. Sage
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Ceres is the largest asteroid in the main belt, and was the first to be discovered, on 1801 January 1 by Giuseppe Piazzi. As a result of a decision by the International Astronomical Union in 2006, it is now "officially" a dwarf planet, but looking at the context—in the middle of the asteroid belt—I continue to think of it as an asteroid. Not much was known about its properties until the *Dawn* spacecraft arrived there in March of this year, though images exceeding the resolution achieved by the *Hubble Space Telescope* were obtained beginning in mid-January, and intriguing details began to be revealed as *Dawn* drew closer to Ceres. Two papers in the December 10 issue of *Nature*, led by Maria Cristina De Sanctis (of the Instituto di Astrofisica e Planetologia Spaziali in Rome, Italy) and Andreas Nathues (of the Max Planck Institute for Solar System Research in Goettingen, Germany) provide the science behind the images that we have been seeing for the last ten or so months.

The *Dawn* spacecraft was launched on 2007 September 27, bound first for Vesta, and later for Ceres. It is the longest-running mission to use an ion engine, which allows acceleration without much fuel, but at the expense of low rates of acceleration. Readers of my age or older will probably remember that Arthur C. Clarke used ion engines to send his spacecraft to Saturn in his book *2001: A Space Odyssey* (in the movie the destination was changed to Jupiter). The good thing about ion engines is that you can burn them for a long time, and *Dawn* achieved a peak velocity of 10 km/s. The *New Horizons* mission to Pluto left Earth's orbit with a velocity of just over 16 km/s (that's the fastest any human-made spacecraft has ever travelled). *Dawn* was gravitationally captured by Ceres on 2015 March 6, and entered a high polar orbit on April 23, at an altitude of 13,520 km. The mission profile has the spacecraft going through a series of orbits of decreasing altitude and on November 16 (the last update on the *Dawn* website as I am writing this on November 20) the engine was burning and the altitude was 715 km. Check out where it is now at dawn.jpl.nasa.gov/mission.

The most striking features revealed by the spacecraft were the bright spots (see Figure 1) inside a large crater named Occator. Nathues concludes that Occator is relatively young. Overall, the surface of Ceres is quite dark, as Nathues explains, it's about the brightness of fresh asphalt. The brightest spot is in a pit ~10 km in diameter and about 0.5 km deep, and reflects about 25 percent of the sunlight incident upon it. Overall, there are about 130 bright spots, and most of them are associated with impact craters.

To determine the origin of the bright spots, Nathues had to use a lot of different clues. The immediately obvious possible explanations were water ice, iron-depleted clay minerals, or salts. In 2014, the *Herschel* orbiting telescope found that water vapour was escaping from Ceres, and traced it back to two localized sources. This suggested that Ceres might be somewhat like a comet, where subsurface ice and dust are mixed and exposed as a result of an impact of a small body on the surface. The ice sublimates, creating a low-lying haze during "daylight," and then freezes out onto the surface during nighttime. Nathues and his collaborators did not find plume activity, so they can rule out the kinds of plumes that are seen on Saturn's moon Enceladus.

Models of Ceres' interior find that its low density of 2.2 g cm^{-3} argues for about 25 percent of its interior to be water ice or water bound to minerals. Nathues points to the "relaxed"

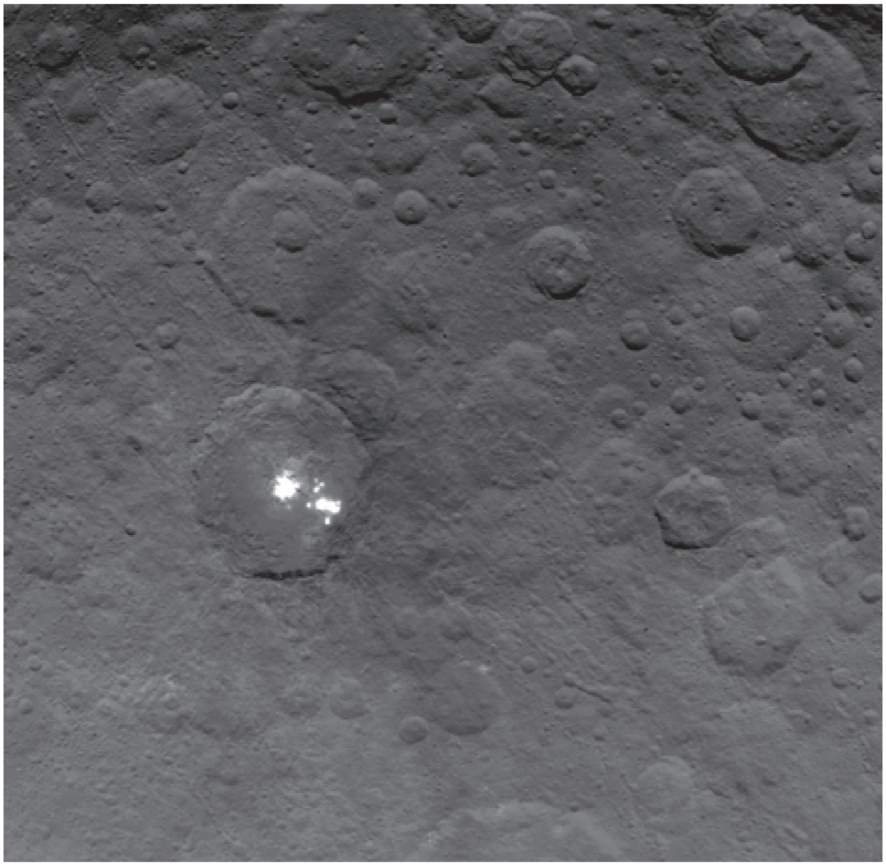


Figure 1 — The bright spots inside Ceres' crater Occator. Image courtesy NASA/JPL-Caltech/UCLA/MPS/DLR/IDA.

rims of its craters and concludes that it likely has an extensive (likely global) subsurface briny ice layer. This likely explains why the bright spots are distributed globally. Nathues concludes that the brightest spots are those where sublimation activity is recent, while it has ceased at the dimmer ones. The conclusion is that Ceres not only contains primitive material, but could also be active like a comet.

Ground and space-(*Hubble*) based observations led to the conclusion that the surface of Ceres looks something like carbonaceous chondrites—a type of primitive meteorite—but with important differences. Various minerals have been proposed to be the bulk of the surface material, but spectroscopy from a distance of several astronomical units (when Ceres is near opposition) is merely suggestive. From a distance of 4300 km, De Sanctis can do a lot better. She finds that the best matches to her spectra are ammonia-bearing clays (this had been suggested earlier), though she is unable to determine the specific clay mineral.

Ammonia on the surface of a body in the inner Solar System is quite uncommon. It is quite volatile and if Ceres formed near where it is now, ammonia would not have been able to freeze onto the surface. The only place where ammonia ice exists now is at or beyond the orbit of Saturn or further from the Sun. It is possible that while Ceres was forming, some pebble-sized objects from the outer Solar System brought the ammonia to the surface of Ceres. Alternatively—and this may be more in line with Ceres' high water content (which is about double that of typical carbonaceous chondrites)—it might have formed in the outer Solar System and then been gravitationally scattered to its present location while the giant planets migrated. One possible way to make Mars small was for Jupiter to migrate inwards, and it certainly appears that the only explanation for the diverse populations of the asteroid belt is for the giant planets to have migrated outwards at some point. If Ceres did form in the outer Solar System, that would make its comet-like activity more understandable, as some Kuiper belt objects are known to have comet-like tendencies.

Next time you observe Ceres, think about comet-like characteristics, and that it may well be well be an interloper from the outer Solar System and not a real asteroid at all. ✶

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

CFHT Chronicles

SPIRou

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

SITELLE's arrival at CFHT increased our suite of instruments to four, but we are not done yet. We have another instrument in development, the **S**pectro**P**olariméter **I**nfra-**Rou**ge or SPIRou—a near-infrared spectropolarimeter and velocimeter aimed at detecting and characterizing exo-Earths, exoplanets like our own world, in the habitable zone of low-mass stars. SPIRou will also investigate how magnetic fields impact star and planet formation. SPIRou is on track to arrive at CFHT in 2017, and we are very excited about this groundbreaking new instrument.

SPIRou takes its name from the Franco-Belgian comic book character. With the first edition in 1938, Spirou began his comic-book life as an elevator operator and bell-boy at the fictional Moustique Hotel. Spirou eventually switched careers to a reporter, but kept his red elevator-operator uniform. The character Spirou is often accompanied by his trusty pet squirrel Spip, which happens to be the name of SPIRou's sister instrument destined for Pic du Midi Observatory in France. The primary investigator (PI) for SPIRou, Jean-Francois Donati, capitalized on the opportunity to create an acronym for the instrument after his favourite childhood cartoon character—an opportunity I think anyone would love to have.

The PI for SPIRou may be in France, but the project is a joint effort across the CFHT community. The co-PI, René Doyan, and co-project scientist, Etienne Artigau, both hail from the Université de Montréal. Major components of the instrument will be constructed at NRC Herzberg in Victoria. Taiwan and Brazil are also making contributions to the project.

What is SPIRou?

What is SPIRou and why are we building it? Let us take the first paragraph of this column and break it down into more understandable terms. SPIRou is a near infrared spectropolarimeter and velocimeter. SPIRou collects the light from stars in

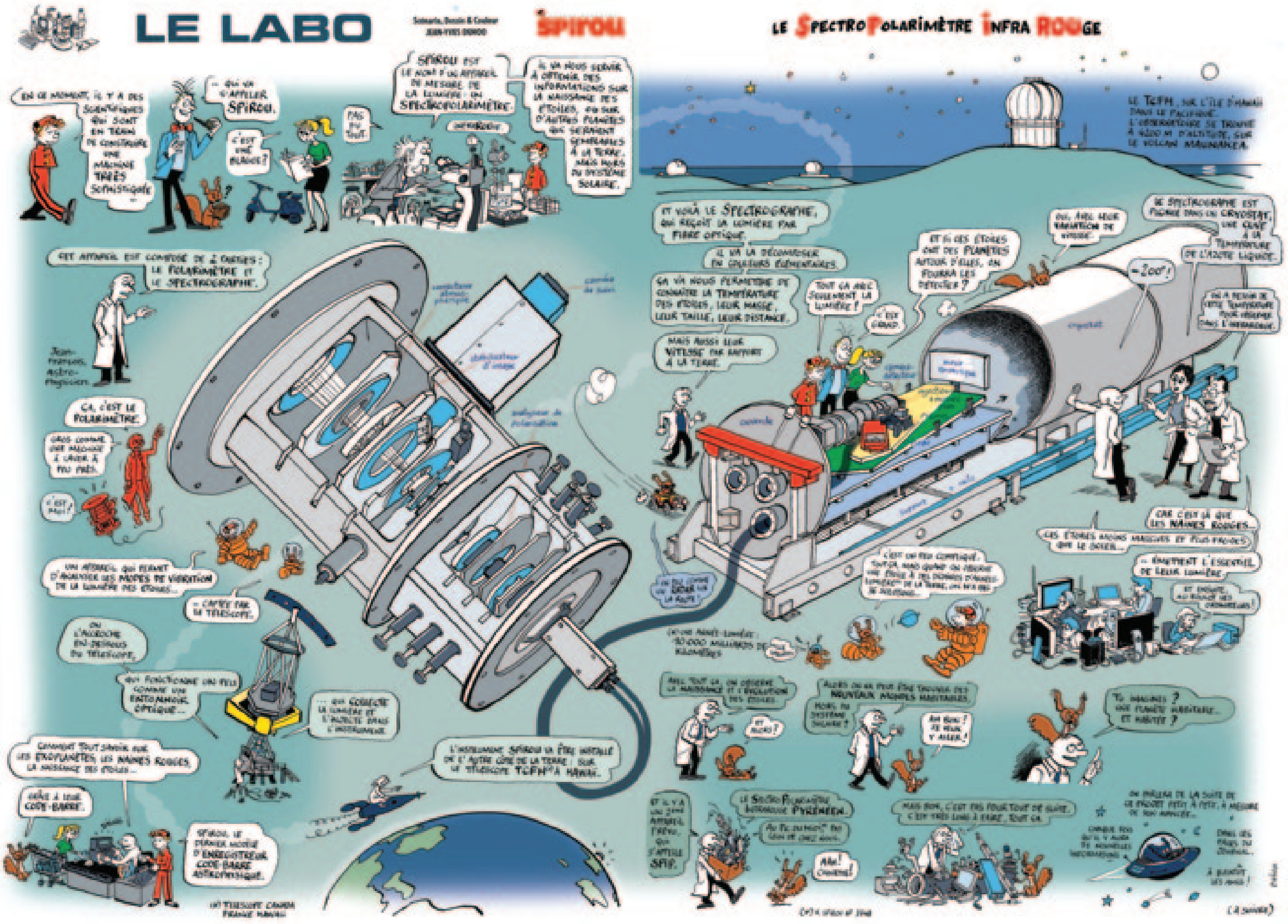


Figure 1 — Special SPIRou comic created for the SPIRou team by Jean-Yves Duhoo and the editions Dupuis as part of the collaboration with Spirou magazine. The collaboration will continue throughout SPIRou's construction and science.

the near-infrared wavelength range of 0.98-2.35 microns (10^{-6} metres). In comparison, ESPaDOnS, CFHT's current spectropolarimeter, operates in the visible wavelength, light that our eyes can see, in the range of 0.37-1.05 microns. ESPaDOnS and SPIRou overlap a very small amount, allowing astronomers coverage of stars from the ultraviolet through the visible and into the infrared. Moving on, a spectropolarimeter is a special type of spectrograph. Not only does it break the light from stars down into their component colours or spectra, yielding all of the information on an object's composition, temperature, distance, etc., it has the additional feature of uncovering the polarization of an object. From the polarization data, astronomers can characterize the magnetic field. Velocimeters are built to obtain very high long-term radial-velocity accuracy. High-precision velocimeters are instruments capable of recording the tiny motions of a star that are the signatures of an orbiting planet. The European Southern Observatory's HARPS in La Silla is a current example of a successful velocimeter.

SPIRou is comprised of several units, each residing in different parts of the CFHT building. One unit will hang off the bottom of the telescope at the Cassegrain (Cass) position. This configuration of SPIRou is inspired by ESPaDOnS, which has a similar unit. The actual spectrograph is in a separate location, because the Cass unit moves around with the telescope. For reasons we will discuss later, we do not want the spectrograph slewing around all over the place. The Cass unit has upper and lower units, each with unique components. The upper unit is the closest part of the instrument to the telescope; in fact, it acts as the mechanical interface with the telescope. The upper unit houses the atmospheric dispersion corrector (ADC), the tip tilt module, and a calibration wheel. The ADC is a nifty device; when in the light path, it corrects the entrance beam for the refracting effect of the atmosphere, particularly at high air mass.

The lower Cass unit houses the achromatic polarimeter, where the magic happens. Before we discuss the polarimeter on SPIRou, we need to take a detour to the land of light. Light is a transverse, electromagnetic wave with an electric field and a magnetic field. In general, light is not polarized; rather, it is made up of very short segments that are each individually polarized. However, we cannot measure those short individual polarized segments, so we see the average result—unpolarized light. Polarized light results from something occurring to the light on its path from the source to the observer. The clue to what that "something" is comes from the type of polarization we see. The scattering of light by electrons or dust grains causes linear polarization. Magnetic fields cause circular polarization. Going back to SPIRou, the optics are adjustable, allowing astronomers the option to measure the circular or linear polarization. One of the challenges in constructing SPIRou is that the science requires accurate and reliable polarimetry to a precision of better than 2%.

Figure 2 — SPIRou cryostat at NRC, with DAO director Dennis Crabtree to show the scale.

Once the light passes through the polarimeter it moves through 30 metres of fibre optics to the spectrograph housed on the third floor of the CFHT dome. These fibres are extraordinary and custom made for SPIRou out of fluoride. Using fluoride ensures that greater than 90% of the light from the telescope will make it through the fibres and into the spectrograph. The fibres are very delicate, potentially making them a challenge to work with.

One major difference between SPIRou and ESPaDOnS is the need for SPIRou to be cryogenically cooled. When working in the infrared, temperature control is essential. The IR is an indication of temperature, so the temperature of the detector needs to be as stable and low as possible. SPIRou will be kept at a temperature of 77K (-200 °C) and needs to be thermally stable to a precision of a few millikelvin. One of SPIRou's key science goals is detecting planets. The precision in temperature is necessary for astronomers to detect the very tiny motions, on the order of nanometres, that reveal planets.

As mentioned earlier, the spectrograph lives on the third floor of the CFHT home and not at the bottom of the telescope. The size of the cryostat is a major reason for that decision, along with the need for the utmost of stability. The entire spectrograph plus cryostat weighs roughly four metric tons. In September, the cryostat arrived at NRC Herzberg where the optical bench housing the spectrograph, mirrors, prisms, and camera that comprise SPIRou will ultimately be assembled before being disassembled and shipped to France for final integration. The detector is a 16 million pixel Hawaii 4RG, an incredibly state-of-the-art camera. I had the pleasure of seeing the cryostat first hand while visiting NRC Herzberg shortly after its arrival. It is incredible. In the design, the optical bench is attached to the right end cap of the cryostat, allowing the rest of the cryostat to slide out of the way when engineers access the bench. The inside of the cryostat will be covered in passive radiation shielding or very high-grade aluminum foil.

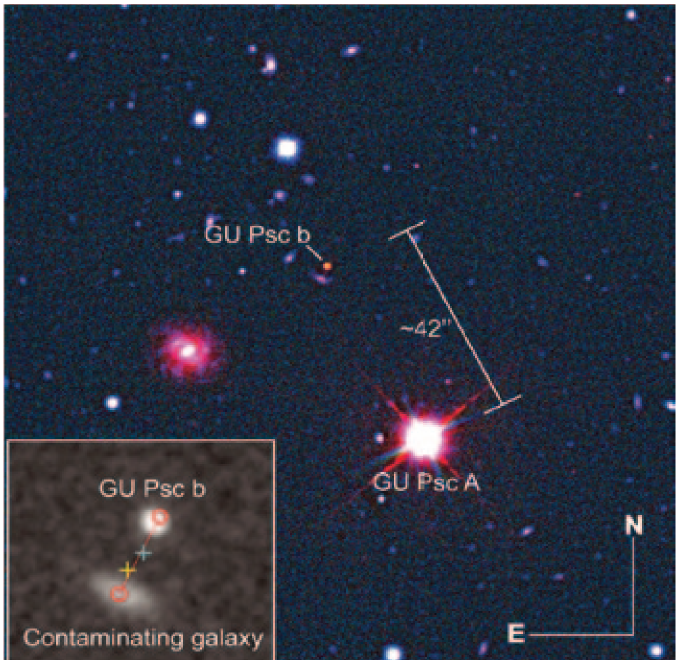


Figure 3 — Photo courtesy of Marie-Ève Naud of GU Psc b. Photo is a composite of visible and IR images from Gemini South Observatory and CFHT.

SPIRou Science

The preceding paragraphs detail the instrument, which begs the question of why? Why are all these institutions joining forces to build SPIRou? The simple answer is that SPIRou is a cutting-edge instrument in the search for exoplanets.

Astronomers can detect exoplanets through several methods. The most clear-cut method is direct imaging. However, exoplanets are very faint compared to their host stars, making them difficult to image. Despite the challenges, several telescopes have directly imaged exoplanets, CFHT among them. In 2014, an international team led by Marie-Ève Naud from Université de Montréal used Wircam at CFHT, Observatoire Mont-Mégantic, the W.M. Keck Observatory, and the two Gemini Observatories to detect the planet GU Psc b around the star GU Psc. The planet is around 2000 AU from its host star and takes roughly 80,000 Earth years to orbit. Astronomers cannot determine the mass of a planet through direct imaging, a disadvantage of the method. Instead, they need to take spectra and use theoretical models to determine the mass. In this case, the team determined GU Psc b's mass to be 9–13 times that of Jupiter. Gemini Observatory, the VLT, and Subaru Observatory all have instruments designed specifically to be capable of direct imaging of exoplanets.

Another method is using planetary transits, as exhibited by the *Kepler* mission. *Kepler* monitors stars by looking at variations in the star's brightness. When a planet passes in front of its host star, a small portion of the star's light is blocked by the planet. This was demonstrated in our own Solar System in 2012, when millions watched the Venus transit. From Earth, we watch the disk of Venus move across the Sun. *Kepler* does not image the disk of the star; instead it analyzes the star's light curve looking for dips. Transits are only seen when the exoplanetary system is in almost perfect alignment with our own Solar System. According to the *Kepler* website, a planet in an Earth-sized orbit has less than a 1% chance of being aligned well enough to produce a transit visible to *Kepler*. In other words, it's very unlikely that *Kepler* could have detected a Venus-like transit in a foreign planetary system. An Earth-like planet transiting a Sol-like star will only change the brightness of the star's light curve by 84 parts per million. SPIRou intends to have a sensitivity of 10 parts per million, making the detection of Earth-like planets possible.

SPIRou's bread and butter will be the radial-velocity or Doppler method to detect its planets. Gravity is the crux of the radial-velocity method. In Newton's system, objects exert a gravitational force on each other. In a star-planet system, the planet's gravity exerts a force on the star, resulting in the star moving in a tiny orbit around the centre of mass of the system. This tiny orbit causes the spectral lines of the star to wiggle a very small amount. A high-resolution spectrograph with incredible radial-velocity accuracy detects this wiggle. SPIRou is both high resolution (greater than 70,000) and highly accurate in radial-velocity measurements (better than 1 metre per second).

The SPIRou science team plans to conduct a legacy survey, similar in concept to the CFHTLS, with three components. The first component is the search for and characterization of exo-Earths orbiting low-mass stars. The team will conduct systematic radial-velocity measurements of nearby M dwarfs and radial-velocity follow-ups of interesting transiting candidates from future missions like NASA's *TESS* (2017 launch), the *James Webb Space Telescope* (2018 launch) and ESA's *PLATO* (2024 launch).

The second component of the SPIRou legacy survey intends to investigate the question of how magnetic fields impact star and planet formation. Currently with ESPaDoNs, the MaTYSSE (Magnetic Topologies of Young Stars and the Survival of close-in giant Exoplanets) large program is examining a similar question, but in optical wavelengths. The MaTYSSE team is comprised of many members of the SPIRou science team including the PI and Co-PI. In July 2015, they announced the preliminary discovery of a hot-Jupiter-type planet orbiting the 2 million-year-old star, V830 Tau—a baby in star years. Young stars are potentially very informative about star formation for obvious reasons. However, they are very challenging to observe due to their enormously active and strong magnetic fields. This activity generates wiggles in their spectra larger than those caused by orbiting planets. As a result, planets around young stars are very hard to detect. The MaTYSSE team uses techniques derived from medical imaging to map the surface of young, active stars, enabling

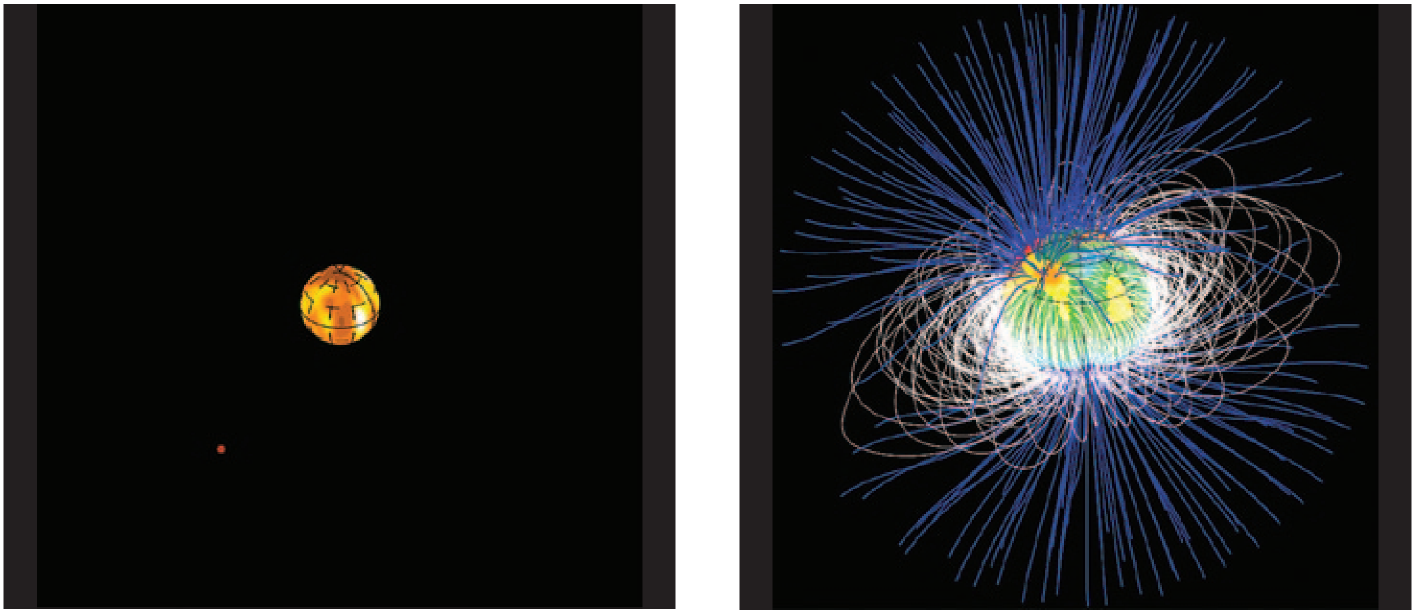


Figure 4 —Star surface and planet (left) and magnetic field lines (right) at the surface of V830 Tau as reconstructed from ESPaDOnS observations.

them to ultimately model how the perturbations from the activity affect the star's spectra. Once these perturbations are modelled, they can be compensated for, thus unveiling the wiggles of planets around the star. The 1.4_{Jupiter}-mass planet potentially discovered around V830 Tau is proof of this method. SPIRou will offer vastly improved performance because it operates in the near IR wavelength—the domain where young stars are far brighter.

The third component ties directly into the second. To investigate the impact of magnetic fields on formation, one must survey the magnetic properties of protostars.

While exoplanets are a key science driver of SPIRou, they are not the only science the project will undertake. Astronomers will also use SPIRou to study topics in stellar physics, like dynamics of fully conductive stars, the weather on brown dwarfs, planetary physics, stellar archeology, and extragalactic astronomy. As one of the first near-IR spectropolarimeters, astronomers using SPIRou will conduct groundbreaking research across astronomy.

Progress Report

So how is SPIRou progressing? The answer is, happily, quite well. As mentioned above, the cryostat arrived at NRC Herzberg in September, along with parts for the optical bench. The NRC Herzberg staff determined the cryostat was not damaged in transport and moved on to testing the cryo's specifications. Their next stop is to mount the optical bench and its supports and optical components within the cryostat before it's shipped to Toulouse in mid-2016.

In April 2015, CFHT staff tested the SPIRou guiding camera with great success. CFHT staff is using the data gathered to develop the guiding software and discuss the various approaches to guiding with SPIRou. One possibility is to follow the model developed by ESPaDOnS, but other options exist.

The machining of SPIRou's parabolic mirror began in June 2015. The mirror will be cut to its final rectangular shape, polished, and coated before its installation into the SPIRou spectrograph. It is anticipated that the mirror will be ready for integration by early 2016.

SPIRou's June 2015 midterm review was deemed a success. The team continues to monitor all the various systems to make sure the project stays on schedule. We anticipate SPIRou's arrival by the summer of 2017. In addition to the construction of hardware components, the CFHT staff is hard at work to ensure we are ready for SPIRou's arrival at a hardware and software level.

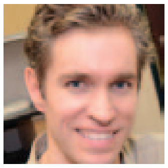
With SITELLE's arrival last June and SPIRou on the horizon, it is an exciting time to be at CFHT. Now that you know about the wonder that is SPIRou, I will continue to provide updates on its progress. Hopefully in 2017, this column will feature results of the first SPIRou commissioning run.

Lots of credit is due for assistance in writing this article. The SPIRou team at CFHT welcomed me to their last meeting and answered all my questions. The SPIRou team has a fabulous website, which I highly recommend http://spirou.irap.omp.eu ✶

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

Dish on the Cosmos

The Next BIG Thing



by Erik Rosolowsky, Department of Physics, University of Alberta

This column is usually filled with news of the latest discoveries from the Atacama Large Millimetre/submillimetre Array (ALMA), but this time it changes the cosmic radio station down on the dial. ALMA operates using light with wavelengths of about a millimetre or smaller, but ALMA is built using the principles developed for a long-wavelength radio telescope. When we change the cosmic radio station down into centimetre wavelengths, we find telescopes are listening to different types of physics.

The Very Large Array (VLA, Figure 1) in New Mexico is one example of a telescope operating at radio wavelengths. Like ALMA, it is an interferometer and can create images of the radio sky with exquisite resolution. However, the longer-wavelength light reveals astrophysical signals from a huge variety of sources. The VLA provides one of the few ways to directly detect the ordinary hydrogen gas that fills our galaxy, as well as hot plasmas that are energized by the radiation of the most massive, bluest stars. The longer-wavelength light also highlights the emission that leaks off high-energy particles, called cosmic rays, that are accelerated to near light speed in supernova shock waves. The VLA even sees emission from some molecules. But, where ALMA focuses on the mysteries of how stars and planets form, the longer-wavelength radiation reveals the energizing effects of stellar deaths and the telltale signatures of exotic objects like black holes, driving huge jets from the cores of galaxies. In one example of recent VLA results, Canadian radio astronomers Judith Irwin, Theresa Wiegert (at Queen's University) and Jayanne English (at the University of Manitoba) and their collaborators presented a study of edge-on galaxies. Their work revealed the startling height that cosmic rays reach up into the halos of galaxies. These new maps implied a ubiquitous connection between the disks of galaxies and far larger magnetic structures, raising questions of how important the magnetic fields are at controlling galaxy evolution.

The VLA began science operations in 1976 and has operated continuously since that time, though there was a major upgrade of the facility that concluded in 2012. A central component of that upgrade was a new digital correlator built by engineers working for the National Research Council Canada at their Penticton, B.C., facility. Even with this upgrade, radio astronomers are hitting limits with what can be accomplished. Interstellar radio waves are incredibly faint—if all the radio radiation collected by the VLA since the beginning of its operations were collected together, it would just about melt a snowflake. Radio telescopes amplify the power of radio signals by a factor 1,000,000,000,000,000,000 just to detect them with modern electronics. Being able to detect interstellar radio signals at all was an amazing feat of engineering.

While the decades of studies have revealed a wealth of information about the invisible Universe, radio astronomers are considering what the next steps for radio astronomy will be. The consensus opinion is that major new discoveries will require a new telescope to be factors of 10 to 100 times better than existing facilities in nearly all aspects of their design, leading to the proposed Square Kilometre Array (SKA). The Square Kilometre refers to the total collecting area of this new telescope. Bigger collecting areas mean the telescope can collect more radiation, improving the sensitivity. For

Figure 1 — The Very Large Array in New Mexico. This operational interferometer is a workhorse of the radio community, observing objects from the Solar System to the edge of the Universe. Image Credit: E. Rosolowsky

Figure 2 — An artists conception of the Square Kilometre Array (SKA). The SKA dishes will be spread across two continents to provide exceptional angular resolution. The facility provides the excellent opportunities to study a range of science topics, including some of the best possible tests of Einstein's landmark general theory of relativity. Image Credit: SKA Organization

comparison, the VLA is a mere 0.013 square kilometres. A radio telescope can attempt to match the sensitivity of a larger facility by staring at a source longer, but one day of SKA observations would require over 10 years of staring at the same object with the VLA to match the sensitivity.

Astronomers are incredibly excited about the scientific discoveries that lie in the "noise" of current astronomical images. The SKA promises breakthrough discoveries in five key areas. Notably, the new facility would be able to vastly expand the known number of pulsars. These pulsars are the ultra-dense neutron star cores of high-mass stars, left behind after these stars undergo supernova explosions. Pulsars are so called because their extremely regular rotation points a beam of radiation toward the telescope each rotation, causing it to appear pulsed. Pulsars form an amazing test bed for physics, including Einstein's theory of general relativity. Relativity recently celebrated its 100th birthday, and it has passed every test posed to it without any alteration to the core ideas of the original theory. Pulsars may reveal a weakness in the theory since they are good clocks operating in strong gravitational fields. With the SKA, astronomers will be able to find elusive systems, such as a pulsar in orbit around a black hole. Studying the pulse profiles from such a system would provide a thorough test of Einstein's landmark theory. A key discovery would be evidence for how Einstein's work was incomplete. We know that the original theory cannot be complete since it does not include the concepts of quantum mechanics, but theoretical physicists are at a loss for how to merge these two successful models. Finding some small, real deviations from Einstein's version of the theory of relativity would give physicists the clue they need. With a clue, they could sift through the hundreds of proposed next steps, finding the one or the few that provide a richer understanding of how the Universe works. Pulsars also offer many additional tests and insights into other physics, including the behaviour of ultra-dense matter. These key questions are being pursued by two Canadian radio astronomers, Vicky Kaspi (McGill) and Ingrid Stairs (UBC), and the SKA will enable these astronomers and others challenging Einstein's theory, hoping for some glimpse of a deeper truth. The other major science themes aim for different goals, such as understanding the mysterious forces of dark energy that are governing the current evolution of the Universe. The SKA will also provide unique insights into the chemical origins of life, and will conduct the most sensitive surveys for radio broadcasts from other purported civilizations.

The science promise of the SKA is vast but the project is huge and challenging to current technologies. In the present vision, the SKA will span the globe, with the constituent telescopes spreading across Australia and southern Africa. These sites are chosen because radio interference from humans easily swamps the signals that the SKA is designed to study. A cell phone on the Moon would be the brightest transmitter in the radio sky in the narrow band over which the phone broadcasts. The telescopes must avoid the fraction of such transmissions that can be avoided and must filter out the rest of these interloper signals. Thus, the SKA will be sited far from Earth-based broadcasters, and the signals from these far-flung stations must be gathered together into a single correlator for processing into an image. This component of the telescope is one of the biggest challenges, since the data transport rates through the telescope network will rival the data rates in the current Internet. The SKA promises to bring several firsts to radio astronomy: it will be the first telescope driven more by computing technology than by the radio receivers. It will be the first truly international radio telescope with partners across the globe. The SKA also promises to bring a huge number of scientific firsts, providing a unique window on the Universe. As the VLA and ALMA reveal the Universe today, we cannot help but wonder about what the next BIG thing will tell us. ✶

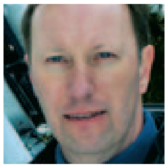
Erik Rosolowsky is a professor of physics at the University of Alberta where he researches how star formation influences nearby galaxies. He completes this work using radio and millimetre-wave telescopes, computer simulations, and dangerous amounts of coffee.

The April *Journal* deadline for submissions is 2016 February 1.

See the published schedule at
www.rasc.ca/sites/default/files/jrascschedule2016.pdf

Imager's Corner

Equipment Review



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

In this edition I'll be doing something a little different, rather than discussing a processing technique, I'll take a detailed look at a couple of new cameras on the market and use my trusty Canon 60Da as a reference.

Another member from the Halifax Centre, Art Cole, purchased a shiny new Canon 7D Mark II and the good folks from Atlantic Photo Supply, the largest mail-order telescope supplier in Atlantic Canada, offered to lend us a Nikon 810A to test as well. There have been rumours about the 7D Mark II around the web for a while and I was eager to put the camera through its paces. Nikon has been billing the 810A as the first full-frame camera modified for astrophotography and it promises to be a strong contender.

The testing started out with some measurements made at room temperature to get an idea of the read noise, gain, and dark current of each of the cameras. Art also had a Canon T3i and I had an older Rebel XT (350D) that we measured for comparison. In order to measure gain and read noise, a couple of bias and flat frames are required. For those with a mathematical bent, the gain is calculated by:

$$Gain = \frac{(F1 + F2) - (B1 + B2)}{\sigma(F1 - F2)^2 - \sigma(B1 - B2)^2}$$

and the read noise is calculated as

$$ReadNoise = \frac{\mathrm{Gain} * \sigma(B1 - B2)}{\sqrt{2}}$$

where F1 is the first flat, B1 is the first bias frame and σ is the standard deviation. In the gain, expression (F1+F2) is the average value of the sum of the two flats and is the square of the standard deviation of the difference of the two flats. The dark current was measured from a five-minute dark frame, knowing the gain and read noise.

Before presenting the data there are a few things to mention. First on the list is the fact that my 60Da, the 7D Mark II, T3i, and the 810A have built in dark suppression. This means that you cannot simply take a dark frame and read the value for the dark current. The value of the dark frame will remain constant no matter how long the duration of the exposure, so the dark level has to be calculated by measuring the noise, removing the bias contribution, and squaring the standard deviation of the result. This works, because in general, the noise or standard deviation is equal to the square root of the dark current. The second point worth mentioning is that the calculations of gain and read noise assume that the raw data is truly raw and not processed in the camera. In the case of the Nikon, this is not the case and the jury is still out on the Canon models, so treat the data here as an approximation.

Now on to the data, the table below lists the gain, read noise, and dark current as measured on all of the cameras at about 27 ˚C.

Camera	60Da	7D MII	810A	350D	T3i
Corrected Gain (E/ADU)	0.2	0.2	0.15	0.2	0.1
Read Noise (e)	2.8	2.7	2.5	3.7	2.7
Dark Current (e/pixel/second)	0.3	0.5	0.3	2.6	1.0
Dark Current Noise (e)	0.6	0.7	0.5	1.6	1.0

Table 1 — Camera data at 27 °C

Now, let's put this in perspective, the values for dark current in the newer cameras are on par with the SBIG STXL-11002 cooled to 15 ˚C and about a quarter of the Celestron Nightscape cooled to 0 ˚C!

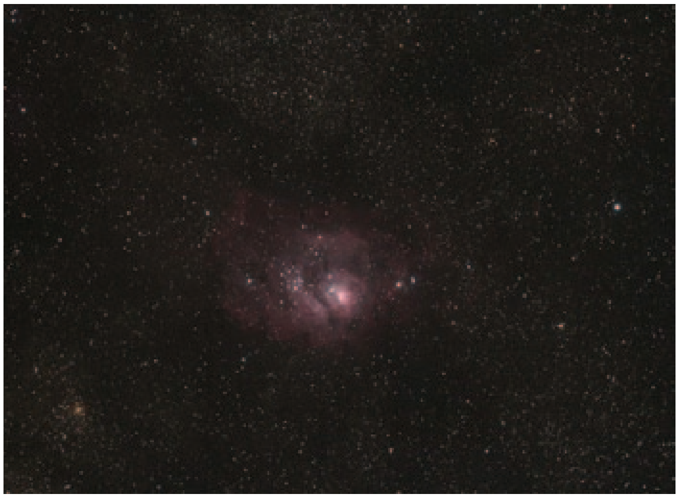


Figure 1 — Canon 60Da

Figure 2 — Canon 7D Mark II

Figure 3 — Nikon 810A

Along with the measurements, Art and I took some five-minute images of M8. Noise measurements are made on the raw M8 images. The individual 60Da, 7D Mark II, and 810A images are shown below after each was stretched using the same curve.

Each of the images looks very similar. The 7D Mark II has less Hα sensitivity, as expected since it is an unmodified camera, but in terms of noise it is very similar to the 60Da and the 810A.

Camera	60Da	7D MII	810A
Standard deviation	604	606	475

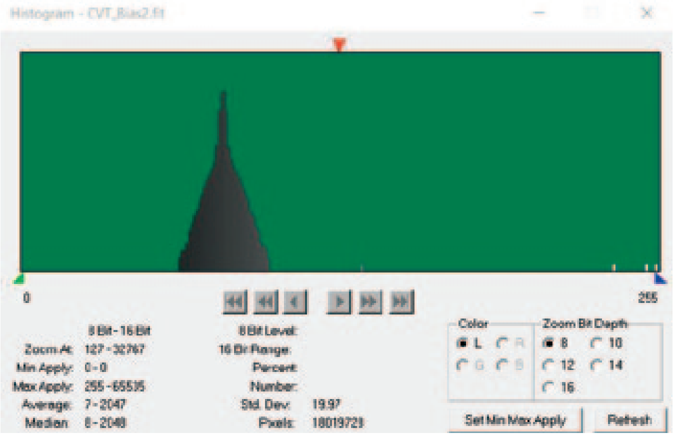
Table 2 — Image noise

The 810A image looks quieter than the other two cameras, but also seems to be slightly blurred. This blurring was somewhat strange as it did not seem to be a problem with the seeing and the measured uncorrected gain was substantially different than the other cameras of similar vintage. This was a bit of a mystery as the pixels in all three sensors are similar in size and full well depth. Looking a little deeper at the histograms for all three cameras, the bias and dark frames reveal some strangeness going on.

Taking a look at all three bias histograms clearly shows that the Nikon has clipped off data lower than the peak value while the both Canons have a more normal histogram.

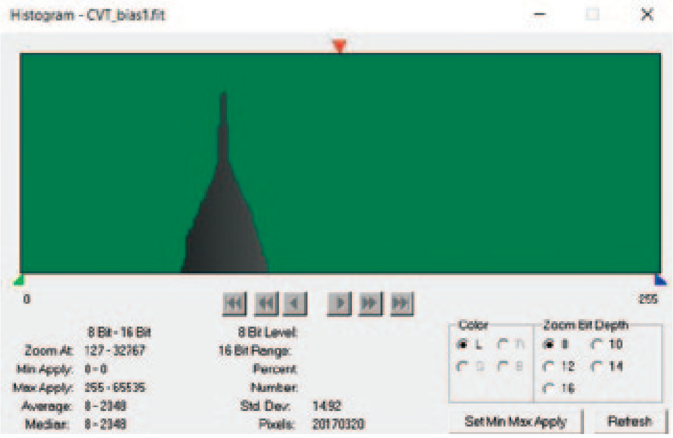
Similar results are seen when you examine the histograms for five-minute dark frames from all three cameras.

Again you can see that the Nikon histogram looks strange, clipped at the peak. This makes the measurements of gain and read noise somewhat suspect for this camera as the measurement technique relies on the data being unprocessed. The histograms, along with the slight blurring of the image data, point to the Nikon processing the raw image in some way. It turns out that there is a family of noise-reduction filters that can account for all of this, but that is a topic for my next column. The apparent filtering of the Nikon should produce roughly a 25-percent reduction in photon noise, which would bring its noise levels to about the same as the other two cameras. The data presented in Table 1 has been corrected for the effect of this filtering.



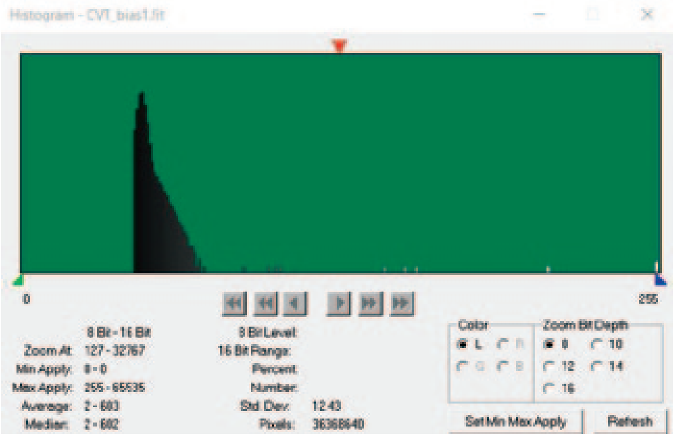
8 Bit - 16 Bit
Zoom At: 127 - 32767
Min Apply: 0 - 0
Max Apply: 255 - 65535
Average: 7 - 2047
Median: 8 - 2048
8 Bit Level:
16 Bit Range:
Percent:
Number:
Std. Dev: 19.97
Pixels: 18019728

Figure 4 — Canon 60Da histogram



8 Bit - 16 Bit
Zoom At: 127 - 32767
Min Apply: 0 - 0
Max Apply: 255 - 65535
Average: 8 - 2348
Median: 8 - 2348
8 Bit Level:
16 Bit Range:
Percent:
Number:
Std. Dev: 14.92
Pixels: 20170320

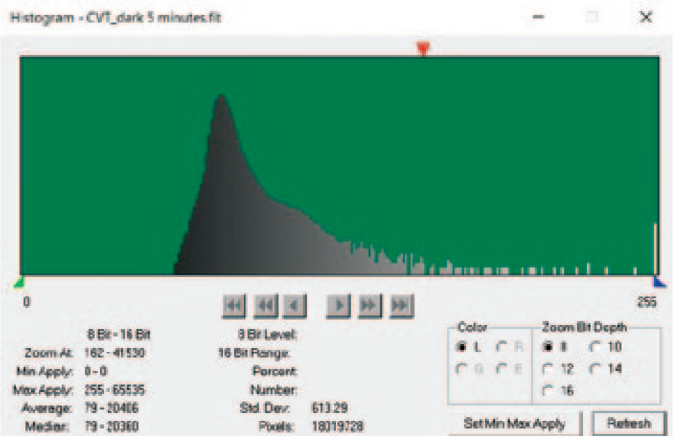
Figure 5 — Canon 7D Mark II histogram



8 Bit - 16 Bit
Zoom At: 127 - 32767
Min Apply: 0 - 0
Max Apply: 255 - 65535
Average: 2 - 603
Median: 2 - 602
8 Bit Level:
16 Bit Range:
Percent:
Number:
Std. Dev: 12.43
Pixels: 36368640

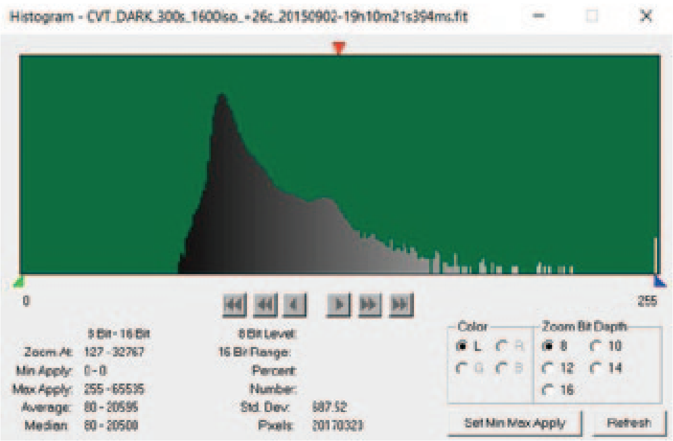
Figure 6 — Nikon 810A histogram

What does all this mean for the camera comparison? All three cameras perform almost to the level of dedicated and cooled CCD cameras and produce deep, low-noise images that rival



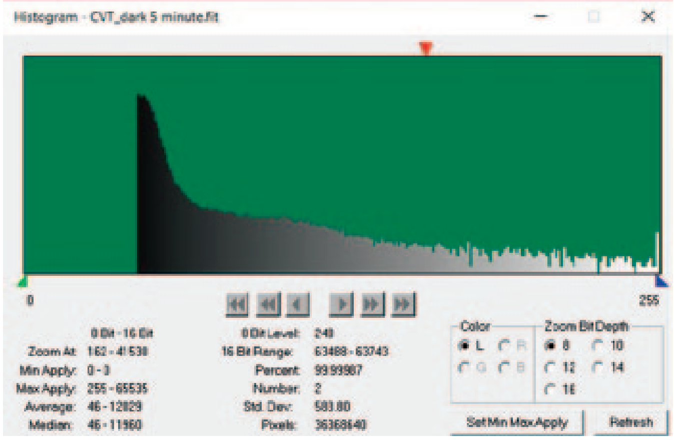
8 Bit - 16 Bit
Zoom At: 162 - 41530
Min Apply: 0 - 0
Max Apply: 255 - 65535
Average: 79 - 20406
Median: 79 - 20360
8 Bit Level:
16 Bit Range:
Percent:
Number:
Std. Dev: 613.29
Pixels: 18019728
Color: ● L ○ R ○ G ○ B
Zoom Bit Depth: ● 8 ○ 10 ○ 12 ○ 14 ○ 16

Figure 7 — Canon 60Da dark histogram



8 Bit - 16 Bit
Zoom At: 127 - 32767
Min Apply: 0 - 0
Max Apply: 255 - 65535
Average: 80 - 20595
Median: 80 - 20508
8 Bit Level:
16 Bit Range:
Percent:
Number:
Std. Dev: 587.52
Pixels: 20170323
Color: ● L ○ R ○ G ○ B
Zoom Bit Depth: ● 8 ○ 10 ○ 12 ○ 14 ○ 16

Figure 8 — Canon 7D Mark II dark histogram



8 Bit - 16 Bit
Zoom At: 162 - 41538
Min Apply: 0 - 3
Max Apply: 255 - 65535
Average: 46 - 12029
Median: 46 - 11960
8 Bit Level: 249
16 Bit Range: 63488 - 63743
Percent: 99.99987
Number: 2
Std. Dev: 583.80
Pixels: 36368640
Color: ● L ○ R ○ G ○ B
Zoom Bit Depth: ● 8 ○ 10 ○ 12 ○ 14 ○ 16

Figure 9 — Nikon 810A dark histogram V

professional instruments of just a decade ago. My trusty 60Da produces low-noise images with great Hα sensitivity while still providing proper colour balance for most daytime work. One often overlooked feature offered on the Canon 60Da that should be standard on any astro DSLR is its articulated view screen. On more than one imaging session, mounted on my Newtonian, it has saved my back while aligning my mount.

The Canon 7D Mark II lives up to the hype that has been showing up on several Internet sites and performs well against my 60Da. It offers great performance with one of the lowest dark currents available in a DSLR. Its Hα performance is a little limited, but the great noise performance allows more aggressive stretching allowing much of the faint red data to be recovered in the final result.

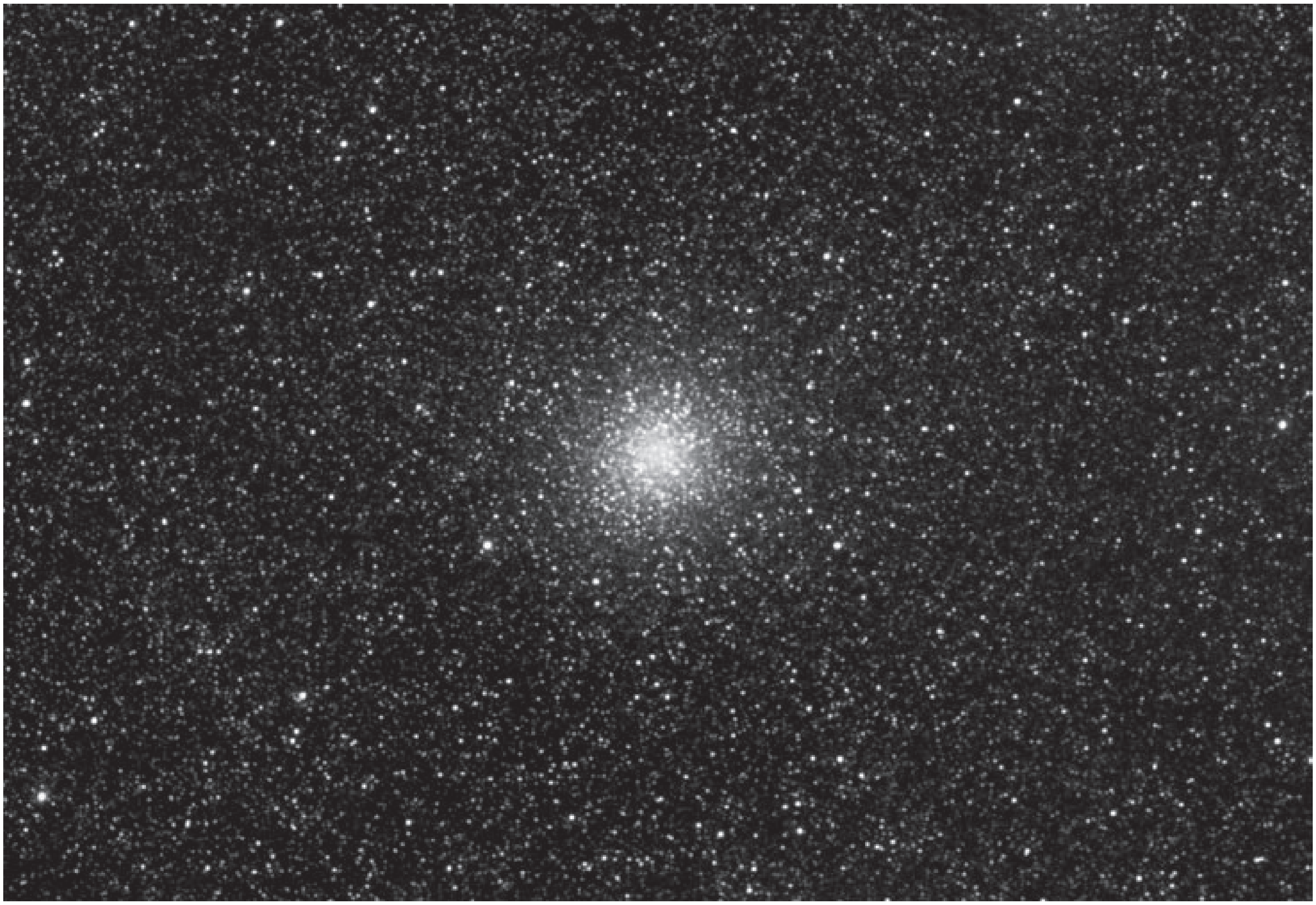
The Nikon is the only full-frame unit in the test and I love the field of view. It is applying some form of noise-reduction filter to the data, but that doesn't detract from the image at all and produces a smooth low-noise result with a barely noticeable bit of blurring. If you are a Nikon fan with a budget that allows the 810A's price tag and already have lenses and adapters for the brand, then the camera is definitely worth a look.

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

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

Great Images

by Ron Brecher



Ron Brecher took this image of M22 at the Huronia Star Party in 2009 using a QHy8 camera and an Astro Physics 106 mm ƒ/6 refractor. Brecher used a Vixen GP/DX mount, KW Telescope KwikGuide, Nebulosity, PHD guiding and processed the final image using PixInsight.

First RASC Tour a Success!

By Randy Attwood FRASC, Executive Director

The first RASC organized tour was a great success. From November 3-9, seven RASC members toured astronomy and space destinations in the Los Angeles area. Tours included the Jet Propulsion Laboratory in Pasadena, Mount Wilson and its 150-foot tower solar telescope, 60-inch telescope and famous 100-inch Hooker Telescope, and Mount Palomar and its famous 200-inch Hale Telescope. In addition, the retired *Space Shuttle Endeavour* was visited at the California Space Center. There were also some non-astronomical visits—the group visited the Walt Disney Concert Hall, the Getty Art Museum, and the Cathedral of Our Lady of Angels—three examples of modern architecture. Also, one evening the group visited the Magic Castle for dinner—a mansion where guests can take in several shows performed by some of the world's best magicians and illusionists. A visit to Oceanside's telescope store—Oceanside Photo and Telescope—was a highlight for shoppers. We even fit in an unscheduled visit to the Roosevelt Hotel in Hollywood—the site of the first Academy Awards presentation in 1929.

Figure 1 — Mount Palomar—our view of the famous 200-inch Hale telescope

Figure 2 — Endeavour—The Space Shuttle Endeavour.

Figure 3 — Griffith Observatory—we were greeted by Griffith Observatory Director, Dr. Edwin Krupp.

What's next? Already being offered is the RASC's National Solar Eclipse expedition in August 2017. Hotels and camp grounds are quickly filling up along the eclipse path—why not bring the family on this amazing trip of a lifetime—witness over 2 minutes of totality in the Grand Teton National Park in Wyoming.

Possible Arizona trip in 2016

With the success of the Southern California trip still in the memory, we are beginning to look at the possibility of running a similar trip in Arizona next year—spots visited would include Kitt Peak National Observatory, Flagstaff and Lowell observatory, Meteor Crater, and of course, dark-sky observing.

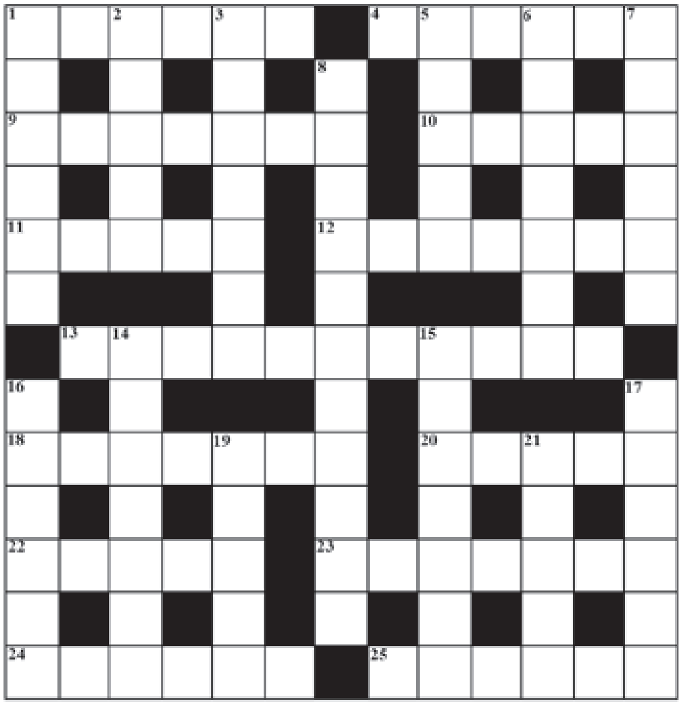
We are also considering repeating the Southern California tour a few years from now.

If any of these tours interest you, contact Executive Director and tour organizer, Randy Attwood in the Society Office (execdir@rasc.ca). ✶

Figure 4 — Mount Wilson—The famous 100-inch Hooker Telescope.

Astrocryptic

by Curt Nason



ACROSS

1. Somehow I charm its ghost on a hop to M31 (6)
4. Stinging star can lash out around astronomical unit (6)
9. Dust particles around very cool stars give chromospheric features (7)
10. Glowing wood spills beer around Cassiopeia at the zenith (5)
11. Instability area gives good man a wish for eternal serenity (5)
12. It's not doing this when you come across a meteor train in Gemini (7)
13. Iron on a blue variable below the belt (5,6)
18. Possessive, fishes for strange music after circular constant (7)
20. See 17D (5)
22. An asteroid rotates daily (5)
23. Emit photons that tear around Ida in retrograde (7)
24. Orion changes iodine to beryllium spinning around Uranus (6)
25. Warped space by Thule heading to opposition, e.g. (6)

DOWN

1. I am so confused after cool star renamed Becrux (6)
2. Turbine part right after Oort scattered (5)
3. Crazy cops lay in wait around Saturn (7)
5. Kids had first idea, in retrospect (5)
6. I lumber around and around Uranus (7)
7. Goateed wagoner strikes gold near European capital (6)
8. Unusual morons stare at us (11)
14. Misplaced desire about Uranus remains after separation (7)
15. Planetary law about 51 bright flashes (7)
16. NEA once seen on the Moon (6)
17. (with 20A) Letter crumpled in sight of a stargazer's bane (6,5)
19. Adult insect, one found initially by Mount Allison's Gemini Observatories (5)
21. Near occultation of young supernova hunters, I hear (5)

Answers to December's Astrocryptic

ACROSS

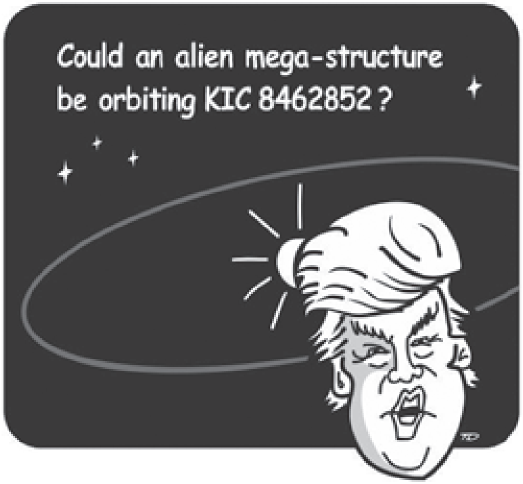
1 CETUS (anag + s); **4** CLAVIUS (Cla(VI)us); **8** MARCELS (anag + ls); **9** TRAIN (t + rain); **10** ROSSI (hid); **11** OLIVINE (anag + e); **12** NEBULA (N(anag)A)); **14** MANGER (2 def); **18** ONTARIO (O(anag)O); **20** NODES (N(ode)S); **22** CUPID (Cup + ID); **23** LALANDE (an(ALAN)ag); **24** SYCORAX (an(CO)ag); **25** MOBIL (2 def)

DOWN

1 CAMEREON (anag); **2** TORUS (homonym); **3** SPECIAL (an(I)ag + L; **4** CASTOR (anag); **5** ALTAI (hid); **6** IMAGING (e=g); **7** SONDE (an(o)ag); **13** BETA PIC (bet a pic); **15** ALNILAM (anag); **16** RUSSELL (r + us + sell); **17** POLLUX (po(LL + u)x); **18** ORCUS (anag – e); **19** RADAR (R + A + D + a + r); **21** DENEB (hid)

It's Not All Sirius

by Ted Dunphy



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Great Images

by Serge Théberge

Located in the constellation of Perseus at a distance of approximately 1000 light-years, NGC 1499, also known as the California Nebula, is a large emission nebula covering approximately 4×1 degrees of sky. Serge took this two-panel panoramic image resulting from a total of 10 hours of data capture, and covering 1.3×0.4 degree crossing the most stormy part of the nebula, using a Takahashi FS152 refractor at ƒ/8 with an SBIG ST10XME camera and Astrodon $H\alpha$ *filter on the Takahashi NJP Temma2 mount at Serge Théberge's remote observatory at Robosky near Orangeville, Ontario.*

Journal

Great Images

The Trapezium is seen in this exquisite image of M42, the Orion Nebula. Blair MacDonald took this image from St. Croix, Nova Scotia, using a Canon Rebel XT unmodified DSLR at ISO 1600. A Canon 60Da was used to image the core.