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Journal

Le Journal de la Société royale d'astronomie du Canada

PROMOTING ASTRONOMY IN CANADA

June/juin 2015
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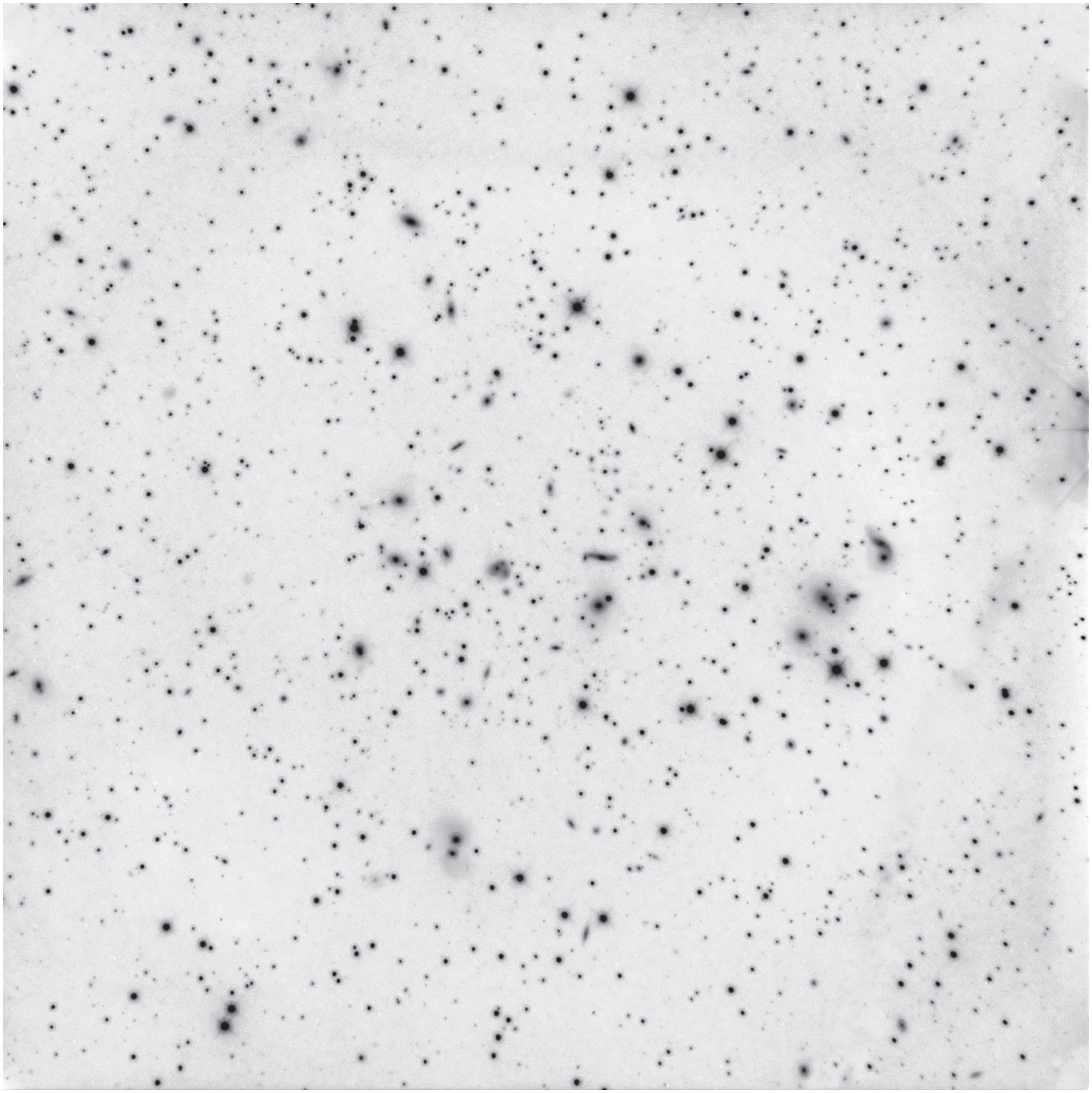
Inside this issue:

Study in Blue and Gold

The Best of Monochrome.

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



Galaxy clusters are difficult to recognize in normal colours, so Dalton Wilson inverted this image to make the individual members of the Hercules Cluster (Abell 2151) stand out. The cluster lies at a distance of 500 mly. Dalton used an Astro Tech 10" RC AP67FR with a QSI540wsg camera for an exposure of 3×300s in RGB and a 2×2-binned 4×900s Luminance. He notes that over 40 galaxies were counted in the image; the cluster contains around 200 galaxies in total.

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Société Royale d'Astronomie du Canada

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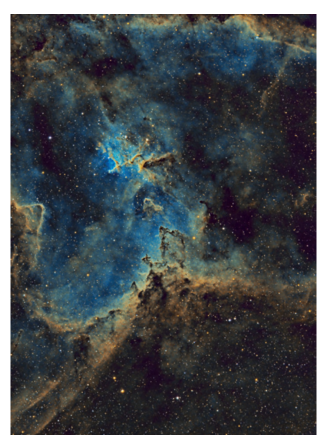

Front cover — Dan Meek provides Journal *readers with this image of the core of IC 1805 (the Heart Nebula), an emission nebula lying at a distance of 7500 light-years in Cassiopeia. The nebula's emission is stimulated by ultraviolet radiation arising from a small group of hot stars near the nebula's centre. Dan caught the photons for this image last October with a 270-minute exposure using a Tele Vue NP127 telescope with a QSI583wsg camera.*

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

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

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Canada

President's Corner

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

April 6 was a momentous day, as Prime Minister Stephen Harper announced in Vancouver, B.C., the Canadian funding of the enclosure and Adaptive Optics system for the Thirty-Meter Telescope. This has long been in the planning stages, and it looked last year like it wouldn't happen, as the money wasn't in the 2014 budget. However, applied pressure by Yours Truly, along with others in the astronomical community, made sure that the message got through—we couldn't afford *not* to be involved. The commitment to provide $243.5 million over ten years ensures that the dome construction can now go ahead. It will be built by Canadians in Port Coquitlam, B.C., and then will be dismantled for shipping to Hawaii, where it will take its place among the domes atop Mauna Kea.

The Adaptive Optics portion of Canada's contribution will be designed and constructed at the National Research Council facility in Victoria. The scientists and technicians there have much experience with such designs, as it was there that the very successful Adaptive Optics Bonnette for the Canada-France-Hawaii Telescope was developed.

The very gratifying aspect of this was that the Prime Minister's Office (PMO) specifically requested representatives from the amateur community—the RASC! Vancouver Centre member Dr. Howard Trottier and I were both invited guests at the Prime Minister's announcement in the Vancouver Space Centre near Kitsilano Beach. We joined other important personages: Dr. Raymond Carlberg, University of Toronto; Dr. Paul Hickson, UBC; Dr. Christine Wilson, CASCA President; and Guy Nelson, President and CEO of Empire Industries.

My sound bite for this momentous decision:

> *The Royal Astronomical Society of Canada is pleased to be part of the large group of people who worked on this tremendous plan, and especially pleased that the Government of Canada supports the Long-Range Plan for Astronomy and Astrophysics (LRP).*
>
> *Canadians can be justifiably proud that their presence will continue to be felt worldwide through the LRP as our leaders push us forward on the leading edge of innovation and discovery. This is a great moment for Canadian astronomy!*

Clear Skies! ✶

Figure 1 — (Left to right) Dr. Ray Carlberg (Canadian Project Director), Dr. Christine Wilson (President, Canadian Astronomical Society), The Honourable James Moore (Minister of Industry), The Right Honourable Stephen Harper, Guy Nelson (CEO and President, Empire Industries Ltd, Toronto), James Edgar (President, Royal Astronomical Society of Canada) Photo: James Moore

News Notes / En manchettes

Green filaments show past quasar activity

The *Hubble Space Telescope* has photographed a set of wispy, goblin-green filaments that are described by researchers as the ephemeral ghosts of quasars that flickered to life and then faded. The glowing structures have looping, helical, and braided shapes and are hypothesized to be long tails of gas pulled apart like taffy under the gravitational forces that result from a merger of two galaxies (Figure 1). The immense structures, tens of thousands of light-years long, are found slowly orbiting a host galaxy, long after the merger was completed.

The first "green goblin" type of object was found in 2007 by Dutch schoolteacher Hanny van Arkel while participating in the online Galaxy Zoo project. That project enlisted the public to help classify more than a million galaxies catalogued in the Sloan Digital Sky Survey (SDSS), and then moved on to add galaxies seen in *Hubble* images probing the distant Universe. The bizarre feature was dubbed Hanny's Voorwerp, Dutch for "Hanny's object."

Astronomer Bill Keel of the University of Alabama found Hanny's Voorwerp so intriguing in follow-up *Hubble* images that he initiated a project to search for other, similar objects that shared the rare and striking colour signature of Hanny's Voorwerp on the SDSS

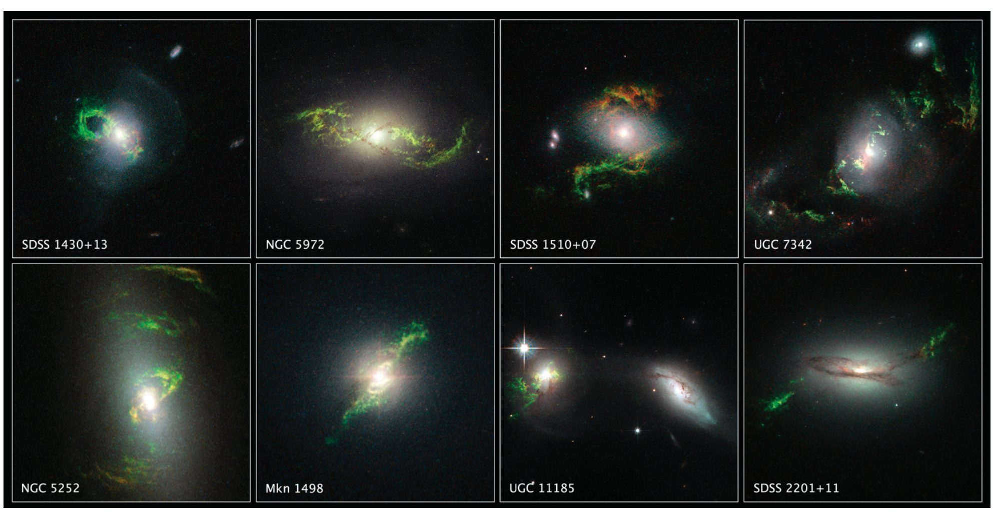


Figure 1 — These Hubble Space Telescope *images reveal a set of bizarre, greenish, looping, spiral, and braided shapes around eight active galaxies. These huge knots of dust and gas appear greenish because they are glowing predominately in light from photoionized oxygen atoms. Each galaxy hosts a bright quasar that may have illuminated the structures. The ethereal wisps outside the host galaxies were blasted, perhaps briefly, by powerful ultraviolet radiation from a supermassive black hole at the core of each galaxy. Because the quasars are not bright enough now to account for the present glow of the blobs, they may be a record of something that happened in the past inside the host galaxies. Image: NASA, ESA, and W. Keel (University of Alabama, Tuscaloosa)*

images. Keel had 200 people volunteer specifically to look at over 15,000 quasar-hosting galaxies. His team then took the most-promising galaxies and further studied them spectroscopically. In follow-up observations from Kitt Peak National Observatory and the Lick Observatory, the group found 20 galaxies that had similar green gas filaments that were ionized by radiation from a quasar, rather than from the energy of star formation, which is typical of most glowing gas clouds. The new clouds extended more than 30,000 light-years outside the host galaxies.

When observed in infrared light by NASA's *Wide-field Infrared Survey Explorer* (WISE) space telescope, eight of the newly discovered clouds were more energetic than would be expected given the amount of radiation coming from the host quasar. The host quasars were as little as one-tenth the brightness needed to provide enough energy to photoionize the gas. Keel believes the features offer insights into the puzzling behaviour of galaxies with energetic cores. "...the quasars are not bright enough now to account for what we're seeing; this is a record of something that happened in the past," Keel said. "The glowing filaments are telling us that the quasars were once emitting more energy, or they are changing very rapidly, which they were not supposed to do."

Oxygen atoms in the green filaments absorb short-wavelength light from the quasar and slowly re-emit it over many thousands of years. Other elements detected in the filaments are hydrogen, helium, nitrogen, sulfur, and neon. "The heavy elements occur in modest amounts, adding to the case that the gas originated in the outskirts of the galaxies rather than being blasted out from the nucleus," Keel noted.

"We see these twisting dust lanes connecting to the gas, and there's a mathematical model for how that material wraps around in the galaxy," Keel said. "Potentially, you can say we're seeing it 1.5 billion years after a smaller gas-rich galaxy fell into a bigger galaxy." The ghostly green structures are so far outside the host galaxies that they may not light up until tens of thousands of years after a quasar outburst, and would likewise fade only tens of thousands of years after the quasar itself does—a delay that reflects the amount of time it would take for the quasar light to reach them.

Keel speculated that this quasar variability might be explained if there are two massive black holes circling each other in the host galaxy's centre, conceivably after two galaxies merged. A pair of black holes whirling about each other could disrupt the steady flow of infalling gas, causing abrupt spikes in the accretion rate and triggering blasts of radiation. When the Milky Way merges with the Andromeda Galaxy (M31) in about 4 billion years, the black holes in each galaxy could wind up orbiting each other in a similar fashion. In the far future, our galactic system could have its own version of Hanny's Voorwerp encircling it.

Compiled from notes provided by the STSI and the University of Alabama

New Hubble Source Catalog

Astronomers at the Space Telescope Science Institute (STSI) and the Johns Hopkins University have created a new master catalogue of astronomical objects called the Hubble Source Catalog. The catalogue provides one-stop shopping for measurements of objects observed with the *Hubble Space Telescope*. All of the images are stored in the computer-based Barbara A. Mikulski Archive for Space Telescopes (MAST); the archive is bursting with more than a million images, which range from distant galaxies to compact star clusters to individual stars. For astronomers, however, a major challenge is the difficulty involved with sifting through the archival gold mine to collect the data they want to analyze. The Hubble Source Catalog now allows users readily to perform a computer search for characteristics of these sources.

The Hubble Source Catalog is a database from which astronomers can obtain the *Hubble* measurements of specific astronomical objects they want to investigate. A query to this database can take just seconds or minutes, while previously it might have required a few months of hard work, searching separate files throughout the archive. This capability promises to open the door to exciting new areas of research with *Hubble* that otherwise might have been too cumbersome to tackle. *Hubble*'s archive is a diverse collection of data from different instruments, exposure times, and orientations on the sky. This diversity greatly complicates the construction of the catalogue.

The catalogue brings together observations from the three primary cameras that have served *Hubble* since 1993: the Wide Field Planetary Camera 2, Advanced Camera for Surveys, and Wide Field Camera 3. The three cameras combined make observations spanning a wide swath of the spectrum, from ultraviolet to visible and near-infrared light. The catalogue lists all of the sources, and includes both a summary and compilation of the measurements for each object. The measurements include information about the brightness of sources, as well as a source's colour and shape. Astronomers released the first version of the catalogue on February 25.

Patterned after the Sloan Digital Sky Survey's online catalogue, the Hubble Source Catalog is a unique addition to the growing number of online astronomical archives that allow astronomers, amateurs, and the public to explore and study the Universe from the comfort of their office, sofa, or favourite coffee shop. The Hubble Source Catalog, however, wasn't designed only for today's astronomers. It will be a valuable resource for future researchers using the next generation of telescopes, such as NASA's *James Webb Space Telescope*, an infrared observatory scheduled to launch in 2018.

Users can access the Hubble Source Catalog primarily through the MAST Discovery Portal (http://mast.stsci.edu), which has been enhanced to support the Hubble Source Catalog project. They should be prepared for a flood of images. A search on

"Messier 13" was truncated to the first 10,000 hits. More details are available at https://archive.stsci.edu/hst/hsc/.

Compiled from notes provided by the Space Telescope Science Institute

ESA begins planning *Asteroid Impact Mission*

This month marked the start of preliminary design work on ESA's Asteroid Impact Mission, or AIM. Intended to demonstrate technologies for future deep-space missions, AIM will also be the agency's very first investigation of planetary defence techniques.

Planned for launch in October 2020, AIM will travel to a binary asteroid system—the paired Didymos asteroids, which will come a comparatively close 11 million km to Earth in 2022. The 800-m-diameter main body is orbited by a 170-m moon, informally called "Didymoon." This smaller body is AIM's focus: the spacecraft will perform high-resolution visual, thermal, and radar mapping of the moon to build detailed maps of its surface and interior structure. AIM will also put down a lander—ESA's first touchdown on a small body since Rosetta's Philae landed on a comet last November.

Two or more CubeSats will also be dispatched from the mothership to gather other scientific data in the vicinity of the moon. AIM should gather a rich scientific bounty—gaining valuable insights into the formation of our Solar System—but these activities will also set the stage for a historic event to come.

For AIM is also Europe's contribution to the larger Asteroid Impact & Deflection Assessment mission: AIDA. In late 2022, the NASA-led part of AIDA will arrive: the Double Asteroid Redirection Test or DART probe will approach the binary system, then crash straight into the asteroid moon at about 6 km/s. "AIM will be watching closely as DART hits Didymoon," explains Ian Carnelli, managing the mission for ESA. "In the aftermath, it will perform detailed before-and-after comparisons on the structure of the body itself, as well as its orbit, to characterise DART's kinetic impact and its consequences.

"The results will allow laboratory impact models to be calibrated on a large-scale basis, to fully understand how an asteroid would react to this kind of energy. This will shed light on the role the ejecta plume will play—a fundamental part in the energy transfer and under scientific debate for over two decades.

DART's shifting of Didymoon's orbit will mark the first time humanity has altered the dynamics of the Solar System in a measurable way. The impact is expected to provide a baseline for planning future asteroid defense strategies, including determining the momentum transfer resulting from DART's impact by measuring the dynamical state of Didymos after the impact and imaging the resulting crater and monitoring the dust environment before and after the impact as a function of time.

Figure 2 — The proposed AIM *spacecraft. Image: ESA.*

A similar collision was achieved back in 2005, when NASA's *Deep Impact* spacecraft shot a copper impactor into asteroid Tempel 1. But the Didymos moon is several tens of times smaller than Tempel 1, so much greater precision will be required to strike it, and the possibility of altering its orbit should be correspondingly higher. The Didymos moon is nearly three times larger than the body thought to have caused the 1908 Tunguska impact in Siberia, the largest impact in recorded history. The 2013 Chelyabinsk airburst, whose shockwave struck six cities across Russia, is thought to have been caused by an asteroid just 20 m in diameter.

Compiled from notes provided by ESA

New *Hubble* image of Messier 22

Figure 3 shows the centre of the globular cluster Messier 22 (M22), as observed by the NASA/ESA *Hubble Space Telescope*. Globular clusters are spherical collections of densely packed stars, relics of the early years of the Universe, with ages of typically 12 to 13 billion years, only slightly younger than the Universe's 13.8 billion years. *Hubble*'s resolving power is able to peer deep inside the cluster, revealing the individual stars in its crowded core.

Messier 22 is one of about 150 globular clusters in the Milky Way, and at just 10 000 light-years, also one of the closest to Earth. It was discovered in 1665 by Abraham Ihle, making it one of the first globulars to be discovered—not surprising, as it is

Figure 3 — Messier 22 from the **Hubble Space Telescope***. Image: ESA,* ***Hubble****, and NASA.*

one of the brightest visible from the northern hemisphere. M22 is located in Sagittarius, close to the dense mass of stars at the centre of the Milky Way that make up the Galactic Bulge. The cluster has a diameter of about 70 light-years and has an apparent size equal to the full Moon. The magnitude of the cluster is not as bright as it should be, because it is dimmed by dust and gas in the intervening interstellar space.

As leftovers from the early Universe, globular clusters are popular study objects for astronomers. M22 in particular has fascinating additional features: six planet-sized objects that are not orbiting a star have been detected in the cluster; it seems to host two black holes; and the cluster is one of only three ever found to host a planetary nebula.

The Milky Way's most distant globular cluster

Astronomers using the Gemini Telescope have found an unusually small and distant group of stars that seems oddly out of place. The cluster, made of only a handful of stars, is located far away, in the Milky Way's "suburbs." It is located where astronomers have never spotted such a small cluster before.

The new star cluster was discovered by Dongwon Kim, a Ph.D. student at the Australian National University (ANU), together with a team of astronomers (Helmut Jerjen, Antonino Milone, Dougal Mackey, and Gary Da Costa) who are conducting the Stromlo Milky Way Satellite Survey at ANU. This cluster is faint, very faint, and "truly in the suburbs of our Milky Way," said Kim. "In fact, this group of stars is about ten times more distant than the average globular star cluster in the halo of our galaxy—it's a lost puppy," Mackey adds.

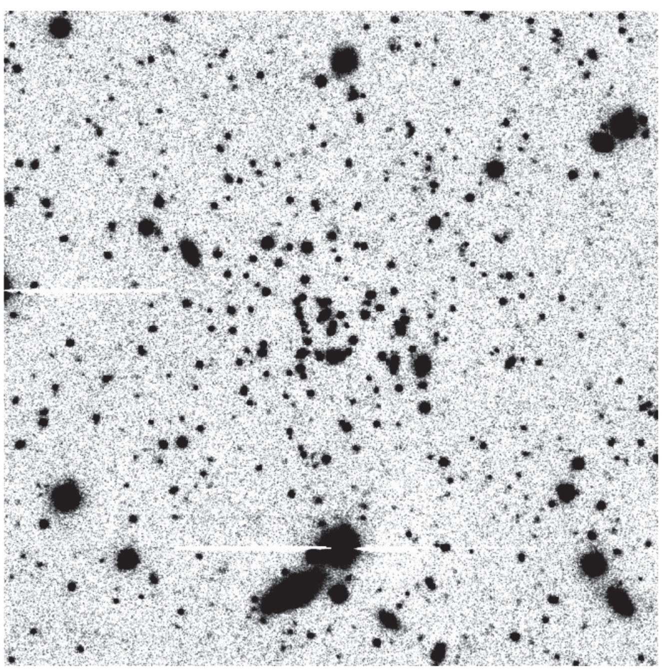


Figure 4 — 4 × 4 arcmin^2 G-band image of Kim 2, at the centre of the image. North is up, east to the left. Image: Australian Astronomical Observatory

The oddly small, far-flung cluster was discovered using the Dark Energy Camera (DECam) on the 4-metre Blanco Telescope at the Cerro Tololo Inter-American Observatory (CTIO) in Chile. The team's first evidence of the unusually remote star cluster came when they ran detection algorithms on a 500-square-degree imaging data field obtained with DECam. "Such objects are too faint and optically elusive to be seen by eye. The cluster stars are sprinkled so thinly over the image, you look right through them without noticing. They are hiding in the sea of stars from the Milky Way. Sophisticated computer programs are our tools to find them," said Jerjen.

Because it is so faint, ultra-deep, follow-up observations using the Gemini Multi-Object Spectrograph (in imaging mode) were taken to confirm that the new globular cluster is among the faintest Milky Way globular clusters ever found. Seven out of 150 known Milky Way globular clusters are comparably faint, but none are located as far out toward the edge of our galaxy. This new globular cluster has 10-20 times fewer stars than any of the other outer halo globular clusters. Also, its star density is less than half of that of other Milky Way globular clusters in the same luminosity (brightness) range.

The new star cluster, named Kim 2, also shows evidence of significant mass loss over its history. Computer simulations predict that, as a consequence of their evolution over many billions of years, including the slow loss of member stars due to the gravitational pull of the Milky Way, star clusters ought to be arranged such that their more massive stars are concentrated toward their centres. "This 'mass segregation' has been difficult to observe, particularly in low-mass clusters, but the excellent Gemini data reveal that Kim 2 appears to be mass segregated and has therefore likely lost much of its original mass," said Da Costa. The finding suggests that a substantial number of low-luminosity globular clusters must have existed in the halo when the Milky Way was younger, but most of them might have evaporated due to internal dynamical processes.

The observed properties of the new star cluster also raise the question about how such a low-luminosity system could have survived until today. One possible scenario is that Kim 2 is not actually a genuine member of the Milky Way globular cluster family, but a star cluster originally located in a satellite dwarf galaxy and was accreted into the Milky Way's halo. This picture is also supported by the fact that the stars in Kim 2 appear to be more chemically enriched with heavier elements than the other outer-halo globular clusters and are young relative to the oldest globular clusters in the Milky Way. As a consequence of spending much of its life in a dwarf galaxy, Kim 2 could have largely escaped the destructive influence of tidal forces, thus helping it to survive until the present epoch.

There are many Milky Way globular clusters formerly and currently associated with satellite dwarf galaxies. It is possible that a significant fraction of the ancient satellite dwarf galaxies were completely disrupted by the tidal field of the Milky Way, while the high density of the globular clusters allowed them to survive in our galaxy's halo. Indeed, Kim 2 is found close to the vast polar structure of Milky Way satellite galaxies, a disc-like region surrounding the Milky Way where satellite galaxies and young halo clusters preferentially congregate. A similar distribution of satellite galaxies is also found in the neighbouring Andromeda Galaxy.

A large fraction of the Milky Way's halo is thought to be populated with optically elusive satellite galaxies and star clusters. New discoveries of satellite galaxies and globular clusters will therefore provide valuable information about the formation and the structure of the Milky Way. Previous surveys like the Sloan Digital Sky Survey have contributed to many new discoveries in the northern sky. However, most of the southern sky still remains unexplored to date. The detection of Kim 2 suggests that there are a substantial number of interesting astronomical objects waiting to be discovered in the Southern Hemisphere and the Stromlo Milky Way Satellite Survey team plans to continue searching for them.

Compiled from notes provided by the Australian Astronomical Observatory

Fast-rotating asteroid litters Solar System with dust

A team led by astronomers from the Jagiellonian University in Krakow, Poland, recently used the W.M. Keck Observatory in Hawaii to observe and measure a rare class of "active asteroids" that spontaneously emit dust and have been confounding scientists for years. The team was able to measure the rotational speed of one of these objects, suggesting the asteroid spun so fast that it burst, ejecting dust and fragments in a trail behind it. Unlike the hundreds of thousands of asteroids in the main belt of our Solar System, which move cleanly along their orbits, active asteroids were discovered several years ago, mimicking comets.

In 2010, a new type of active asteroid was discovered, which ejected dust like a shot without an obvious reason. Scientists gravitated around two possible hypotheses: One states the explosion is a result of a hypervelocity collision with another minor object. The second explanation describes it as a consequence of "rotational disruption," a process of launching dust and fragments by spinning so fast that the asteroid's own gravity is insufficient to hold it together, causing it to break apart. Rotational disruption is the expected final state of what is called the YORP effect—a slow evolution of the rotation rate due to asymmetric emission of heat.

To date, astronomers have identified four objects suspected of either collision- or rotation-driven activity. These four freakish asteroids are all very small, at a kilometre or less, which makes them unimaginably faint when viewed from a typical distance of a couple hundred million miles. Despite prior attempts, the tiny size of the objects kept scientists from determining some of the key characteristics that could prove or disprove the theories.

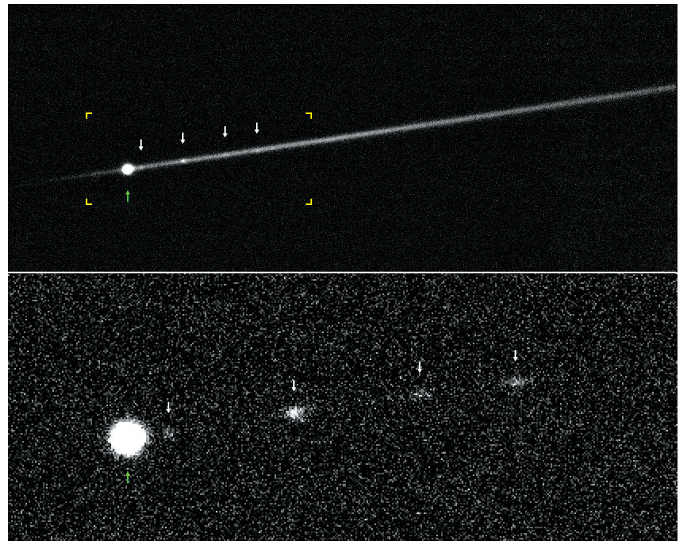


Figure 5 — Active asteroid P/2012 F5 captured by Keck II/DEIMOS in mid-2014. The top panel shows a wide-angle view of the main nucleus and smaller fragments embedded in a long dust trail. The bottom panel shows a close-up view with the trail numerically removed to enhance the visibility of the fragments. Image: M. Drahus, W. Waniak (OAUJ) / W.M. Keck Observatory

That is, until last August, when the team led by Michal Drahus of the Jagiellonian University was awarded time at Keck Observatory. "When we pointed Keck II at P/2012 F5 last August, we hoped to measure how fast it rotated and check whether it had sizable fragments. And the data showed us all that," Drahus said. The team discovered at least four fragments of the object, previously established to have impulsively ejected dust in mid-2011. They also measured a very short rotation period of 3.24 hours—fast enough to cause the object to impulsively explode. The astronomers calculated the object's rotation period by measuring small periodic fluctuations in brightness that reflect the rotation of the irregular nucleus.

"This is a well-established technique, but its application on faint targets is challenging," said Waclaw Waniak of the Jagiellonian University, who processed the Keck Observatory data. "The main difficulty is the brightness must to be probed every few minutes, so we don't have time for long exposures. We needed the huge collecting area of Keck II, which captures a plentiful amount of photons in a very short time."

The success wouldn't be possible if the selected target, P/2012 F5, were not an ideal candidate for this study. Alex R. Gibbs discovered the object on 2012 March 22 with the Mount Lemmon 1.5-metre reflector. It was initially classified as a comet, based solely on its "dusty" look, but two independent teams quickly showed that all this dust was emitted in a single pulse about a year before the discovery—something that doesn't happen to comets. When the dust settled in 2013, another team using the University of Hawaii's 2.2-metre telescope on Mauna Kea detected a star-like nucleus and suggested a maximum size of two kilometres.

"We suspected that this upper limit was close to the actual size of the object. Consequently, we chose to observe P/2012 F5 because—despite its small size—it appeared to be the largest and easiest to observe active asteroid suspected of rotational disruption," said Jessica Agarwal of the Max Planck Institute for Solar System Research, who chose P/2012 F5 as the subject.

As a result of the study, P/2012 F5 is the first freshly fragmented object in the Solar System with a well-determined spin rate, and this spin rate turns out to be the fastest among the active asteroids. A careful analysis made by the team shows that these two features of the object are consistent with the "rotational disruption" scenario, though alternative explanations, such as fragmentation due to an impact, cannot be completely ruled out.

Compiled from notes provided by the W.M. Keck Observatory

Astronomers solve decades-long mystery of the "lonely old stars"

An overwhelming majority of RR Lyrae variable stars have for long appeared to live their lives in solitary, without a companion star. This is at odds with the majority of other stars in the sky, of which about 50 percent have one or more companions. In fact, of about 100,000 known RR Lyrae variables, only one has been identified as having a binary relationship. RR Lyrae variables are among the oldest stars in the cosmos and contain precious information about the origin and evolution of the stellar systems that harbour them, such as the Milky Way itself. However, the lack of RR Lyrae stars in binary systems has made a direct assessment of some of their key properties difficult. Most often, theory had to be invoked to fill the gap.

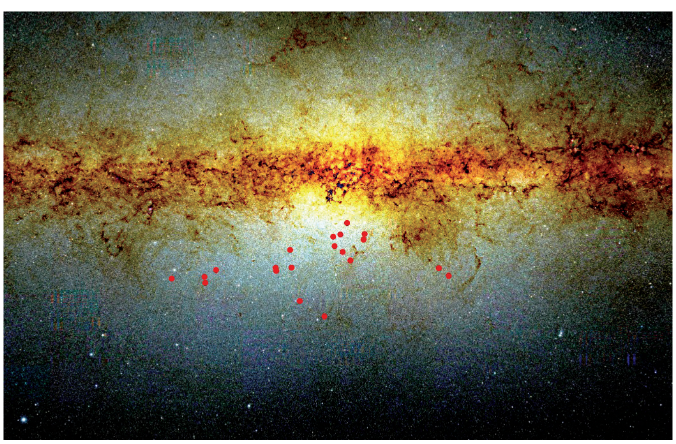


Figure 6 — Map of the sky toward the central bulge of the Milky Way, with the positions of the binary candidates indicated as red circles. The background image is based on near-infrared observations obtained in the course of the Vista Variables in the Vía Láctea (VVV) ESO Public Survey. The scale is approximately 9.7 by 5.2 degrees. The centre of our galaxy can be seen at the top of the figure, slightly to the right of the centre. Credit: ESO/ Márcio Catelan.

Now, however, an international research team led by experts of the Millennium Institute of Astrophysics (MAS) and the Pontificia Universidad Católica de Chile's Institute of Astrophysics (IA-PUC) have found evidence that these stars may not abhor companionship so thoroughly after all. In a letter published in the journal *Monthly Notices of the Royal Astronomical Society*, the team reports on the identification of as many as 20 candidate RR Lyrae binaries—an increase of up to 2000 percent with respect to previous tallies. Twelve of those candidates have enough measurements to conclude with high confidence that they do indeed consist of two stars orbiting each other.

In their study, the scientists made use of light travel time to entice evidence of a companion from the light curves of RR Lyrae variables. "The RR Lyrae stars pulsate regularly, significantly increasing, and then decreasing, their sizes, temperatures, and brightness, in a matter of just a few hours. When a pulsating star is in a binary system, the changes in brightness perceived by us can be affected by where exactly the star is in the course of its orbit around the companion. Thus, the starlight takes longer to reach us when it is at the farthest point along its orbit, and vice-versa. This subtle effect is what we have detected in our candidates," explained Gergely Hajdu, IA-PUC Ph.D. student and lead author of the study.

Hajdu attributed the detection of the 20 candidates, found by analyzing the roughly 2000 best-observed RR Lyrae stars towards the central parts of the Milky Way, to the high quality of the data and the long timespan of observations. The measurements were based on data published by the Polish OGLE Project, which obtained the measurements using the 1.3-m Warsaw telescope located at Las Campanas Observatory in northern Chile. The OGLE team repeatedly observed the same patches of the sky for many years. Indeed, the systems detected by Hajdu *et al.* have orbital periods of several years, which indicates that the companions, though bound together by gravity, are not very close to one another. "Binaries with even longer periods may also exist, but the current data do not extend long enough for us to reach strong conclusions in this respect," he adds.

For co-author Márcio Catelan, MAS Associate Researcher, IA-PUC astrophysicist and Hajdu's thesis advisor, these results have significant implications for astrophysics. " We can now exploit the orbital information contained in these binary systems—and there are quite a few of them now—in order to directly measure their physical properties, especially their masses but possibly also their diameters, thus opening new doors to discoveries that until recently seemed impossible," he says.

Compiled from notes provided by the Royal Astronomical Society

Research Paper / Articles de recherche

Time-Sequence Study of a Persistent Meteor Train

by W. John McDonald and Reg Dunkley, Victoria Centre
(wjmcd.mcdonald@gmail.com; reg_dunkley@yahoo.ca)

Abstract

A luminous persistent train[1] following a very bright meteor was captured in a sequence of digital single-lens-reflex (DSLR) camera images over a 35-minute period during the Geminid shower of December 2014. The evolution of the train can be clearly seen and exhibits features that suggest a ballistic origin with more than one source. Other factors, including upper winds, influence part, but not all, of the evolution. Complementary images from an all-sky camera at a distance of 15.2 km from the DSLR camera location show three bright eruptions at the brightest part of the track that are likely the source of the ballistic sources seen in the DSLR images. Possible contributions to the observed structure of the train, including ballistics and the upper winds, are discussed.

Résumé

Un train lumineux qui persiste suivant un météor très brillant a été capté dans une séquence d'images digitales à l'aide d'un appareil réflex mono-objectif (DSLR) pour une période de 35 minutes durant les Géminides de décembre 2014. L'évolution du train se voie clairement et démontre des caractéristiques qui suggèrent une origine balistique à plus d'une source. D'autres facteurs, y compris des vents en hauteur, influencent en partie cette evolution. Des images complémentaires d'une camera ultra-grand-angulaire à une distance de 15.2 km de la position de l'appareil DSLR montrent trois éruptions brillantes dans la partie la plus lumineuse de la trajectoire. Celles-ci sont vraisemblablement la source des sources balistiques observées dans les images DSLR. Les contributions possibles, y compris la balistique et les vents en hauteur, sont discutées.

Imaging the Event

A Canon 6D camera (modified to extend the red sensitivity) with a 50-mm Sigma *f*/1.4 Art lens lens mounted on an iOptron Sky Tracker was prepared for recording Geminid events and aimed in the direction of Orion for a test exposure of 4 minutes at *f*/2.8 and ISO 160. Sky conditions at the time of the exposure sequence were clear, +5 °C, with no wind.

During the exposure, there was a very bright flash, lighting up the sky. When the image was examined, it was found to have captured part of the track. A second exposure for 2 min at f/2.8 and ISO 320 was started 357 sec after the first. It showed a very bright train developing. As a result, a sequence of 13 additional 2-min exposures was taken. The first 6 images are shown in Figure 1. The full set of 15 images can be seen at http://rascvic.zenfolio.com/p906009768 and a time sequence video at https://www.youtube.com/watch?v=nMHK6c-9Iuc

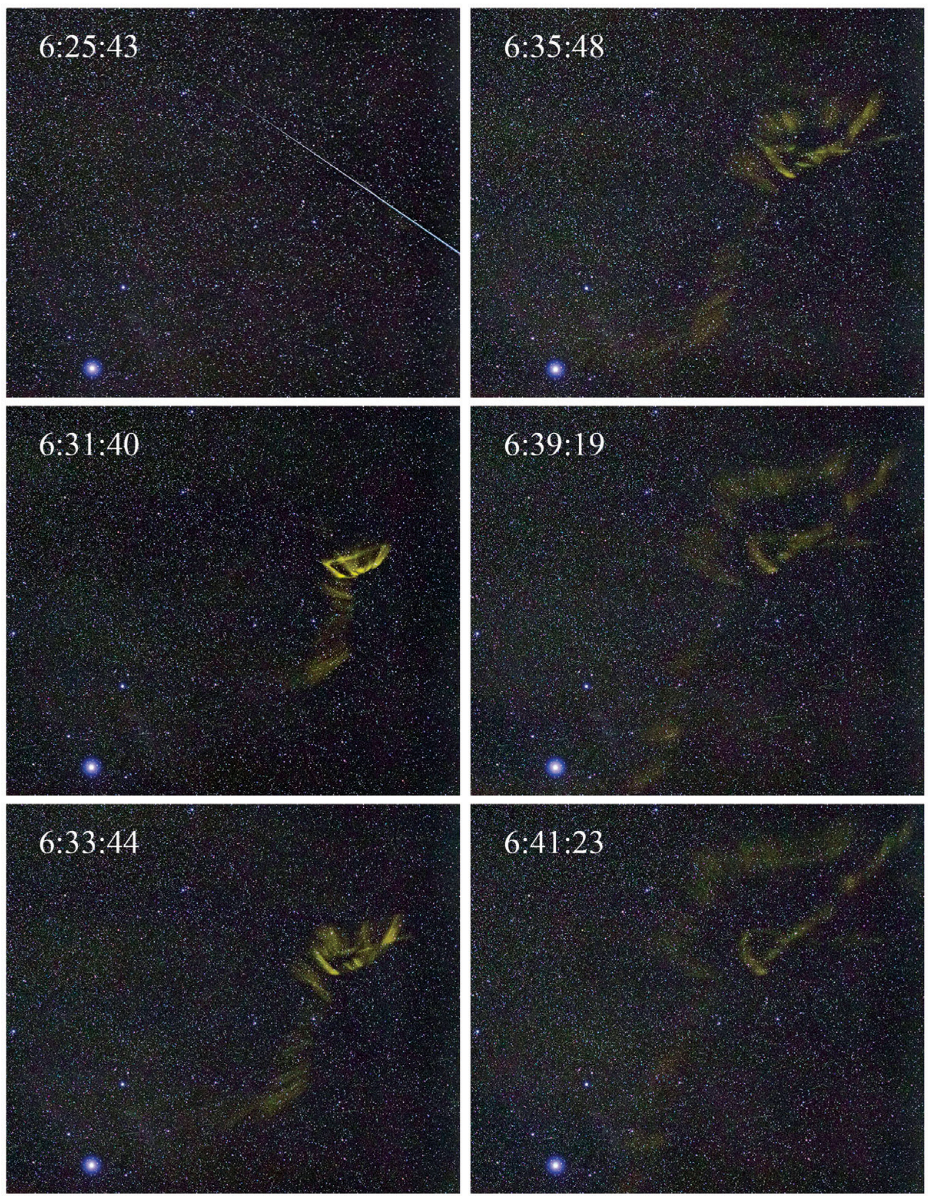


Figure 1 — The first 6 of 15 DSLR images. The numbers refer to the start of the exposure in Universal Time.

Figure 2 — Composite image of video from all-sky camera 20141215_062925

An all-sky camera operated as part of the New Mexico State All-sky Camera network (http://skysentinel.nmsu.edu/allsky) by Victoria Centre's Sid Sidhu also captured the event (Figure 2). A video of the event taken with the all-sky camera can be seen at https://www.youtube.com/watch?v=MjHeYZNqSeY. Examination of the video and the individual frames (Figure 3) revealed a series of three closely spaced flares that are likely contributing to the character of the train. In addition, a fragment can be seen emerging from the meteor after the second eruption.

The Track and Source of the Meteor

Based on the timing from the all-sky camera, the luminous meteor track that was captured on the initial 4-minute exposure of the DSLR occurred on 2014 December 15 at 06:29:29 UTC, had a duration of 1.9 seconds, and occurred 18 hours after the predicted peak of the Geminid meteor shower[2].

The meteor was still glowing when it left the right edge of the image in Figure 1 (6:25:43 UTC). The celestial coordinates of the beginning (**B**) and endpoints (**E**) of the meteor track on the image were determined by analyzing the background star field with Uranometria 2000 (Tirion *et al*. 2012). These values, together with the altitude and azimuth of the points, are found in Table 1. On December 15, the radiant of the Geminid shower was predicted to be located within one degree of Castor in the constellation Gemini. A great circle, along the track beginning at endpoint **E**, including start point **B** and then extending to the upper left, would pass 13.6 degrees above Castor. This is fairly close to the radiant and therefore it is likely that this is a Geminid rather than a sporadic meteor.

The parent bodies of most meteor showers are comets. The Geminids, however, are associated with the asteroid (3200) Phaethon. Because Phaethon comes unusually close to the Sun (0.14 AU) during its short 1.43 year period, the 5-km-diameter asteroid is subjected to intense heating with temperatures approaching 800 ˚C during perihelion. In 2009 and again in 2011, the satellite *STEREO A* detected a tail of dust being ejected from Phaethon (Jewitt *et al.* 2013) and it was dubbed a "rock comet." This dust tail, however, was too weak to replenish the Geminid meteoroid stream, which is considered the densest of all meteor showers (Madiedo *et al.* 2013). Mystery surrounding the Geminid meteoroid stream continues to generate considerable interest.

The average approach velocity of a Geminid meteoroid at the top of the atmosphere is 35 km/s (standard dev = 2.6)[2]. When compared to the approach velocity of the Leonids (71 km/s) or the Perseids (58 km/s), Geminids are relatively slow. The height at which Geminids begin to emit light is generally lower than the Leonids or Perseids, because the lower velocity requires denser air, deeper in the atmosphere, to generate sufficient heat to cause the head of the meteor to emit light.

Recent expansion of professional and amateur all-sky video-camera networks, together with cooperative data sharing, has resulted in an increase of multi-station observations of Geminids. For example, quality-controlled Geminid data obtained from the Slovak Video Meteor Network and Central European Meteor Network (Toth *et al.* 2011) reveal that in 2010, on average, the Geminids began to emit light at a height 96. 4 km and ended at 84.2 km. Preliminary results from a larger number of multi-station Geminid observations obtained in 2013 by the United Kingdom Meteor Observing Network (UKMON)[3] determined that the mean height at which Geminids became visible was 91.7 km, but many of these meteoroids continued to emit light at 70 km. Most Geminids, therefore, appear to be luminous in the range between 100 km and 70 km. The flaring during the descent and the persistent emission in its aftermath suggest that this particular meteor was more energetic that most. As a result, both the approach velocity and height range of this meteor may be greater than average.

The separation from the DSLR camera location and the complementary all-sky camera location is 15.2 km. This baseline appears to be too short to obtain triangulation for reliable height estimates but efforts to "fine tune" the camera calibration are underway. The array of all-sky camera images (Figure 3), however, provides a valuable source of timing information as well as evidence of flaring and fragmentation. There is a subtle hint of a faint widening of the meteor track

	Right Ascension	Declination [deg]	Altitude [deg]	Azimuth [deg]
Beginning Point (B)	04h 50.56m	+3.0	42.9	159.9
End Point (B)	04h 11.0m	-6.0	35.4	174.0
Second Flash	04h 28.4m	-2.0	39.0	168.2

Table 1

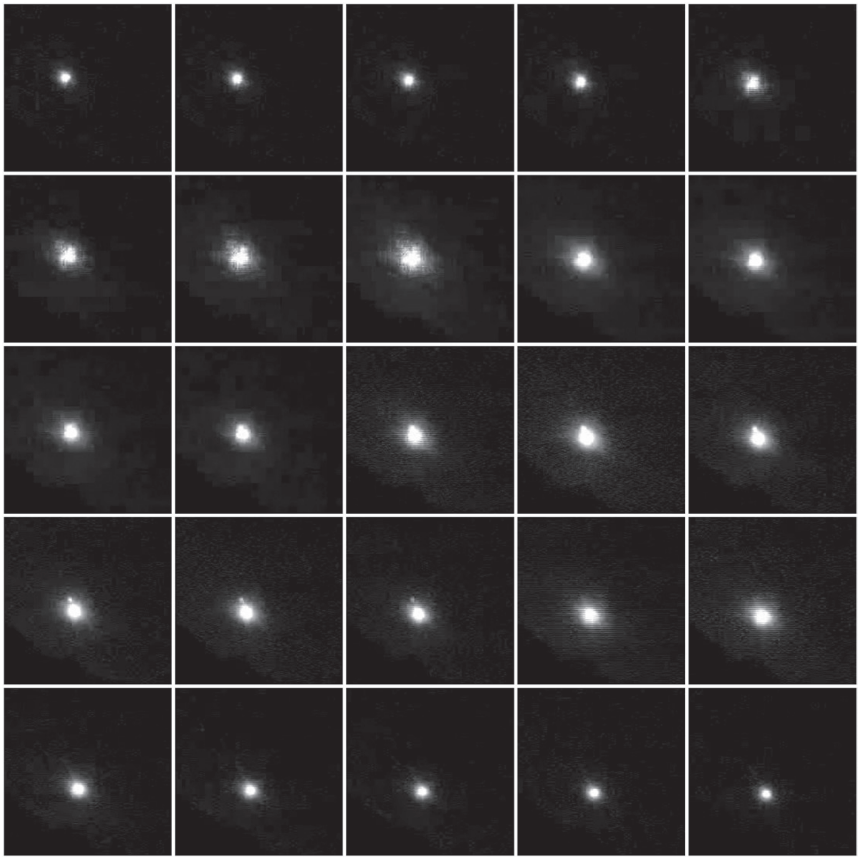


Figure 3 — Video frames from the all-sky camera showing multiple eruptive events at 20141215_062925. In the original video, three significant eruptions can be seen as well as a fragment coming off after the second one.

on the DSLR image (Figure 4) that may correspond to the position of the second flash detected by the all-sky camera.

The celestial coordinates of the possible location of the second flash are in Table 1. The total arc length of the meteor track in the image is 13.26 degrees. The arc length from the beginning of the track to the possible position of the second flash is 7.43 degrees and it was traversed in 1.2 seconds. At a constant speed, 11.76 degrees would be covered in 1.9 seconds duration of the all-sky camera video. This arc length is at least 1.50 degrees shorter than what was captured in the image but this contradiction might be explained by the likely deceleration of the meteoroid as it descended into the lower denser atmosphere. As a result, the location of the second flash appears to be consistent for the two cameras and it seems that almost the entire track of the meteor was captured by the DSLR camera.

The Persistent Meteor Train

On occasion, an eerie glow is visible in the aftermath of a meteor. Now and then, videos of this phenomenon appear on the Internet and generate considerable interest (https://vimeo.com/114924011). Usually they begin as a linear remnant of the meteor track, called the "train," which can quickly become distorted into complex shapes by the vertical wind shears present in the upper atmosphere. One of the longer-lasting meteor trains is called a "reflection train" and it occurs when daylight or twilight illuminates dust particles left in the trajectory of the fireball. When the December 15 meteor occurred, however, the Sun was well below the horizon. When the aftermath of a meteor is long lasting and self-luminous, it is called a "persistent meteor train." A JRASC article (Borovička 2006) describes the various phases of persistent meteor trains. The "afterglow" and "recombination" phases last about 3 seconds and 10 seconds respectively. These phases are followed by the much longer-lasting "continuum phase" that can last tens of minutes. The sequence of two-minute DSLR exposures began 2 minutes and 11 seconds after the flash of the meteor and lasted over 30 minutes. They captured the complex pattern of the continuum phase of a persistent meteor train.

Spectra of this phase reveal that the luminosity is associated with a broad continuous emission rather than discrete emission lines (Borovička 2006). Observations from a study of Leonids (Jenniskins 2006) supported the theory that a catalytic reaction between iron, oxygen, and ozone molecules was likely responsible for the chemiluminesence that provided the self-luminous property. The iron was introduced into the upper atmosphere by ablation from the meteoroid. Other molecules may also be involved, and it remains an area of active research. A study of 20 persistent meteor trains (Yamamoto *et al.* 2005) found that the upper height of these trains was 95 km and suggested that the density of oxygen and ozone played a role in this limit.

The complex pattern of glowing envelopes associated with this persistent meteor train makes it particularly intriguing. We will focus on three distinct zones that exhibit different qualities and follow their evolution during the first 8 minutes of the event. They will be referred to as the advection zone, the divergent zone, and the stationary zone. The 06:31:40 image in Figure 1 is the first DSLR 2-minute exposure taken 2 minutes 11 seconds after the meteor flashed across the sky. The advection zone is the area of faint yellow envelopes located in the lower right side of this image. The divergent zone is the network of bright yellow elements in the upper right portion of the picture. The stationary zone is a bright yellow horizontal line embedded in the divergent zone whose character will become evident through comparison with subsequent images.

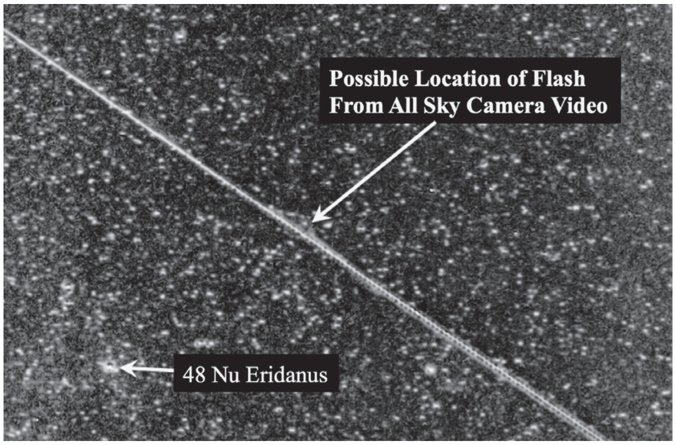


Figure 4 — Slight expansion of meteor track may indicate location of a flash.

The Advection Zone

It is interesting to follow the evolution of faint yellow envelopes on the lower right side of the 06:31:40 image as they progress on the subsequent sequence of 2-minute exposures. This is best visualized through animation of the images[4] but the motion can also be displayed by outlining these elements for several images and superimposing the sequence on one graphic as shown in Figure 5. Inspection of this figure reveals a general right-to-left progression of morphing envelopes, where the leading edge of one outline closely matches the trailing edge of the next outline. This implies that the DSLR camera is actually recording the progress of a very thin shell of luminous gas as it moves across the sky. The associated arrows on the graphics correspond to 2-minute motion vectors. The tracking of the camera introduces 0.5 degrees of motion for every two minutes because the luminous gas belongs to the atmosphere, not the rotating celestial sphere. Upper-level winds are another source of motion.

It is challenging to measure winds or monitor the rarified atmosphere where most meteor trains glow. The atmosphere in the range of 70 to 100 km elevation is referred to as the mesosphere and lower thermosphere. The density of the air is far too low to suspend sensors. The ceiling of routinely launched weather balloons is 30 km (10 millibars). The service ceiling of the Concorde, the world's highest flying commercial airliner was 18 km. The air at meteor levels, however, is too dense to permit orbiting satellites. Sounding rockets and data from the descent of over 100 *Space Shuttle* missions are about the only way to get direct measurements. Remote sensing using radar, lidar, spectroscopes, interferometers, and specialized satellite sounders has provided additional information. Because relatively little is known about this region, it is sometimes referred to as the "ignorosphere." Schlatter (2009) provides an interesting overview of the upper atmosphere. In order to estimate winds at any location or time, an empirical tool called the Horizontal Wind Model HWM07 (Drob *et al*. 2008) has been developed. It is based on over 6 million observations taken over a 50-year period and also has a component that responds to geomagnetic disturbances. This model does not incorporate local meteorological perturbations such as the upward propagation of atmospheric gravity waves and so it could be in significant error on any given day.

Upper-level winds from this model[5] were obtained for Victoria on December 14 at 2200 hours (2014 December 15 06:00 UTC). Associated geomagnetic inputs of F10.7 = 160 and Ap = 10 were used. The camera can only detect tangential motions and so only the tangential component of the wind is displayed in Figure 8. It is adjusted for an azimuth of 168 degrees, which is the direction of the bright yellow array on the image. From the graph, it can be seen that the wind has a leftward (eastward) speed of 50 m/s between an elevation of 60 to 70 km and that this speed decreases to a uniform speed of ~18 m/s between 80 to 100 km. There is vertical wind shear present between 70 and 80 km. Inspection of the vectors in Figure 5 reveals that the leftward (eastward) motion is faster at lower levels of the image. This trend is consistent with the wind model in the 70- to 80-km range. It is likely, therefore, that the motions of the envelopes are caused by the advection of the upper-level winds. For that reason, we refer to this region as the "advection zone."

The Divergent Zone

The most fascinating feature on the 06:31:40 UTC image in Figure 1 is the network of bright yellow lines on the upper right side. In some ways, this area resembles a time exposure of a busy intersection at night where the bright

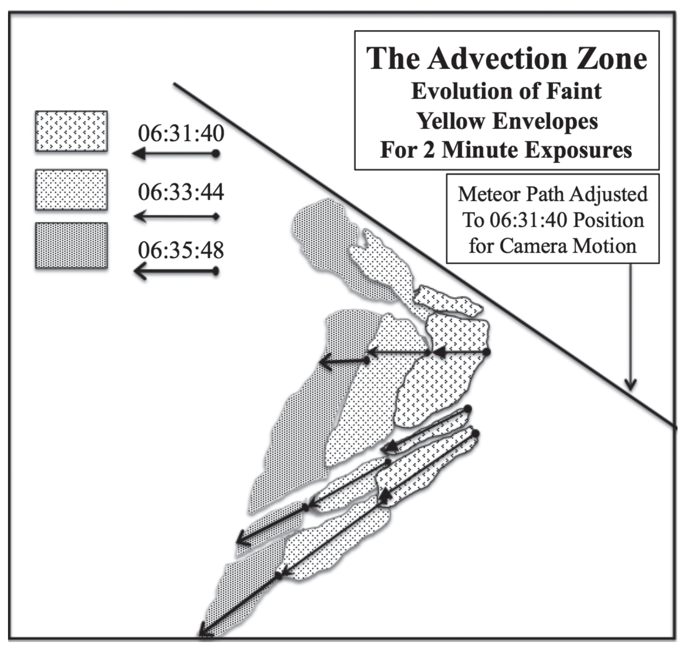


Figure 5 — Superposition of faint yellow envelopes. The leading edge of the initial envelope is very close to the trailing edge of the next envelope and this is consistent with wind advection. The numbers refer to the start of the exposure in Universal Time.

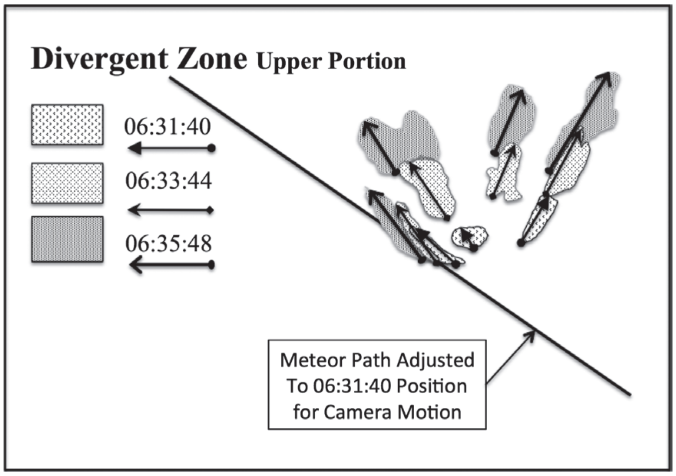


Figure 6 — Superposition of the boundaries of bright yellow envelopes. Notice that the elements diverge outward, inconsistent with an advective process. The numbers refer to the start of the exposure in Universal Time.

yellow lines are similar to the path left by taillights. As with the advection zone, the behaviour in this area is best visualized through animation of the images[4]. As was done in Figure 5, the key elements were outlined for three consecutive images and superimposed on one graphic in Figure 6. In contrast to the uniform, orderly motion that characterized Figure 5, the elements in Figure 6 are diverging outwards in different directions and therefore this area is referred to as the "divergent zone." Such disparate motions cannot be explained by the advection of a uniform wind field.

To avoid overcrowding, not all elements were included in Figure 6. In order to incorporate more detail, parts a, b, and c of Figure 7 add more elements but only focus on one individual exposure. Upon close examination, it appears that in each image the lower trailing edge of the elements form a ring shape. An ellipse was drawn on each graphic to emphasize this property. In each subsequent image, the ellipse appears to rise and expand. The semi-major axis of the ellipse in 7b is approximately twice that of the ellipse in 7a. Similarly, the semi-major axis of the ellipse in 7c is approximately three times longer than that of the ellipse in 7a. This suggests there is a uniform rate of expansion occurring every two minutes and that the semi-major axis would shrink to zero 2 minutes before the exposure for 7a began.

Another interesting characteristic is that the elements on the top of each ring are growing with time while the elements at the bottom of the ring are remaining much smaller. One explanation for this is that the elements at the top of the ring are approaching (moving out of the image) while the elements at the bottom of the ring are receding (moving into the image). The elements also possess a ray-like structure similar to that of projectiles being expelled from an explosion.

When compared to the advection zone, the divergent zone is much more luminous, suggesting more-energetic processes. Taken together, the features in the divergent zone are consistent with the model of an explosion where we are looking through the bottom of the ring as the glowing gases move outward and away from a centre of origin.

The Stationary Zone

While most elements in the divergent zone are moving outward, there is one feature that is almost motionless. When superimposed, the elements in figure 7d appear to overlap each other and therefore it has been dubbed the "stationary zone." The position of the initial element of the stationary zone has been identified in Figure 8.

The possible positions of the first and second flashes that were detected in the all-sky camera video were also labelled

Figure 7 a, b, c, d — Notice, that in a, b, and c, the trailing edge of the envelopes can be connected by a ring. Elements on top of the ring appear to approach, moving out of the page, while elements on the bottom of the ring appear to recede into the page. Their motion is in sharp contrast to the nearly stationary behaviour depicted by the composite in d. The numbers refer to the start of the exposure in Universal Time.

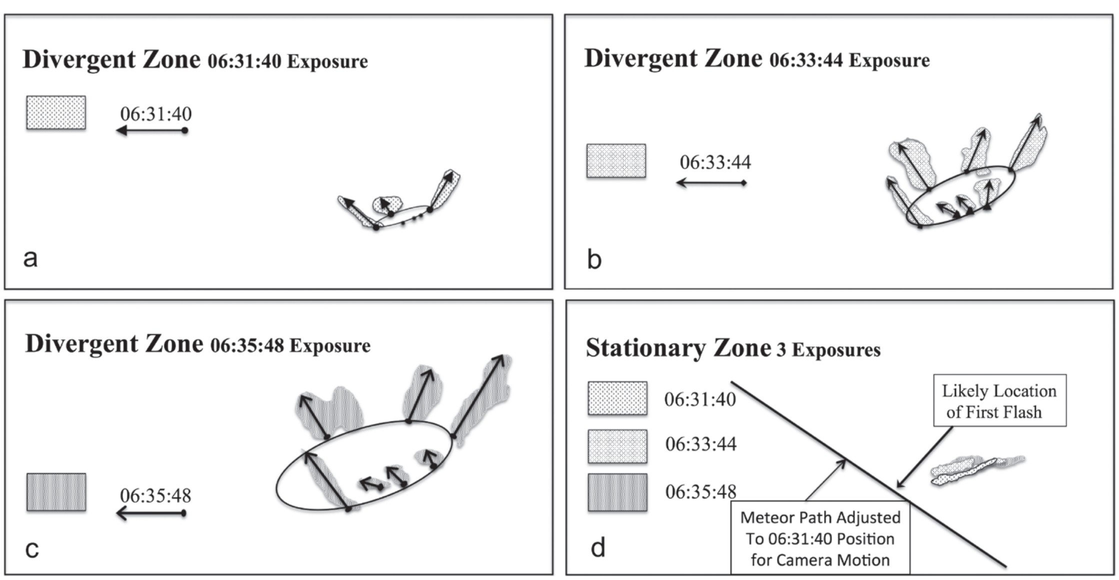
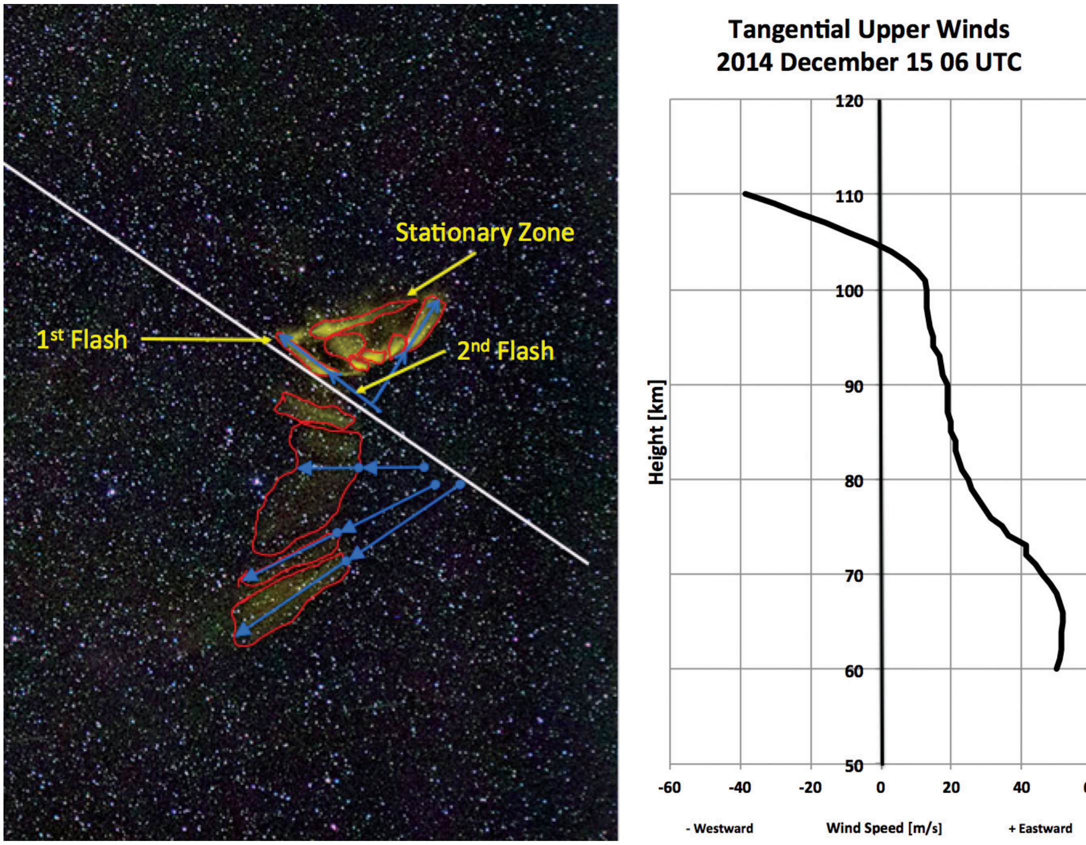


Figure 8 — Details of the 2-minute exposure starting at 06:31:40 UTC



in Figure 8. The position of the second flash was directly determined from the slight widening of the meteor track in Figure 4. The location of the first flash, however, was determined by first calculating the angular distance travelled during the 0.2 seconds between flashes and then by moving up the track that distance from the position of the second flash. It is interesting to note that the estimated position of the first flash is adjacent to the stationary zone.

The Gap in Exposures

It should be noted that the initial exposure, which was 4 minutes in duration, ended at 06:29:43 UTC, some 14 seconds after the occurrence of the meteor. It was also 1 minute 57 seconds before the first two-minute exposure commenced. While we will never know what actually occurred during this gap, we do have two-minute motion vectors on the 06:31:40 image. The initial position two minutes earlier can be estimated by extending the vectors backwards a similar length from their start point and this is shown in Figure 8. For the advection zone, the initial positions were distributed along the track of the meteor. For the divergent zone, however, the vectors intersect at a point fairly close to the position of the second flash.

Discussion

The all-sky camera video provided valuable timing information, evidence of three flashes or eruptions, and proof that a fragmented remnant was left in the track of the meteor. This information was integrated with our analysis of the motion and evolution of the glowing envelopes captured by the DSLR imagery. Although we were unable to obtain precise measurements and numbers through triangulation, we have obtained insight into a number of processes that contributed to the evolution of this persistent meteor train and present the following conceptual model.

Pale yellow envelopes in the advection zone, located in the lower right of the imagery, were likely created by a thin shell of chemiluminesence gas as it moved across the sky (Figure 5). The subtraction of associated motion vectors in Figure 8 indicate that the meteor track provided a distributed source for these chemiluminesence gases. The motion of these envelopes is consistent with the advection of gases by a typical upper-level wind field predicted by the HWM07 horizontal wind model with eastward winds increasing below 80 km.

The much brighter elements in the divergent zone, located in the upper right of the imagery, imply more energetic processes than those involved in the advection zone. The diverging rays depicted in Figure 6 cannot be explained by wind advection. The uniform expanding rings identified in Figure 7 a, b, and c are consistent with the aftermath of an explosion. When motion vectors in the divergent zone are subtracted in Figure 8, they intersect along the meteor track near the position of the second meteor flash. We believe that this second flash is a record of a ballistic event, likely triggered by thermal stresses, in which highly energized ablated molecules and ions are expelled in ray-like elements. The expanding rays at the top of the rings in Figure 7 a, b, and c are approaching, while the elements at the bottom of the ring are receding.

The zone of stationary horizontal elements identified in Figure 7d and Figure 8 is in marked contrast to the expansive nature of the divergent zone. The stationary zone is clearly formed by a different process. It has been shown that the stationary zone lies just to the right of the position of the first flash. We propose that the first flash was an explosion that expelled molecules and ions in a direction that is largely radial to the camera axis so that it would appear to hover at one altitude as it receded and faded.

The brightest element lies between the positions of the first and second flashes very close to the initial track of the meteor. It can still be discerned in an exposure that began at 06:57:55 UTC, over 28 minutes after the meteor blazed across the sky. The all-sky camera showed that the fragment that was visible at the time of the second flash remained close to the meteor track. Perhaps the remnants of this fragment seeded the upper atmosphere with a richer concentration of catalytic molecules that sustained a stronger and longer eerie glow of chemiluminesence.

Beyond the third 2-minute exposure, the patterns of the meteor train continued to morph. Due to uncertainties in the upper-level wind field and the height of the glow, it was decided to end the study at this time frame.

The great good fortune of capturing a bright meteor with both a DSLR camera and a nearby all-sky video camera does not happen every night. If you do get lucky, however, keep taking exposures! You too may capture a persistent meteor train. It is a great passport into the fascinating field of meteoritics.

Acknowledgements

Mr. Sid Sidhu of the RASC Victoria Centre has patiently operated an all-sky camera for over a decade. Sid's video imagery played a vital role in the quest to understand the evolution of this meteor train. The authors are very grateful for his important contribution. The authors would also like to thank Mr. Jeff Brower and Mr. Ed Majden of the B.C. Meteor Network (www.bcmeteors.net) for sharing their knowledge, enthusiasm, and encouragement. ✶

Endnotes

1 Train is the term defined by the International Astronomical Union (IAU) to refer to anything (such as light or ionization) left along the trajectory of the meteor after the head of the meteor has passed. Millman P. JRASC, Vol. 55, p. 265.

2 International Meteor Organization Meteor Shower Calendar for 2014 www.imo.net/calendar/2014#gem

3 UKMON Annual Report for 2013, See Geminids Section www.ukmeteornetwork.co.uk/2014/05/ukmon-annual-report-2013/

4 Video of Geminid Meteor Train 2014 December 15 http://youtu.be/nMHK6c-9Iuc

5 Horizontal Wind Model Data from HWM07 can be obtained using a convenient iPhone/iPad/iPod Touch App called *MSISatmos*. It is available free of charge from the iTunes App Store. For more information go to: http://sites.google.com/site/msisatmos

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Featured Articles / Articles de fond

The March 20 Total Solar Eclipse

by Jay Anderson, Winnipeg Centre
(jander@cc.umanitoba.ca)

An astronomical time-honoured ritual took place on March 20 this year when thousands of "eclipsophiles" gathered at ritual sites in the North Atlantic to pay homage to the passing lunar shadow. Travellers assembled from around the world to watch, placing their faith in geometry, Solar System dynamics, and the weather forecast. Some were rewarded handsomely; others were not.

Eclipse chasing (Jay Pasachoff objects to the term, venturing that the eclipse comes to him, not the other way around) began as a pastime in England in 1715, after Edmund Halley, a year earlier, calculated and constructed a map that showed the track of the eclipse. The map was produced in good time—the first to be available beforehand—so that travellers had time to reach England and stand under the shadow. Indeed, the first eclipse chaser may well be Jacques-Eugene d'Allonville, Chevalier de Louville, who travelled to London at personal expense to stand beside Newton during the event.

The March 20 event this year was noteworthy for its overwater passage, touching land only on the Faroe Islands, half way between Scotland and Iceland, and on the Svalbard Archipelago, midway between Norway and the North Pole. Just as notable was the very great popularity of the event, which saw thousands travel to each of these remote islands to catch a view of the eclipsed Sun, especially as the weather conditions are not particularly favourable at either site. At least 15 aircraft were in the air to watch from above clouds, but their experiences were not always positive. Three regularly scheduled flights diverted or delayed departure to let passengers see the eclipse; the pilots even circled to let both sides of the aircraft witness the event.

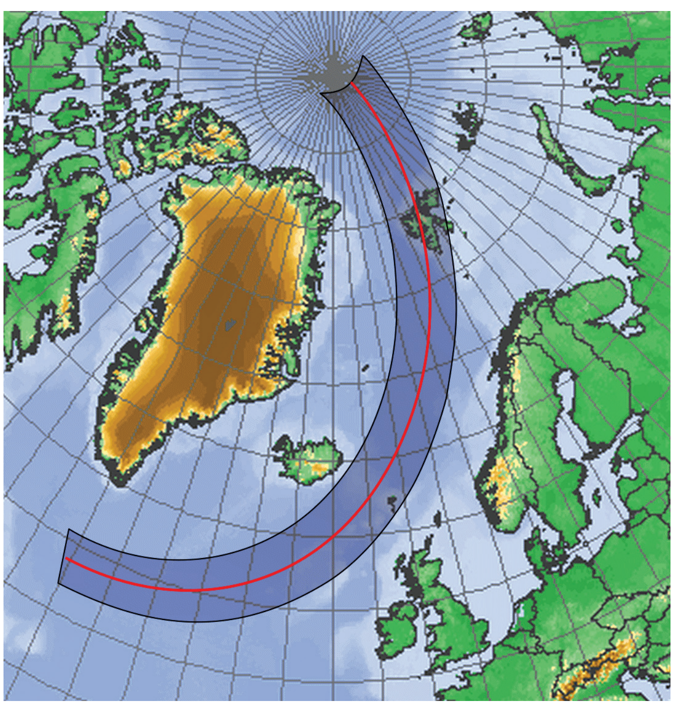


Figure 1 — The track of the eclipse across the North Atlantic.

At Svalbard, where this watcher travelled, every available piece of accommodation was occupied, so much so that some travellers flew in for the event and left immediately afterward on the next flight southward. To be sure, accommodation at Longyearbyen, one of only two significant communities on Spitsbergen Island, was somewhat limited, but informal estimates suggest that the town's population of 2000 doubled for eclipse day.

Rooms for tourists are much easier to come by on the Faroe Islands, and the route from Europe, by plane from Denmark, Iceland, or Scotland, or by ferry from Scotland, is much less expensive than the flight to Svalbard, and so the islands were visited by a much larger eclipse-seeking crowd than farther north—as many as 8000 from some estimates. The islanders took advantage of the opportunity by raising prices, a sadly normal event wherever eclipses are found around the globe.

Svalbard is an interesting island: administered by Norway, but not part of Norway; without immigration regulations (anyone can move and live there); mostly uninhabited; with more polar bears than people; blessed with low taxes; and with pretty warm temperatures considering its latitude of just below 80 degrees north. Because a branch of the Gulf Stream reaches the islands, the west side usually has open water year round, which gives Longyearbyen (named after Longyear, an American entrepreneur) an average annual temperature of only -4.7 °C. Temperatures and clouds are highly variable, which made eclipse-day temperatures, at -16 °C, welcome, since cold temperatures come with sunny skies on the archipelago. And clear it was—a magnificent, deep blue, crisp sky with only one cloud on a nearby mountain to spoil the record.

At my eclipse site, operated by TravelQuest Tours, we were joined by chasers from Japan, Australia, the USA, Canada, Norway, Germany, South Africa, and a cross-section of other European countries. A large tent, warmed by propane heaters, and buses that were kept running provided refuge from the cold, which was tolerable by Canadian standards, but cold for most of the rest of the world. Many would-be photographers had to adopt "Plan B" when the computers that were to control their cameras failed in the approach to totality. By one measure, temperatures fell from -16 °C at first contact to -22 °C just after totality.

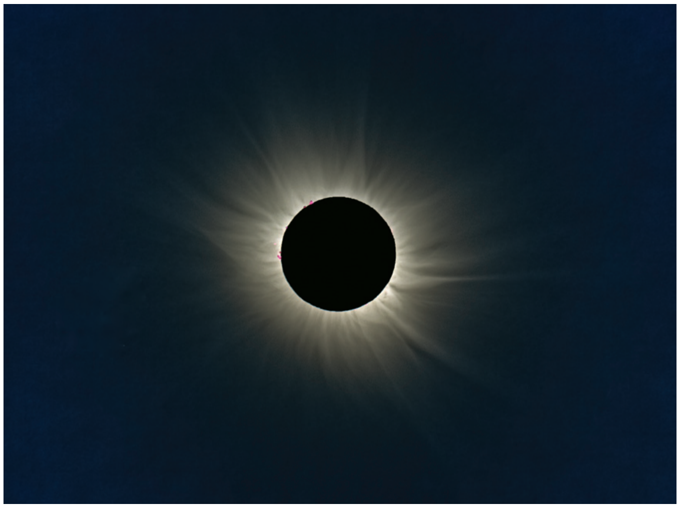


Figure 2 — A composite image of the total eclipse. Image: Judy Anderson; image processing: Alson Wong.

The eclipsed Sun was a spectacular example of a solar max corona, with at least eight plumes surrounding the black lunar disk. Two bright prominences stood out on the limb as the eclipse started, but several more were uncovered as the lunar disk slid across the Sun. The chromosphere was noticeable, but not dramatic. What was dramatic were the shadow bands that flitted across the snowy ground in the 15 seconds before and after totality. The diamond ring at the end came on slowly and more dramatically, bringing the 400 people on the site to cheers and congratulations. Though the sky transparency was exceptional, the background was bright because of the reflective snow cover.

In the Faroes, a recently departed frontal system left broken to overcast cloudiness across the islands, so very few eclipse watchers were able to see the event. Edmonton's Paul Deans was one who managed to see a part of the eclipse:

> *...at the Vagar airport in the Faroe Islands, we caught about 1 min 18 sec of totality, from diamond ring to cloud cover. We had cloud at first contact and rain off and on after that. Rapidly moving clouds, with larger and larger gaps, flowed eastward overhead. In the last 10 minutes prior to totality, the Sun was cloud free...then cloud and cloud streamers moved in during the last minute. We briefly lost the Sun in cloud (screams of "Noooo" rose from the group), but then we saw beads thru cloud. The diamond ring thru cloud (with iridescence) was amazing, the sky around the Sun cleared, and the prominences and corona were stunning. We could see heavy cloud rapidly moving in, and we lost totality before third contact. About five minutes later, it was raining.*

At Torshavn, the capital, most observers were clouded out completely. Some intrepid chasers managed to follow a hole in the cloud and see the whole eclipse, but there were few of them that scored that well.

Those who eschewed the cloud and elected for a view from high altitude had mixed experiences on the many flights that intercepted the eclipse track. For some, it was a fantastical experience, viewing the Sun and the shadow below from a high-altitude viewpoint. For others, windows were plagued by ice crystals and scratched plastic, sometimes with the Sun at too high an angle to view comfortably. Even so, the unfortunate circumstances did not entirely subtract from the experience, as many YouTube videos testify.

Attention has now turned to the 2016 eclipse in March, which will take place over Indonesia and the Pacific, and for which accommodation is already getting scarce. In the background, and looming larger every month, is the August 2017 eclipse over the United States. No doubt that one will be the "eclipse of the century" or the "super-duper eclipse" in keeping with the usual American hyperbole. ✶

Jay Anderson is an eclipse watcher and editor of the Journal.

David Dunlap Observatory and World War II

by Lee Robbins
Department of Astronomy and Astrophysics, University of Toronto, Toronto, Ontario

There were a number of significant ways that the University of Toronto contributed scientifically to the Canadian World War II effort in addition to the approximately 10,000 individuals from the university who served in the armed forces. Among them, the University of Toronto led Canada's efforts in aviation medicine[1]. The most notable of these that have appeared in print are the contributions to aviation medicine by Frederick Banting and Wilbur Franks. Banting, who won the Nobel Prize in 1923 for his discovery of insulin, participated with the Royal Canadian Air Force (RCAF) in research concerning the physiological problems encountered by pilots operating high-altitude combat aircraft. He headed the RCAF's Clinical Investigation Unit; a team investigated the physiological problems caused by high speeds and high altitudes. High speeds, particularly in aerial dives and dog fights, produced blindness and then unconsciousness as blood was drawn from the eyes and the brain by the effects of accentuated gravity. Banting also built the first decompression chamber in North America, in 1941, to study the effects of high altitudes, and an accelerator to test the effects of speed. He also worked on treatments for mustard gas, oxygen masks, and biological and chemical warfare (Friedland 2002, 356-359).

Professor Wilbur Franks invented the first anti-gravity or G-suit used in combat. Franks' G-suit was first used by the Royal Navy Fleet Air Arm during the invasion of North Africa in November 1942 (Friedland 2002, 357-358).

Less well known are the contributions made by individuals working at the David Dunlap Observatory. When the observatory opened in 1935, just a few years prior to the outbreak of hostilities in Europe, it housed the second largest telescope in the world, and it was just beginning to conduct productive research and establish itself as a world-class institution. Since the opening (Hogg & Hogg 1935), under the directorship of Dr. R.K. Young, staff had been working on the determination of radial velocities of stars not previously measured. Helen Sawyer Hogg had also begun a program of observations at the Newtonian focus of globular clusters by direct photography. The 74-inch telescope was being used from twilight to dawn every clear night of the year, although it was the policy of the observatory since its inception that two hours were set aside every Saturday night from the first of April to the end of October for public viewing (Heard & Hogg 1967).

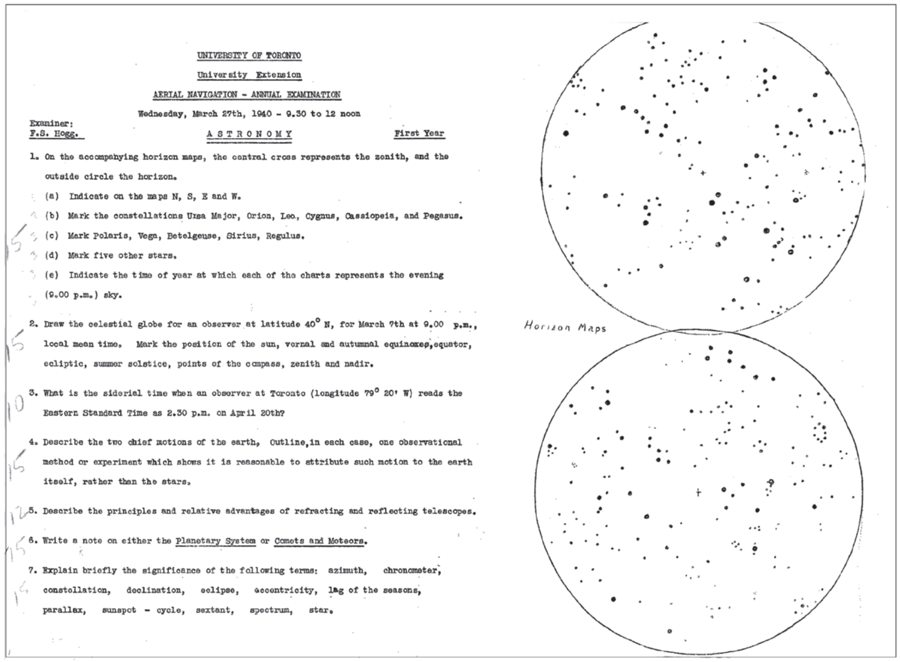
Figure 1 — DDO staff and students in 1939. Front row (L to R): Ruth Northcott, Clarence Chant, Helen Sawyer Hogg, Edna Fuller. Back row: Gerald Longworth, Andrew Bunker, George Tidy, R.K. Young, Frank Hogg, Peter Millman, Jack Heard.

World War II had a significant impact on the observatory's research and teaching activities. Figure 1 shows a photograph, taken at DDO, of the staff and students at the start of the war. One by one, staff members left for war service. According to Helen Sawyer Hogg, during the war years, Young and Frank Hogg alternated between nights observing and days teaching at the university. Because many of the male astronomers had left for various war duties, Helen Sawyer Hogg was first given teaching duties at the university[2].

During the first year of the war, astronomical air navigation was of primary importance in training navigators for the Commonwealth Air Forces. This was prior to the development and wide deployment of radar navigation techniques. Many of the staff and faculty from the DDO enlisted in the various armed forces and got involved in the teaching of air navigation, as there was a good deal of reliance placed upon those with astronomical training for the development of training systems. An example exam from a First Year University Extension Astronomy course on Aerial Navigation taught by Frank Hogg is shown in Figure 2.

Many advances in air navigation were spurred by the war. A great deal of effort went into the simplification of the procedure of obtaining astronomical fixes by air navigators. Frank Hogg, who had accepted a position at the observatory in 1935 (and became director in 1946, a position he held until his death at age 46 in 1951), was not accepted into the service because of health reasons but he still taught classes in navigation (Chant 1951, Heard 1951). In the early days of WWII, Frank Hogg developed a two-star sextant, shown in Figure 3, that eliminated the time-consuming and error-prone computations of working out and plotting the sextant sights on two and three stars (Heard 1969). Several prototype models

Figure 2 — Aerial Navigation Exam given by Frank Hogg in March 1940.


UNIVERSITY OF TORONTO

University Extension

AERIAL NAVIGATION - ANNUAL EXAMINATION

Wednesday, March 27th, 1940 - 9.30 to 12 noon

Examiner:
F.S. Hogg.

A S T R O N O M Y

First Year

1. On the accompanying horizon maps, the central cross represents the zenith, and the outside circle the horizon.
   (a) Indicate on the maps N, S, E and W.
   (b) Mark the constellations Ursa Major, Orion, Leo, Cygnus, Cassiopeia, and Pegasus.
   (c) Mark Polaris, Vega, Betelgeuse, Sirius, Regulus.
   (d) Mark five other stars.
   (e) Indicate the time of year at which each of the charts represents the evening (9.00 p.m.) sky.

2. Draw the celestial globe for an observer at latitude 40° N, for March 7th at 9.00 p.m., local mean time. Mark the position of the sun, vernal and autumnal equinoxes, equator, ecliptic, summer solstice, points of the compass, zenith and nadir.

3. What is the siderial time when an observer at Toronto (longitude 79° 20' W) reads the Eastern Standard Time as 2.30 p.m. on April 20th?

4. Describe the two chief motions of the earth, Outline, in each case, one observational method or experiment which shows it is reasonable to attribute such motion to the earth itself, rather than the stars.

5. Describe the principles and relative advantages of refracting and reflecting telescopes.

6. Write a note on either the Planetary System or Comets and Meteors.

7. Explain briefly the significance of the following terms: azimuth, chronometer, constellation, declination, eclipse, eccentricity, lag of the seasons, parallax, sunspot - cycle, sextant, spectrum, star.

were built in the DDO machine shop by Gerry Longworth, and these served as test models for the Armed Service in Canada, including the Navy, and in the United States (Fernie 1979). Dr. Heard actually tested one of these instruments while leaning out the rear window of an Avro Anson bomber while on a training flight from London to Coboconk, Ontario (Heard & Hogg 1967). Dr. J.D. Fernie (Fernie 1979) writes that although, with training and practice, the two-star sextant, which dramatically lessened the amount of tabular consultation and data reduction and could cut the observation time in half, was not adopted due to the difficulty of making the observations and its limitations to latitudes higher than about 10 degrees north. A letter to Dr. Hogg from Wing Commander E.E. "Tubby" Vielle at the British Air Commission based in Washington, D.C., dated 1942 August 1, also refers to the development of radio devices to aid air navigation taking preference over astronomical navigation. Radar was also used in an offensive strategy by giving aircraft the ability to attack targets at night or during inclement weather.

Dr. C.A. Chant recruited John F. Heard in 1935 to work at the newly established David Dunlap Observatory. In November 1940, Dr. Heard enlisted in the Royal Canadian Air Force and was on leave of absence from the university until 1945. He became an instructor in navigation under the Commonwealth Air Training Plan, rising to the rank of Wing Commander and he played a major role in the development of aerial navigation, particularly that for hours of darkness. For six years after the war, he was Chairman of the Navigation Research Panel of the Defence Research Board (Hogg 1977). After Frank Hogg's death in 1951, John Heard became the DDO director, retiring in 1965. He continued his academic career in the University of Toronto's Department of Astronomy, retiring as Professor Emeritus in 1976. Heard went on to earn an international reputation for his research in stellar spectroscopy.

Figure 3 — Side (L) and bottom (R) view of a prototype model of Frank Hogg's two-star sextant manufactured at the David Dunlap Observatory, circa 1940.

Peter Millman was hired on to the faculty by Chant in 1933 to assist with planning the DDO and to help with the teaching. His main research focused on stellar radial velocities, but he also started a systematic program of meteor observations with emphasis on spectroscopy. Dr. Millman's career at the DDO was interrupted early in 1941, when he enlisted in the Royal Canadian Air Force. Initially he was one of numerous scientists teaching aerial navigation to air crew trainees in Canada, followed by active duty in England as an Operational Research Officer. In 1946, he retired with the rank of Squadron Leader and resumed his scientific career with the Dominion Observatory in Ottawa (Halliday 1991).

George H. Tidy, an observing assistant, joined the Royal Canadian Navy as a radio technician in July 1940, and was stationed in southern England. He was mistakenly reported lost in the battle of Java in March 1942, and an obituary was published in the April 1942 *Journal of the Royal Astronomical Society of Canada* (Young 1942), but he was later released from a Japanese prison camp (Heard & Hogg 1967). He did not return to astronomy but took up a senior position at the Defence Research Board of Canada (Heard 1970).

W.F.M. Buscombe, an observatory part-time assistant, also enlisted in November 1940 and became a weather forecaster and instructor in meteorology in a civilian capacity with

Figure 4 — (a) Astro Compass MK II, (b) Dalton International Convention on Aerial Navigation (ICAN) Dead Reckoning Computer, (c) Bubble Sextant Mark IX and (d) David White Company Theodolite.

the Dominion Meteorological Service. Andrew Bunker, a telescope operator, joined the U.S. Weather Bureau, forecasting weather on flights for bombing missions[3]. Gerald Longworth, DDO night assistant and mechanic, signed up in 1944 and served as a Petty Officer in the Royal Canadian Navy.

The Department of Astronomy and Astrophysics archives still house many of the instruments that were used for teaching air navigation. Some of these include: astro compasses (Figure 4a), which were suspended from the navigator's upper observation dome and used to calculate true north from the position of the Sun or stars; Dalton Dead Reckoning computers (Figure 4b), which were strapped to the pilot or navigator's knee and used for air navigation; bubble sextants (Figure 4c), used on board aircraft to obtain the altitude of the Sun or other celestial bodies; and a theodolite (Figure 4d), used for tracking the position and altitude of sounding balloons to determine wind velocities at various heights above ground.

By the end of the war there were only three names that appeared in the DDO telescope-observation logbooks: Frank Hogg, R.K. Young, and Ruth Northcott. Frank Hogg, DDO's newly appointed Director in 1946, had a smaller teaching staff than in the prewar years; however, the University of Toronto's student enrollment had doubled in the years immediately after the war with little increase in funding (Heard 1976). The staff that remained at the observatory worked to keep the observatory running at all possible times and still maintain their increasing daytime teaching responsibilities. DDO continued to develop and grow through the postwar period, teaching programs in radio astronomy, galactic astronomy, and theoretical astrophysics and cosmology, and trained a new generation of astronomers in Canada. ✶

Acknowledgements

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Endnotes

1 Canada's Aerospace Medicine Pioneers: www.asc-csa.gc.ca/eng/sciences/osm/aviation.asp

2 Oral History Transcript from Interview of Dr. Helen Sawyer Hogg by David DeVorkin on 1979 August 17. Niels Bohr Library & Archives, American Institute of Physics, College Park, MD USA. www.aip.org/history/ohilist/4679.html

3 Andrew F. Bunker papers. Woods Hole Oceanographic Institution. Data Library and Archives. http://dla.whoi.edu/manuscripts/node/185736

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Inviting the Right Aliens to Tea—the State of the Question at the Victoria Centre, 1931

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

Abstract

In 1931, the Victoria Centre presented the symposium "On Possibilities of Life in the Universe," with speakers drawn from the professional and amateur ranks of Centre membership. The event was probably the first Canadian symposium on extraterrestrial life, possibly the earliest in North America, and a precocious example of pro-am collaboration in astrobiological outreach. This paper assesses the positions of the speakers in light of the best informed astronomical thought of the day, considers the symposium as evidence for or against the "Sagan" thesis postulating a shrivelling of planetary science in the wake of the early 20th-century deviant Lowellian planetology, and probes the symposium's total eclipse from the subsequent historiography of the "Extraterrestrial Life Debate," and its complete lack of influence. As with all good stories, there are lessons and surprises.

Figure 1 — At the time of the 1931 Life on Other Worlds symposium, Victoria basked in its genteel reputation. Copyright Speculum astronomica minima.

Origins

"Origins" is a word with the power to allure. The intelligent life we know best likes to search for "origins." The attraction of the word owes something to its evocation of times removed from the present and of places far from familiar, of profound unknowing, of things coming into being that formerly were not, and with the finality of beginnings. The public are said to respond well to the term. The number of "hits" returned from entering "origins" into the search engines on the websites of the European Space Agency and NASA amply demonstrates the power of the word: 104,000 hits from the ESA, and 94,400 hits from NASA.[1]

Modern accounts of what is now called "astrobiology" place the origin of its first conferences and symposia in the late 1950s and early 1960s, such as the First International Symposium on the Origin of Life on the Earth, held in Moscow on the eve of Sputnik (1957 August 19-24) and attended by A.I. Oparin, Harold Urey, and Stanley Miller, among others (Oparin *et al.* 1959). A conference held under the auspices of the Lowell Observatory and the Rand Corporation on 1957 June 18 was called the "first American symposium on Astrobiology" (Wilson 1958, 43; Dick 1996, 139) and featured Audouin Dollfus of the astrophysical observatory at Meudon (hardly an American), and the newly-minted "American" Hubertus Strughold (courtesy of Operation Paperclip).[2] More alive in the historical imagination is the Green Bank Conference, otherwise known as the first Conference on Interstellar Communication, held at the National Radio Astronomy Observatory in 1961, whose select participants included Otto Struve, Frank Drake, and a precociously brash Carl Sagan (Pearman 1963; Dick 1996, 427-431; Davidson 1999, 125-127). It was at this meeting that that well-known creed, the "Drake Equation," was first discussed (Ćirković ٢٠٠٤; and for those with a taste for the bizarre, Maccone 2012). These are among the early astrobiology conferences that matter. Was there anything earlier?

Several antecedents are occasionally brought forth. Precedent usually goes to a 1923 symposium "On the Origin of Life," featuring "three wise men of Harvard with respective leanings toward the heavens, the earth, and the ether," with Harlow Shapley representing "the astronomer's point of view," alongside a professor of biology, and an ordained professor of ecclesiastical history. The Director of the Harvard College Observatory is the only one of the three to devote part of his address to what we now call astrobiology (Davison 1924, 100, 103; Dick 1996, 54, note 35 refers to the event briefly).

In modern histories of astrobiology emanating from English-speaking North America, the most frequently cited pre-space-age, life-on-other-worlds "symposium" is one that would now count as a "virtual" event. The "symposium" included some of the most-recognized names in American astronomy, distinguished for scientific achievement, official position, or notoriety: Henry Norris Russell, Harlow Shapley, George Ellery Hale, Walter S. Adams, Edwin Brant Frost, Robert G. Aitken, C.G. Abbot, Clyde Fisher, William W. Coblentz, V.M. Slipher, and William H. Pickering (Garbedian 1928, 1-2, 22; Dick 1996, 105-106; Markley 2005, 160-165).[3] It would have been a memorable occasion during the last month of 1928—had it happened. The "symposium" was a literary device of the *New York Times* reporter H. Gordon Garbedian, who it seems contacted the astronomers and physicists he quotes to ascertain their answers to the sensationalist question "Is Mars dead or alive?" Less-than-careful readers of the *Times*, falling prey to Garbedian's rhetorical strategy, could be forgiven for mistaking his wholly paper "symposium" for an actual meeting of astronomers.[4]

In fact, the earliest North American "astrobiology" conference may very well have taken place in Victoria, B.C., on 1931 April 23, two decades before the Green Bank Conference.[5] The symposium "On Possibilities of Life in the Universe" was an RASC event, its nature strongly shaped by local circumstances, and its legacy essentially determined by those same factors. These points will be taken up in the concluding discussion below.

"On Possibilities of Life in the Universe"—the speakers

The Victoria symposium's stated goal was to consider "... whether or not there are other worlds like ours, inhabited by forms of intelligent life having some of the characteristics of human beings" (Beals *et al.* 1931, 343). There were five speakers, all drawn from the membership of the Victoria Centre of the RASC. Two were professional astrophysicists from the Dominion Astrophysical Observatory (DAO), Drs. C.S. Beals and J.A. Pearce; one, N.C. Stewart, D.L.S., was a professional surveyor, in effect a professional practical astronomer; another was a meteorologist, Captain J.H. Hughes; and the list is rounded out with an "advanced amateur," H. Boyd Brydon. Depending on how one classifies the participants, there were either: a) two professionals (Beals and Pearce), and three amateurs (Stewart, Hughes, and Brydon); b) or two professionals (Beals and Pearce), one semi-professional (Stewart), and two amateurs (Hughes and Brydon); c) or four professionals (Beals, Pearce, Stewart, and Hughes), and one amateur (Brydon). The final classification stresses the continued relevance of the constellation of disciplines found in observatories from the 18th century to early 20th century, reflecting an astronomy-embracing physics, geography, geodesy, seismology, surveying, cartography, meteorology, and statistics, for which science studies have latterly coined the term "observatory sciences" (Aubin *et al*. 2010; this is probably the background of the RASC's venerable motto "dedicated to the promotion of astronomy and *allied sciences*"). The categories in 1931 may have been fluid. Irrespective of the binning of the participants, the symposium was, in fact, a pro-am project, and in this, it seems to have been unique among early symposia devoted to astrobiological outreach.

Figure 2 — C.S. Beals, the chairman of the symposium, contemplating with dread his imminent retirement from government astronomy (1964). Copyright RASC Archives.

It may be of interest to delineate briefly the speakers' astronomical profiles.

Carlyle Smith Beals (1899-1979) was a spectroscopist, with a doctorate from Imperial College, London (1926, supervised by Alfred Fowler, followed by a University of London D.Sc. in 1934), and, at age 32, a respectable publication record for the time, including some of his earliest work on Wolf-Rayet stars. He had been at the DAO for three years, and held the position of "Astronomer, Grade 2." He would go on to greatness (or what passes for greatness in our profession): among his scientific triumphs was his fundamental work on the distribution of gas in interstellar space (1939). In 1940 he became Assistant Director of the DAO, and in 1946 he was appointed Dominion Astronomer, affording him the opportunity to organize Canada's highly successful impact-structure discovery program. In 1931, he was President of the Victoria Centre, and in the initial stages of what we would now call his "early career," although such modern jargon does not map effortlessly on the past (Locke 1979; Wright 1980; Brooks & Whitehorne 1992; Hodgson 1994).[6]

Joseph A. Pearce (1893-1988) was also a spectroscopist, with expertise in binary systems. He collaborated extensively with J.S. Plaskett on the DAO's radial-velocity program, and he and Plaskett were able to provide the observational evidence to support Lindblad and Oort's model of the differential rotation

Figure 3 — H. Boyd Brydon, standing engineer and conference participant, shown standing (1933). Copyright RASC Archives.

of the galaxy. In 1931, he'd been at the DAO for seven years and held the rank of "Astronomer, Grade 4," a senior position. He'd received his doctorate from the University of California a year before the symposium and could claim a significant number of publications up to that time. He was a Past President of the Centre, in five years would become Assistant Director of the DAO, and in 1940, Director, at which point Beals would succeed him as Assistant Director. Beals said of Pearce that "...it was his boast that he could put on a good four-course dinner any night in the Dome at midnight" (Beals 1968, 307; Wright 1989).[7]

Of the three "amateurs," Brydon was to become the best-known in wider RASC circles. He had received his diploma in electrical engineering from Finsbury Technical College in London, and the greater part of his professional life was spent as a stationary engineer in the Chicago region; he came to Victoria for his retirement. His first venture into the pages of the RASC *Journal* was by virtue of this symposium; by 1945, he will have published 45 contributions in JRASC, including two substantial monographs (1940-41; 1944), and a coauthored paper with R.M. Petrie, a future DAO Director. When Brydon is awarded the Society's Chant Medal in 1941, it will be another future DAO Director, Ken Wright, who will pen the citation. Death alone prevented him from becoming National President. An amateur who could enjoy such esteem from professionals, and pen technical monographs on photometry and occultations for amateurs comfortable with the necessary mathematics, was no mere stargazer, no "naturalist of the night" caught in the glare of the full Moon like a deer in headlights (Wright 1942; Williams 1950).[8]

Norman Charles Stewart (1885-1965) received both a diploma in civil engineering (1909) and a Bachelor's degree in Applied Science (1911) from the University of Toronto, and achieved qualification as a Dominion Land Surveyor (1912); at that time, surveyors were trained in accurate time determination, celestial observation, and data reduction, and institutions regularly offered astronomy classes tailored to the needs of surveyors and engineers. He was qualified as a British Columbia Land Surveyor (*ca*. 1912), and eventually joined the Topographical Surveys Division of the British Columbia Department of Lands & Forests, reaching the top of Parnassus as Surveyor-General and Director of Surveys and Mapping for British Columbia (1946-1950). At the time of the symposium, his major JRASC paper on "Surveying from the Air" had appeared (1931), he was Victoria Centre's 2nd Vice-President, and he had been an RASC member for three years (Elms, Stewart 1931).

Compared to his colleagues, Captain J.H. Hughes's life now appears obscure. Nothing can be reported here of his educational background, age at the time of the symposium, or career, nor in which country's military service he held the rank of captain, or whether his captaincy was a merchant navy qualification, or, heaven forbid, an evangelical rank. Hughes is described in an RASC publication as "Meteorological Observer, Mill Bay, B.C." (Gage 1929, 117). He was elected to the RASC two years before the symposium, and in 1930 became a Councillor of the Centre. Hughes was elected 2nd Vice-President a month after the symposium's proceedings appeared, only to vanish from the Society's national records soon thereafter. There might be an interesting story to be recovered from local archives regarding Captain Hughes's disappearance from the Society.

"On Possibilities of Life in the Universe"—the discourse

As was only fitting, Beals, as Centre President, assumed the role of president of the symposium, delivering the Introduction (Beals *et al*. 1931, 359-344), setting the scene, and closing with the Summary and Discussion (359-360). His contributions are well-organized, current, and measured: "Our approach to such a subject must necessarily consist largely of conjecture, based on the experience of life on the earth and on the rather inadequate data of astronomy" (ibid. 343). One can find the same words—or nearly the same words—in the professional astrobiological literature of today. Beals notes that, through instrumental necessity, the main objects of study have to be the planets of the Solar System. Popular myths based on antiquated science are mentioned, including, surprisingly, the stellar inhabitants of the Sun, a legacy of the first generations of Herschelian astronomy; one would not have expected that idea to persist for so long (Crowe 2011—this example is more recent than any Crowe cites). Beals gives a pessimistic view of the possibility of exoplanets, but his pessimism is based on dynamic encounter models of Solar System formation, such as the Chamberlin-Moulton hypothesis, which were then mainstream science (Brush 1978; these were under fatal attack by 1935).

Pearce spoke next, addressing "Life on the Earth," which he tackles in two parts; "A. The Origin of Life" (345-346), and "B. Evolution of Life" (346-349). His presentation is, by his own admission, based solely on a single author, Henry Fairfield Osborn, Curator of the Department of Vertebrate Paleontology of the American Museum of Natural History in New York. Osborn was a powerful but controversial figure in the life sciences, whom a recent biographer has characterised as "a first-rate science administrator[,] and a third-rate scientist" (Rainger 1991). Pearce, being neither a paleontologist nor biologist, may not have known of Osborn's reputation among his colleagues, but the reliance on a single source ought to have been worrying. It is interesting that Pearce felt it necessary to state that "our scientific authorities without exception prefer the evolutionary to the creative origin of life" (345), and he opted to describe both briefly, before outlining an evolutionary path for life on Earth. Also of interest is his report that: "Experiments are being pushed forward by a host of zealous investigators and it is confidently felt that the demonstration of the physico-chemical origin of life will not be long forthcoming" (364). Unfortunately, Pearce is reticent about naming any of the "host of zealous investigators." His comment may have resulted from an overly optimistic reading of Haldane (1929); in the event, the world had to wait another two decades for the Miller-Urey Experiment (Miller 1953). The grip of Pearce's single source is evident: "Slowly but steadily upward man has marched through the Pleistocene as if an indwelling, purposeful power directed his development towards a glorious entelechy [=transition from potentiality to actuality]" (349). This is not a report of the speaker's original work, nor is it even a high-level review of the contemporary literature. One useful point of Pearce's chronological structure is its illustration of how late in the game the genus *homo* appeared, which, while hardly original, may have been new to some of his audience.

Captain Hughes follows with "Conditions on Mercury, Venus, and the Outer Planets" (349-352). Mars was the destination of choice for astrobiological speculation, so Hughes had clearly drawn the short straw. He presents an unadorned narrative of more-or-less current Solar System planetary vital statistics, from which he ascertains the likelihood that planets have breathable atmospheres and comfortable temperatures for humans. His presentation is commendably level, utilitarian, and accompanied by due qualifications. He concludes: "that vegetable and animal life, as we know it, is incredible on Mercury: possible on Venus and extremely unlikely on the outer planets" (352). Venus's candidature may seem surprising, but what we know of its atmosphere and climate were not known then; in 1935 Forest Ray Moulton could write in a popular exposition that: "It is probable but not certain, that this planet is not the abode of life" (Moulton 1935, 98).

Brydon's contribution was "Lowell's Conception of Mars as the Abode of Life" (352-355). It was located in the privileged central spot of the program, and dealt with what had been the central *locus* of the extraterrestrial-life debate for the previous four decades. Like Pearce before him, Brydon admits his overwhelming reliance on a single source, in this case Percival Lowell and his eponymously named observatory. Brydon repeats the claims that Mars Hill enjoyed unparalleled seeing conditions, that Slipher's spectroscopic detection of water and oxygen was wholly accepted, that Lowell's temperature determinations were of unquestionable reliability, that the canals drawn by Lowell and associates were real and constituted real proof of intellectually advanced Martians. Brydon's talk stands apart from the others. It is the only one of the five in which a source is presented in words bordering on adulation ("Lowell's two great books, *Mars and its Canals* [1906] and *Mars, the Abode of Life* [1908]"; 355); in which institutions that do not favour the speaker's interpretation are slighted ("detail is clearly seen there [*i.e.* Lowell Observatory] that is either invisible or observed poorly elsewhere;" 352); in which perceived disciplinary stasis is portrayed as desirable ("Definite spectroscopic proof of water vapour...obtained in 1908 by E.C. Slipher.... Professor Lowell in 1907 showed that the mean temperature…the three essentials for the propagation and maintenance of life…was proved 20 years ago;" 353); and in which the speaker does not avail himself of the language of intelligent qualification to indicate the relative weight the scientific community assigns to the material he reports. Byrdon's rhetoric of confidence ought to have raised doubts among his audience in the confidence they were willing to invest in his material.

Up next was Stewart, with "Information Concerning Mars Gained at Recent Favourable Oppositions" (356-359), a fact-based treatment in the style of Captain Hughes's earlier talk. Stewart's Martian vital statistics were up to date, he gives the impression of having consulted the best sources he could find, he duly notes some of the problems with the Lowellian Martian paradigm, and cites Trumpler's less-sensational reading of the canals with approval (358). In line with mainstream opinion, he closes on the likely possibility of vegetable life existing on Mars, but expresses reservations about anything more: "That there is evidence of plant growth is believed by most astronomers, but that there is animal life and that it has progressed into intelligent life is still very much a conjecture" (359).

It is notable that Brydon and Stewart both acknowledged assistance from professional observatories, the former thanking E.C. Slipher of Lowell Observatory "for the loan of the exceptionally fine series of slides" (353), and the latter W.H. Wright of the Lick Observatory for copies of infrared and ultraviolet images of Mars and the Moon (357).

In his concluding summary and discussion, Beals is reasonable, responsible, and cautious:

> *…it may be of interest to refer to certain considerations of general probability having regard…to the evolutionary process…on earth. As regards human life…its evolution…has been an exceedingly slow, precarious and uncertain process.… If we conceive of evolution as a race against time with the production of intelligent beings as the goal, then earth has won out with so small a margin to spare…that we may regard our existence…to be a fortunate accident.… Conditions on that planet [Mars]…are definitely less favourable to the existence of life than on the Earth. The temperature is lower, the atmosphere is thinner, the water vapour present much less.… The final appeal must always be to observation and until there is more general agreement.… The existence of intelligent life on Mars must be regarded as unsettled (359-360).*

Beals's words were not geared to bring comfort to the true believers in Lowell's autobiographical Martian narratives. They could be interpreted as a rebuke to Brydon's uncritical faith in Lowell. Did more amateurs that evening side with Beals, or with Brydon? Perhaps it is good we cannot know the results of such a straw poll at this remove. The results might have been disappointing.

The measure of astronomical opinion

Encountering the Victoria symposium some eight decades after it was published, one is immediately struck by the continued life of the Lowellian paradigm. Modern science is supposed to work through meeting an intriguing problem with a rigorous hypothesis, stringent experimental design, meticulous data collection and reduction, and publication via double-blind peer review. Lowell's "science" was singularly lacking in all these respects (Crowe 1986, 517-546; Hetherington 1988, 49-64; Strauss 2001, 176, 222, 228, 265). It comes across, rather, like the most obscene caricature of science imaginable.

Contemporaries of Lowell who were excellent astronomers, such as Antoniadi, Barnard, Campbell, Cerulli, Maunder, and Newcomb, patiently and scientifically dismantled each of his unscientific presuppositions, methods, and results. He ought not to have had a popular following in 1931, 15 years after his demise, and it is inconceivable that any professionals would have handled his work and reputation with sympathy, yet retain a following he did, and scientists felt they could not entirely ignore his legacy. Percival Lowell lived on as a revenant to haunt aspects of planetary science up to the return of data from *Mariner 4*.

Research by Robert Markley (2005) has established the afterlife of Lowell's influence in the period of the Victoria symposium, and David Strauss's biographical study of Lowell (2001) enables one to comprehend how his works could have appealed to those who thought they were consuming "science." Together they enable some comprehension of why and how Lowell was still a factor in discussions of the possibility of life on other worlds.

Markley is certainly correct to write that: "The scientific literature about Mars between 1916 and 1964 is more varied and ambiguous than most historians suggest, and the narrative that Lowell had crafted in the 1890s remained a significant part of midcentury accounts of the red planet" (Markley 2005, 151). Temperature determinations of the Martian surface conducted at Mount Wilson by Petit and Nicholson, and at Lowell by Coblentz and Lampland in 1924-1926 gave values -10°C to +20°C, suggesting to Trumpler and others that the surface temperatures would not be inimical to vegetation as it was known on Earth (Markley 2005, 158). In 1931, the spectroscopic determinations of water vapour on Mars by Lowell's E.C. Slipher, while contested, were not considered conclusively overturned. A telling assault on Mars Hill happened in 1933 as a result of new work by Walter S. Adams and Theodore Dunham at Mount Wilson, which found levels of water and oxygen on Mars well below anything capable of sustaining Earth-like biota (Markley 2005, 159). Slipher's 1907 values for water, cited by Brydon in 1931, were actually measures of telluric water!

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Figure 1 — The Halifax Centre's Mike Bonin stayed up on Boxing Day to take this image of the Pleiades Cluster from St. Croix Observatory north of Halifax. Mike used a Nikon D5100 for this 120-minute exposure on an Explore Scientific AR 102 telescope.

Figure 2 — Dan Meek sent us this image of the edge-on spiral galaxy NGC 4565 in Coma Berenices, one of the most popular galaxy targets for visual observers. A slight warping can be seen in the axis of NGC 4565 that tells on an ancient interaction with another galaxy. The image is a 420-minute LRGB exposure taken with an 11-inch EDGE SCT and QSI583wsg camera.

Figure 3 — Sometimes unusual objects lurk in the vicinity of popular observing targets, such as in this image of the region around the reflection nebula Messier 78, lying between Orion's Horsehead Nebula and Barnard's Loop. Lynn Hilborn took this dramatic scene using his Teleskop Service Star 71 ƒ/4.9 telescope and a modified Canon 6d. Exposure was 29 exposures, each of 4 minutes at 3200 ISO.

Figure 4 — There was a major geomagnetic storm on St. Patrick's Day, so Steve Irvine set up his camera and took 265 15-second images of the ensuing aurora—and combined them all to produce this unusual image. During the exposures, a car passed on a nearby road, illuminating the landscape on the right side. The time-integrated aurora reminds the Editor of a lava lamp.

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The temporal location of the Victoria symposium meant that Lowell could still be invoked by someone minded to do so, because his science had not been decisively overturned.

What still remains to be explained is how an advanced amateur like Brydon, capable of critical thought in some areas and of disciplined work in instrument design and the exposition of mathematical approaches to occultation science and variable-star programs for amateurs, could abandon his critical sense and "fall for Lowell." A careful, dispassionate reading of Lowell's works ought to have revealed a Lowell of whom it was said "he devotes his energy to hunting up a few facts in support of some speculation instead of perseveringly hunting innumerable facts and then limiting himself to publishing the unavoidable conclusions, as all scientists of good standing do" (by A.E. Douglass, quoted in Strauss 2001, 90), and who "had published his claims for the likelihood of intelligent life before he had left Boston to make his first observations in Flagstaff" (Strauss 2001, 252). There must have been another factor at play to make Brydon and others like him into Lowellians. And that factor was most likely an appeal to their emotions.

Strauss reasons that "an important element of his [Lowell's] appeal to readers was the dramatic and personal way in which he presented his work on Mars…. Lowell's books thus appealed to an audience of men and boys who sought in literature, as in life, male heroes with whom they could identify…. Lowell's own adventures as scientist and explorer were the true subjects of his books, to which factual information was subordinated" (Strauss 2001, 74-75). Strauss's explanation could very well fit Brydon's case—it is the best explanation I've found thus far for his contribution to the Victoria symposium. It would explain why Beals the astrophysicist found himself having to provide timely correction to counteract the "schoolboy" Brydon's display of Martian fervour in favour of the Lowellian hero. I like to think I would have done as Beals did in the same circumstances.

The "Sagan" thesis and the symposium

From the early 1970s to the early 1990s, it was not uncommon to encounter the view that the bad odour generated by the Martian canal controversy atrophied professional interest in planetary science, an effect stretching from before Lowell's death in 1916 up to the shock of Sputnik in 1957 (Brush 1996, 56; Nolan 2008, 57, 60; these citations show the persistence of the view). This can be called informally the "Sagan Thesis," as it occurs in Carl Sagan's obituary of Gerard Peter Kuiper, his doctoral supervisor (Sagan 1974). Viewed within that narrative, the Victoria symposium appears curiously out of time and out of tune with the contemporary astronomical world, its west-coast participants isolated and intellectually lost in space. Another view that began to be aired in the late 1990s as a result of careful historical reassessment argued that the decline in professional involvement in planetary studies *ca*. 1916-1957 was much exaggerated (Dick 1996, 1998; Doel 1996; Markley 2005). This historiographical correction has the virtue of offering a more convincing intellectual and social setting for understanding the Victoria symposium.

The legacy—lost in the sands of time

What was the legacy of the Victoria symposium? While it may have been the earliest such event to have happened on North American soil, it appears to have left no legacy. When interest in science-based astrobiology revived in the late 1950s, no one referred to the symposium, not even as a historical example. When work on the history of astrobiology blossomed forth in the 1980s, the symposium was not cited. It ought to have been noted as any early institutional effort to present the state of the question, however derivative it may have been. Why was it ignored? Several possible reasons can be offered. None of the Victoria speakers presented their own original research. None of the speakers moved in the circles from which astrobiology with professional pretensions would arise. Beals and Pearce, the only presenters at Victoria who would go on to forge meaningful international reputations, particularly Beals, were taken up with "more respectable" areas of astrophysical research, and when Beals finally turned to planetary studies, it was to impact cratering. Not producing other work in the astrobiology field, Beals and Pearce would have no occasion to refer to the symposium in print, so knowledge of it would not be sustained through citation cycles.

Readers of this account can give the symposium a legacy, through the act of remembering it as a possibly pioneering North American effort that originated in Canada, the first astrobiology EPO symposium with pro-am participation. And if there's a lesson, it's provided by the salutary example of the competent amateur who made himself incompetent by not adopting a professionally sceptical attitude in the face of his own favourite theory. ✶

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Endnotes

1 www.esa.int/ESA (accessed 2015 January 21); www.nasa.gov/ (accessed 2015 January 21). Performing an identical search on the Canadian Space Agency/Agence spatiale canadienne site returns 46 hits; www.asc-csa.gc.ca/eng (accessed 2015 January 21). Perhaps comparisons are invidious.

2 Strughold's legacy is contested. His post-WWII colleagues and successors acknowledge him as the "father of space medicine," but his earlier career as a prominent medical researcher and Nazi officer in Hitler's Germany has not been fully explained. Campbell & Harsch 2013 urge exoneration, but do not entirely dispel the doubts raised by the contextual account Weindling 2004 presents; Pellis 2014 offers a brief *status questionis*.

3 Incidentally, over half of these astronomers were, or became, honorary members of the Society. Listed in order of election they are Pickering (1894), Hale (1900), Frost (1906), Adams (1945), Russell (1946), Shapley (1947).

4 Garbedian's use of leading words in framing the astronomers' replies (*e.g.* contrast Abbot's words with Pickering's, 1) , and his allocation of space privileging the cause of Lowellian canalists espousing intelligent life on Mars is unlikely to have pleased most of his experts. Levine (2008) characterized Garbedian's writing as "...prose remarkable by genre standards for its careless enthusiasm..." (278). Perhaps Garbedian's style contributed to the *Times*' circulation figures.

5 Readers should note that while the term "astrobiology" went back to at least the late-19th century, its meaning then was the study of "astral influences" on Earth's biota, a form of astrology(!); *e.g.* Deshler 1898, 4. The more modern meaning of the "scientific" investigation of life in the Universe beyond the Earth can be found in print from the early 1940s; (Lafleur 1941)."Exobiology" introduced *ca*. 1960 and astrobiology became synonyms (Lederberg 1960). The further semantic refinement of folding life on Earth within the study of life in the Universe has been precisely dated and institutionally localized by some to 1995-1996 when "a deep organizational restructuring at NASA precipitated a rebirth of the field under a new name, 'astrobiology'" (Dick 2013, 140; the name was not new, but the strictures on its use were). Under this new dispensation, the "scientific" investigation of life in the Universe beyond the Earth was to be solely known as "exobiology." Whether this shuffling of semantic deck chairs is an "advance" remains to be seen. "Astrobiology" as used in this paper conforms to the latest usage, purchasing convenience at the price of flexibility and chronological aptness.

6 A former DAO colleague jocularly remarked of Beals's appointment as Dominion Astronomer that "This reminds me of one of the great accomplishments of C.S. Beals—he spent 20 years at DAO and never, as far as I can tell, published the orbit of a spectroscopic binary! Of course you see what happened to him—they finally shipped him off to Ottawa!" (McClure 1993, 293). Rosenfeld (2011) erred in naming Beals as the "last Dominion Astronomer" (130); he was in fact the penultimate holder of that office.

7 I have been confidently assured that such traditional observing skills have gone the way of the photographic plate, the more's the pity!

8 The absence from JRASC of a biographical memoir for Brydon after his death might seem an odd occurrence, but such negligence on the part of the Society was not unusual.

CFHT Chronicles

Diary of a Sunwatcher

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

It's 6:45 a.m. and a small group of astronomers is preparing to leave for the summit of Maunakea to observe at the Canada-France-Hawaii Telescope (CFHT). That's right, 6:45 a.m., not p.m. Say the word astronomer to the average person and visions of someone peering through a telescope into the darkness of space comes to mind. Solar astronomers work in the daytime observing our Sun, but generally, astronomers are not known for their daytime work. Today is different. We are heading to the summit to observe the planet Venus with a French/Portuguese team headed by a longtime user of CFHT, Thomas Widemann.

Figure 1 — The Venus team: Thomas Widemann, Joana Oliveria, and Pedro Machado in the remote observing room at CFHT's Waimea headquarters.

Today's crew consists of two astronomers, Pedro Machado and Joana Oliveria, plus two CFHT staff members. David Woodworth is one of our remote observers, accustomed to working at night observing with CFHT's three instruments. Today he is driving the telescope and keeping an eye on the technical aspects of the observations. The other staff member is me, CFHT's outreach manager. My primary job today is to watch the Sun. Daytime Venus observations are scheduled very carefully; usually they occur when Venus is at its maximum elongation from the Sun. It is slightly different this time; our observations are occurring in conjunction with another set of daytime Venus observations on the summit. The second observations are in the infrared and occurring at the nearby Infrared Telescope Facility (IRTF). The opportunity to obtain simultaneous spectra in multiple wavelengths is too perfect an opportunity to pass up, even though Venus is closer to the Sun than ideal.

We arrive at Hale Pohaku, the base facility located at about 2750 m up the mountain, around 7:45 a.m. Complete with dorm-style rooms and a cafeteria, Hale Pohaku is home-away-from-home for those working on Maunakea. We need to acclimatize here for an hour before we head to the summit at 4200 m. Working at the summit of Maunakea is physically

Figure 2 — The telescope ready for the start of Venus observations.

demanding due to the high altitude; without proper time to acclimatize, people can suffer from altitude sickness. The high altitude can affect even the most hardened veteran of the summit; hence the hour spent at 2750 m for the body to adjust to the decreasing oxygen levels. The time at Hale Pohaku also offers the ideal chance to eat breakfast and discuss our strategy for the day. David, Pedro, and Joana worked together yesterday on the Venus observations, so today's discussion is primarily for my benefit. As a sunwatcher, it is my job to work with David to prevent sunlight from hitting our 3.6-m primary mirror.

Around 8:30 a.m., we drive to the summit. The road from Hale Pohaku to the summit is almost 13 km of treacherous switchbacks; four-wheel-drive vehicles are necessary. It takes us half an hour to reach the top. The first half of the trip is on unpaved roads. Between the steepness of the climb and the dust from the road, we cannot drive more than 30 km per hour. The last half of the ride is on pavement, but the rise does not let up. Once we near the summit, we can see the last snowy remnants of a mid-March blizzard covering the ground, particularly the areas surrounding the telescope facilities.

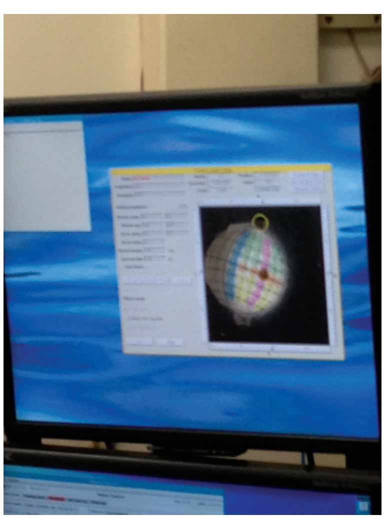

Figure 3 — Thomas and Pedro's colourful homemade guider taped over the actual ESPaDOnS guider. The black circle is the ESPaDOnS fibre, showing through the plastic. The colourful circles are positions on Venus the team wants to observe. They move the telescope small amounts to line the guider up with their intended target before beginning observations.

Next to CFHT lies a 3-m snow drift left behind by the snow plough when it cleared the road.

Once we arrive at the telescope, the process of opening begins. Opening CFHT is normally a straightforward operation. The remote observer, who controls everything from our Waimea offices, opens the dome shutter and then the mirror covers, before taking sky flats or slewing to the first target. This morning's plan is more complicated. We need to move the telescope to Venus's position first (Figure 2) and then open the shutter. It sounds simple, but the complication comes from the position of the Sun, located just above Venus. Once the telescope is in position, it is my job to stand by the telescope and watch while David opens the shutter. We communicate by walkie talkie and I need to let David know if sunlight comes too close to the telescope structure. I watch sunlight enter the dome, moving across the dome floor. It is a delicate balance; if the shutter is too far open, then sunlight will come too close to the telescope. Too far closed, and Venus will be occulted by the shutter. Once we are at a good shutter position, only a third of the way open, David slews the telescope back to the zenith.

Our mirror covers open by pneumatic pressure; the telescope must be upright to achieve the proper air pressure for them to open without issue. With Venus at an airmass of over 4 at the start of observations, we cannot open the mirror cover in position on the planet. Instead, we have to slew to zenith, open the mirror covers, and slew back to Venus. The whole process is stressful. David and I need to make sure that the telescope is in the proper position for observations but far enough away from the Sun that sunlight doesn't hit the primary mirror. Sunlight on our 3.6-m primary mirror could result in a fire or, at the very least, damage to the dome or telescope. Finally, I manually move the dome into position while David guides me from the control room. At night, the whole process is automated; the Sun makes two people necessary.

By 10 a.m., all the prep work is done and it is time to start science. Pedro and Joana will be using CFHT's spectrograph ESPaDOnS (Echelle SpectroPolarimetric Device for the Observation of Stars) for their Venus observations. The team plans to use ESPaDOnS to study the dynamic motions of Venus's atmosphere. Venus's thick atmosphere makes observing the planet's surface in the optical impossible. Thomas and Pedro plan to use the Doppler shift calculated from ESPaDOnS spectra to measure the velocity of the atmosphere and how the velocity changes in relation to position on the planet.

Taking an ESPaDOnS spectrum requires careful alignment of the instrument's fibre optics on the target. For regular observations, the remote observer uses a finding chart with a marked target, usually a single star. The observer aligns the star with the fibre, indicated by a dark circle on the guider, and begins. But Venus is much closer than the typical ESPaDOnS target, so it is much larger in the guider window. After years of observing with ESPaDOnS, Pedro and Thomas devised

Figure 4 — The author, standing next to the telescope at the start of Venus observing.

the perfect way to make sure they are observing the correct location on the planet—a Venus-sized, clear plastic circle with each target marked, taped on the computer screen over the ESPaDOnS guide window (Figure 3). It is the ultimate combination of high tech meets low tech.

As Pedro and Joana take their observations, I periodically head upstairs to tweak the dome position under David's direction. Dome movements are another of those steps that are automated at night, but with the peril of the nearby Sun, we have to do it by hand. We observe for an hour until the Sun's approaching transit makes it impossible.

During the break, we eat summit lunch. Five days a week, the Hale Pohaku cooks load a truck with lunch and drive it up to the top for the summit crews to eat. Everyone heads over to the summit lunch shack, a squat-concrete building not far from CFHT, and picks up their lunches to take back to their facility. The quality varies: not all food can be cooked, driven up the mountain, and eaten at 4200 m. We luck out—it is taco day.

Over lunch, Pedro fills us in on the progress of the observations, the plan for the afternoon, and the results of last year's Venus observations. He is part of a team that made a recent discovery regarding a Y-shaped feature in Venus's atmosphere, visible only in the ultraviolet. The team found that centrifugal forces might lead to the creation of this Y feature. The centrifugal force pulls unknown particles in the lower atmosphere away from the centre of Venus's rotation and up into the upper atmosphere. These particles absorb the ultraviolet light, causing the dark Y-shape feature visible in the planet's atmosphere. As the particles move from the equator, they get caught up in the winds of the upper atmosphere. Near the poles, Venus's winds move faster, leading to the distortion of the Y shape in those regions. Pedro worked on the mathematical modelling of the centrifugal force.

Thomas frequently collaborates with ESA's *Venus Express* mission, following up their space-based observations with ground-based ones. Even with the *Venus Express* mission completed, additional ground-based observations, like those from ESPaDOnS, are needed. Thomas is also a member of the science team for CFHT's near-infrared spectropolarimeter and high-precision velocimeter, SPIRou. He hopes to use SPIRou to take infrared observations of planetary atmospheres when it arrives in 2017.

By 1 p.m., the Sun is back in position and so are we. David and I repeat the setup of slewing the telescope and opening the dome, but with one exception. Venus is now high enough in the sky that we can open the mirror covers in position, saving us precious observing time. Pedro and Joana take data for two more hours, while David and I run up and down the stairs tweaking the dome slit position. Running up and down the stairs is a bit of an exaggeration; due to the high altitude and lack of oxygen we cannot really run, we walk at an appropriate pace. As observations near completion, the shutter moves become more frequent. Eventually, we end up in the reverse situation from the morning: the Sun is below Venus in the sky. While we can block the Sun from above using the shutter, we do not have anything in place at the opening of the dome slit to block the Sun from below. By 3 p.m., no amount of dome movements can keep us observing. David and I shut the dome and park the telescope, and we head back down the mountain.

The day's results are remarkable. Pedro and Joana acquired just shy of 200 spectra from various positions on Venus. By the time they wrapped up observations two days later, they took nearly 800 spectra in four days of observing. I talked with Pedro before he flew back to Portugal and he declared the run a success. I now look forward to next year when Thomas, Pedro, and Joana return for another run and I can return to my role as a sunwatcher. ✶

Mary Beth Laychak has loved astronomy and space since following the missions of the Star Trek Enterprise. She is the CFHT Outreach Coordinator, located on the summit of Maunakea on the Big Island of Hawaii. She will give us reports about the telescope and the activities there in her regular column.

Second Light

Saturn's Rotation Period

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

You would think that as Saturn is the second-largest planet in the Solar System, a basic property like its rotation rate would be well known. You might think it, but it isn't so. Saturn's rotation period has been uncertain for over 10 years, which you would not guess from the entry in the *Observer's Handbook*, where it is listed as 0.44401 days. This corresponds to 10 hours, 39 minutes and ~22 seconds. This is the value established by radio observations performed by *Voyager 2* as it flew by Saturn in 1981. But when the same measurements were performed after *Cassini*'s arrival in 2004, the resulting period was 10h 47m 6s. It was impossible that the planet's rotation rate would change by 8 minutes in just over 20 years, so the radio observations were not measuring what people thought they were measuring. Since then, other attempts have been made to determine Saturn's rotation period, which have only added to the uncertainty and increased the range, which is currently between 10h 32m and 10h 47m. Now, Ravit Helled of Tel Aviv University and her colleagues have used a novel method to estimate the period (see the 2015 April 9 issue of *Nature*, first published online on March 25). They find a period of 10h 32m 45±46 s.

Saturn presents a unique challenge in the Solar System. The clouds do not necessarily follow the bulk rotation of the underlying body—anyone who has watched clouds move through the skies on Earth will be aware of that. Jupiter, Uranus, and Neptune all have the same problem, but those planets have magnetic axes that are not aligned with the rotation, so the motion of the magnetic field—which is anchored in the solid body below the clouds—is an accurate indicator of the rotation period. Earth's magnetic field also is not aligned with the rotation axis. Saturn, on the other hand, has a magnetic field that is almost exactly aligned with the rotation axis, meaning that there is no pole sweeping by our line of sight to determine the period.

There have been numerous attempts to determine Saturn's period. One study looked at the potential vorticity of Saturn's clouds and estimated a rotation period of 10h 34m 13±20s. Another combined *Cassini*'s measurements of Saturn's gravitational field with *Pioneer* and *Voyager* radio data, along with wind measurements, and put forward a rotation period of 10h 32m 35±13s. An analysis of cloud motions favoured a period of ~10h 39m.

Helled and her collaborators looked at the gravitational "moments" of Saturn, as measured by *Cassini*. A rotating body, particularly one rotating rapidly like Saturn, is not spherical. The deviations from spherical can be represented in what is called a "multipole expansion," where the corrections needed to accurately represent the gravitation field are "moments" (Figure 1). Helled used the J_2, J_4, and J_6 moments (the only ones known for Jupiter and Saturn), on the assumption that any deviations from a pure sphere arose only from rotation. She then used additional constraints (involving the change in density with radius, using models of the interior structure) and finally reached a period of 10h 34m 13±20s.

A fair number of assumptions and model uncertainties are involved in this estimate, so she then applied the same technique to Jupiter, whose period is very well known. Her method delivers a period of 9h 55m 57±40s, which, within the uncertainty, is indistinguishable from the official period of 9h 55m 29.7s.

As the *Cassini* mission draws to a close in 2017, the spacecraft will pass close to Saturn and the gravitational moments will be determined with increasing precision, which will decrease the uncertainty of the period by about 15 percent.

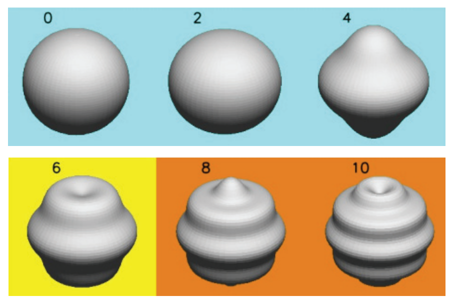

Figure 1 — The deviations of a rotating body from a sphere can be parameterized. The biggest deviations are captured by the lowest orders. Think of it this way: Saturn's shape can be represented by the sum of a fraction of a sphere (moment 0), plus a fraction of moment 2 (the equatorial bulge), plus a fraction of moment 4, plus or minus a fraction of moment 6. In this case, the contributions are: $0.4J_0 + 0.8J_2 + 0.85J_4 + 0.9J_6$. At this time, moments 2 and 4 are fairly well known. Moment 6 has been measured, but there is considerable uncertainty. Moments 8 and higher have not been determined. Image courtesy of Dr William Hubbard of the Lunar and Planetary Lab of the University of Arizona.

It seems funny to think that in 2015 we should be unsure about one of the fundamental parameters of the Solar System, but science is like that. That is just how science works—better measurements lead to better understanding, and sometimes a complete change, as in 1915, when Newton's gravity was replaced by General Relativity. Some year soon, the *Observer's Handbook* will catch up, and Saturn's period will likely be changed to something around 10 hours and 34 minutes. ✶

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

Orbital Oddities

Inferiority Complex

by Bruce McCurdy, Edmonton Centre
(bmccurdy@shaw.ca)

I belong to a rare subset of planetary observers who has likely spent more time viewing Venus than any other planet. Since first having identified the brilliant inner planet shortly after my entry into astronomy in 1985, I have followed every evening apparition with relish, and every morning one with bacon (which is to say, at least once a week or so). I'm especially taken by conjunctions of Venus and the (always-crescent) Moon, and I have set my alarm many times to get up to view such a spectacle.

More to the point, in my summer job at the observatory at the Telus World of Science, Venus has been a very frequent target during daytime sessions—and this far north, they are *all* daytime sessions for much of the summer. I also sweep up the second planet during my weekly volunteer shifts throughout the school year, currently a Saturday afternoon gig. Its proximity to the Sun is an advantage in that, at any time our local star is high in the sky, Venus is "up" as well. It's an everyday feature of our programming, except when it is too close to the Sun to be safely observed. Such circumstances are limited to times around superior conjunction, which actually occur in the summer months just once every eight years.

How close is too close? Experience has taught me anything within 5° of the Sun results in an uncomfortably bright background sky, but anything beyond that is within the reach of our battery of telescopes. The instrument of choice is the 7-inch Astrophysics Starfire refractor that RASC Edmonton Centre purchased from Terence Dickinson and installed in the observatory some two decades ago. The telescope's relatively moderate aperture serves to dim the background sky, especially at high power. It is important to note that very careful techniques are required, including hard-locking the scope once the target is acquired.

In reality, I will give the Sun a much wider berth than a mere 5° around the time of superior conjunction, when Venus is small, nearly full, and virtually unchanging from day to day. But around inferior conjunction, there's plenty of incentive to view rapidly changing Venus as a large, skinny crescent, skirting a little above or below the Sun.

At first blush, it sounds like an unobservable (non-) event. In conjunction *with the Sun*? Say no more! But while inferior conjunctions are not highlighted in bold in the *Observer's Handbook*, to this admittedly quirky observer, they have become a can't-miss event on my own observing calendar every 19 months or so.

Figure 1 — Neither low target nor clouds nor ice on the Observatory rails could deter your intrepid observer from spying thin crescent Venus at inferior conjunction on 2014 January 10.

My earliest understanding of the visibility of observing the second planet during inferior conjunction took shape during a conversation with Father Lucian Kemble sometime in the mid-1990s. "Lamplighter Luc" spoke of his own experiences observing crescent Venus during its approaches in April of 1977 and 1985. Indeed, it had been a topic of a paper he presented at the General Assembly in Edmonton in 1985, one subsequently committed to JRASC by David Chapman a year after Lucian's passing in 1999. (Kemble/Chapman, 2000.)

In our conversation, attended by a number of lucky RASCals at the home of Murray and Joanne Paulson, Lucian addressed the eight-year near-repetition of the cycles of Venus, of how not just the inferior conjunctions, but the entire preceding evening apparition and following morning one repeated themselves to a high degree of similarity. He also spoke of the possibility of seeing Venus as *both* a morning and an evening star on those occasions that its conjunction takes it well north of the Sun. Although this wasn't part of his paper, Lucian had actually accomplished this feat in 1985. I was intrigued.

As Lucian had stated in the closing remarks of his paper:

> *I encourage other RASC members to try their hand at this aspect of their observing programmes, taking advantage of the long summer twilight hours in our northerly latitudes. Be prepared for some more forthcoming inferior conjunctions of Venus: August 22, 1991, 8°.23 south of the Sun; April 1,*

1993, 7°.87 north of the Sun (i.e. the next eight-year cycle); and, of course, for those of us/you still around, the great pair of transits in June 2004 and 2012. Good Luck!

Lucian himself was not lucky enough to see those latter events, having passed on in 1999. But he had lighted a spark in this RASC member that they were can't-miss astronomical events, and I went to some lengths (Fort McMurray, Alta., and Yellowknife, N.W.T., respectively) to successfully observe both. As I occasionally joke, this makes me a co-holder of the little-publicized world record, "Most Venus Transits Observed, Lifetime," with, presumably, a few thousand other folks.

I am, however, on a much shorter list, possibly even unique to myself, of people who have observed *every* inferior conjunction of Venus since 1998. That streak currently stands at 11 and counting, though at most I will add only three more observations before my string is doomed to end in June of 2020.

The key to this, as to virtually every repetitive observation of Venus, lies in the near-perfection of its eight-year cycle. During this time, the two planets have each completed a near-integer number of revolutions of the Sun, 13 for Venus, 8 for Earth. The inner planet "laps" our outer one five times in that span, a synodic cycle of 1.60 years. When visualized from above, over the course of five inferior conjunctions Venus (and Earth) inscribes a nearly perfect pentagram against the ecliptic. This was discussed in some detail in past iterations of this column. (McCurdy, 2004; 2013; see Figures 2 & 3.)

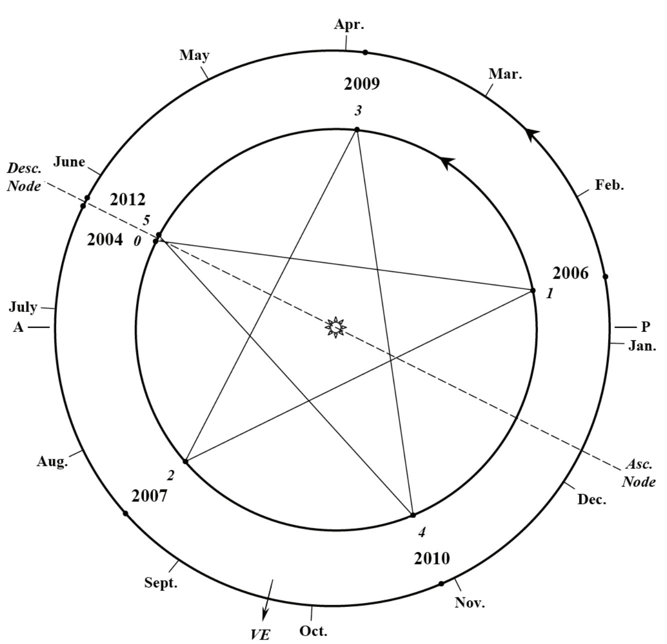

Figure 2 — The synodic period of Venus is 1.6 years = 2.6 revolutions of Venus. After five such periods, the two planets have completed a near integer number of orbits (13 for Venus, 8 for Earth) and have returned to very near their initial positions. A sequence of consecutive inferior conjunctions of Venus as shown here, inscribes a near-perfect pentagram that rotates extremely slowly over a period of centuries. Diagram: Bishop (2012).

My good fortune was in the timing of my quest. Not only did the two transits nicely account for Venus's two closest brushes with the Sun, but the geometry of the pentagram ensures that all four of the others occurred at a significant distance above or below it. Indeed, in every case during the period in question, that separation has been greater than the 5° margin

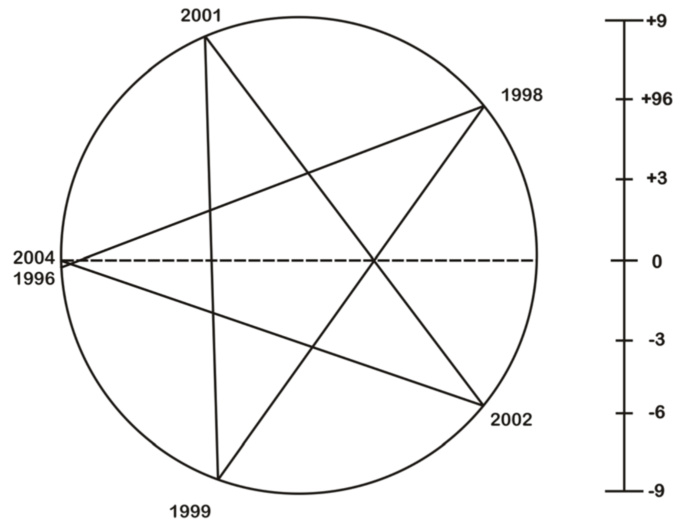

Figure 3 — A re-oriented view of the pentagram, with the nodes expressed horizontally (dashed line). The dates shown in this figure, adapted from McCurdy (2004), are eight years (minus two days) removed from those shown in Figure 1, and are at very similar ecliptic longitudes. This circular representation has a second, nifty feature: a built-in sine curve. The vertical scale on the right can be used to estimate the distance of Venus from the ecliptic at each conjunction. With one of the points on the pentagram very near 0° (Series A, 1996, 2004), the remaining points are temporarily in almost symmetrical pairs: Series C (1999) and D (2001) at –8° and +8°; Series B (1998) and E (2002) at +6° and –6°. Neither the vertical scale nor the symmetry is exact, because neither planet has a truly circular orbit.

Figure 4 — Although Venus and the Sun will temporarily have the same longitude, their separation at Inferior Conjunction on 2015 August 15 will be almost 8°, more than double the separation between Venus and the Moon as captured in this image of their conjunction of 2015 March 22. (Photo by the author.)

Inferior Conjunctions of Venus 1996-2020									
Series A		Series B		Series C		Series D		Series E	
1996 June 10	-0°30′	1998 Jan 16	+5°39′	1999 Aug 20	-8°07′	2001 Mar 30	+8°01′	2002 Oct 31	-5°42′
2004 June 8	-0°11′T	2006 Jan 13	+5°31′	2007 Aug 18	-7°59′	2009 Mar 27	+8°10′	2010 Oct 29	-5°59′
2012 June 6	+0°09′T	2014 Jan 11	+5°11′	2015 Aug 15	-7°50′	2017 Mar 25	+8°18′	2018 Oct 26	-6°15′
2020 June 3	+0°29′								

Table 1 — Adapted from Meeus (1983–95), a list of inferior conjunctions of Venus from 1996–2020 has been split into five columns showing five distinct series of similar events at intervals of 8 years minus 2.4 days. The grayed events of 1996 and 2020 are/will be unobservable, the two in between in 2004 and 2012 were seen in silhouette against the Sun; all others occur/red at least 5° from the solar disc.

described above, thanks to the fact that Venus' inclination of 3.4° is greatly exaggerated by its proximity to Earth. Add in a little "slush" in right ascension to allow for my own parameters defining success, namely seeing Venus within 24 hours, plus or minus, of inferior conjunction. Each time I have been able to observe the slender crescent in relative comfort, albeit with great caution.

The five-fold, near-symmetry means that the same five apparitions occur in sequence, then begin over with only very slight change. In Table 1, the particulars of inferior conjunctions as presented by Meeus (1983–95) are restated in five columns to highlight the near repetition. I have labelled them Series A to E. The visual highlights of each:

Series A, 1996–2004–2012–2020 (June). While I enjoyed the wonderful evening apparition of Venus in 1996, its inferior conjunction was utterly impossible as the planet passed a few arcminutes south of the Sun. In 2004 and 2012, observation of IC was possible during the paired Transits of Venus. In 2020, Venus will skirt just a few arcminutes north of the solar disc and will be unobservable from the ground.

Not only were the transits exceptional events in and of themselves, in 2004 I was also able to observe the annulus of Venus (a full ring, bright on the sunward side, much dimmer on the opposite limb) of sunlight filtering through its atmosphere when it was some 4° from the Sun, three days before the transit. Even though it was still inward-bound, it was already closer to the solar disc than even the moment of inferior conjunction in any other series.

Series B, 1998–2006–2014 (January). This was my first successful observation in the sequence, in January 1998, when I observed in the morning hours before sunrise with binoculars, and then tried again in the evening but failed. In 2006 and again in 2014, I observed Venus telescopically closer to mid-day, a slender crescent with its "horns" pointed straight up, as it passed comfortably north of the Sun. Each progressive event of this series drew Venus progressively closer to the Earth, itself near perihelion at that time of year. The most recent pass of 2014 January 10 was the closest of my lifetime at 0.26612 AU; by luck that inferior conjunction occurred very close to local noon here in Edmonton. Under trying conditions both in the sky and on the ground, I was able to catch a few glimpses of the delicate crescent between broken cloud. (Figure 1)

Series C, 1999–2007–2015 (August). The first two of these were the best observed ICs due to my near-daily summer gig at the observatory. From day to day, I was able to enjoy the rapidly changing position angle of the horns of the crescent, pointing to the lower right, then straight down, then to the lower left from one day to the next through the scope, upside-up but mirror-reversed due to the star diagonal. There will be a similar opportunity this August as Venus again enjoys a superb evening apparition high in the spring sky, approaches the descending node just as it has a fine conjunction with Jupiter at the beginning of July, and then dives below the ecliptic to pass nearly 8° below the Sun in mid-August.

Series D, 2001–2009-2017 (March). In both 2001 and 2009, I successfully completed the "double" of seeing Venus as both Morning Star and Evening Star on the same day. These observations were done with binoculars and naked eye, although I also copped a mid-day telescopic view on one of those occasions. The March inferior conjunctions are about as far north of the Sun as the August ones are to the south, with the impending inferior conjunction of 2017 March 25 to crest 8°18′ above the Sun.

Series E, 2002–2010–2018 (October). These are the toughest ones of the five to catch, passing south of a low-lying Sun by gradually increasing margins, to exceed 6° next time around. Because these passes are to the south, Venus will have disappeared out of the evening sky well before the conjunction itself, and the absence of a daily work schedule at the observatory removes much of the continuity of the pass from the experience. In 2002 and 2010, success was achieved only through some persistence (read: "obsession") on the part of this observer to mark the calendar and make the effort on the day. But worth it in its own right, not to mention its role in keeping my "streak" alive, such as it is.

If mine is indeed a "world record" it is destined to last a good while. The nature of the slowly-rotating pentagram means that one if not two of every five inferior conjunctions will occur too close to the Sun to observe. Only around the time of the next pair of transits in 2117–2125 will it again be theoretically possible to achieve this delightfully obscure feat. ✶

Dedication: This article was written in loving memory of Father Lucian Kemble (1922–1999), a wise man whose curiosity and knowledge inspired the eye, the mind, and the imagination.

Bruce McCurdy is marking his 30th year as a member of RASC Edmonton Centre, and his 29th as a volunteer at the Public Observatory of Telus World of Science—Edmonton. He has contributed Orbital Oddities to JRASC since 2000.

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Sky Conditions at Your Finger Tip

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

I'm a big fan of the Clear Sky Charts (http://cleardarksky.com/) by Attilla Danko. I regularly refer to charts for my home, the observatory, and other locations.

When Windows *Vista* came out—sorry, maybe you blocked that memory—it introduced a feature called Sidebar Gadgets that included a clock, photos, one's local weather, *etc.*, not unlike the Dashboard on the Mac OS. I recall that Brian Gibson of the Mississauga Centre wrote an applet pretty quickly that took advantage of this new capability of the PC computer. It could display your favourite three CSC charts. Brian went on to update this *for Windows 7*. Microsoft has since deep-sixed gadgets.

Inspired, but not willing to jump into the murky waters of *Vista*, I wrote my own custom app for the Yahoo!Widgets platform. This meta-environment supported any version of the WinOS and would allow, like Gadgets, the installation and arbitrary placement of small, live-feed applets anywhere on the desktop. I programmed my widget to support up to six CSC locations. Like Brian's app, I made the small 2-bar Clear Sky Chart hyperlink to the full webpage, by location. A short time later, Yahoo! discontinued support of their widgets and I was out in the cold again.

Today, I use small custom apps or "meters" that I created for the gorgeous Rainmeter environment on my Windows desktop. This means that whenever I glance at my electronic desktop, I have current, up-to-date, sky-condition information.

The retired developer also tackled the iOS platform. Brian wrote an app called *myCSC*, which runs on the iPhone, iPad, and iPod Touch. Brian's latest version lets you configure up to five locations. When you tap on a location bar, a menu appears that lets you visit the full webpage, view the map with cloud overlay, change the location, and so on.

I briefly used an early version of the iOS app on my old, found iPod Touch and it worked pretty well. If you're interested, head to the iTunes store and search for *myCSC* by Anything Binary.

Having recently, both feet in, jumped into the Android tablet world, I immediately started loading up on astronomy and science apps. Imagine my disappointment in learning that there was not a CSC gadget or widget or live-feed thingee for Google-backed mobile OS. Dang! And, certainly, at

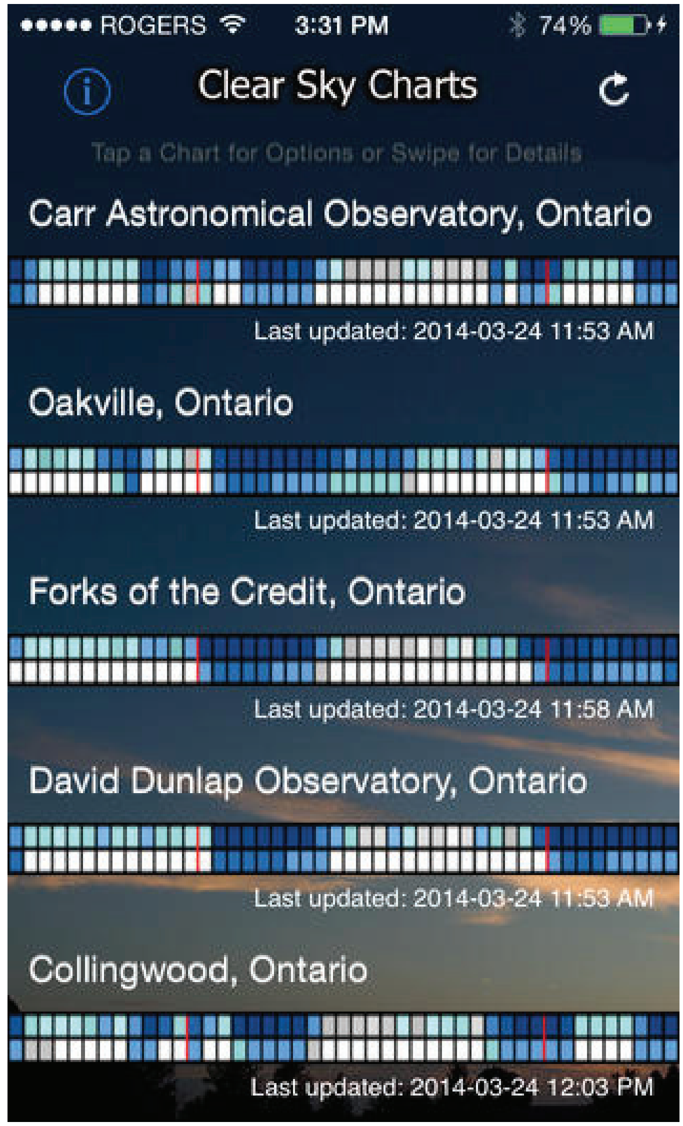

Figure 1 — The Clear Sky Chart display for selected Ontario sites.

the moment, I'm not prepared to write one. But then I remembered... *the competition*.

Back in the fall, I stumbled across the Clear Outside project (http://clearoutside.com/) by the First Light Optics people in the UK. Quickly I added this predictive website to my personal weather portals and resources. Happily, FLO has produced apps for both iOS and Android devices.

The Clear Outside (CO) tablet or smartphone app shows a display that closely matches the website. It is not really fair to put the Android offering up against the iOS app: it is not an apples to apples comparison, if you'll forgive the pun. It is more appropriate to compare the CO app to a full CSC webpage. The CO app is very informative.

The Sunlight bar in the CO app is like the Darkness bar of the main CSC webpage image—it shows graphically when the sky is bright with sunlight and the various stages of

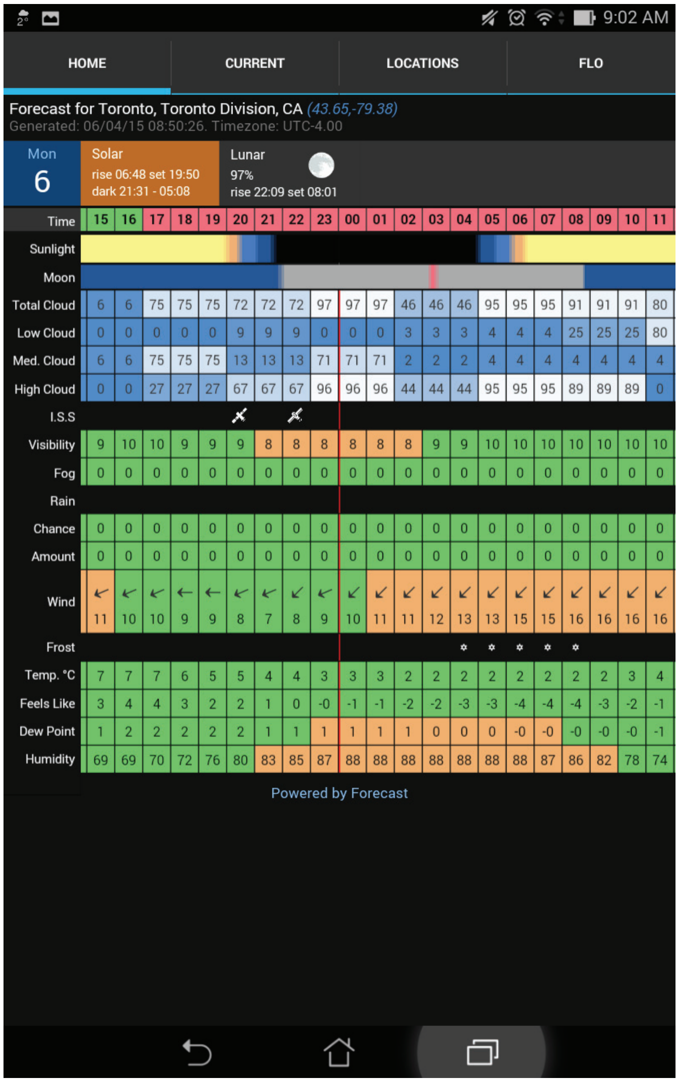

Figure 2 — The Clear Outside display for Toronto

twilight. Moonlight is, of course, taken into account by CSC; a separate bar is shown in the Clear Outside display. The Total Cloud bar is similar to the Cloud Cover row. CO goes further by indicating low, medium, and high cloud—dark blue is best. Like Clear Sky Chart, there are Wind, Humidity, and Temperature rows. The CO app does not, however, predict Transparency or Seeing. That said, there are many more bars that provide additional information. In this respect, Clear Outside leaves Clear Sky Charts in the dust.

CO shows sunrise and sunset times, Moon rise and set times, as well as the phase visually and numerically. The red lines inside the Sunlight and Moon rows hint at the transit times. The Clear Outside tool also shows bars for air visibility (in miles), fog, rain along with POP (Probability of Precipitation) and amount, frost, wind chill, and the dew point.

I was very surprised to see an icon for the International Space Station. That's cool. And it will prove very handy this summer, I'm sure.

The Time bar, at the top naturally, is the "high level" indicator of the evening's conditions. It uses an easy-to-interpret red-amber-green coloured chip. Get ready to head outside if it is showing green.

Swipe left or right on your touch-sensitive display to view different times or days. Look at the predictions for the next few days. The Clear Outside webpage shows seven days into the future; the Android app shows six. Swipe or drag slowly so to centre on midnight tonight.

It is easy to configure your favourite observing sites via the Locations tab. I already have a few loaded and ready to go.

Clear Outside updates hourly.

The CO app uses the latitude and longitude you provide or the tablet's current location data to find a nearby weather source. The weather data is gathered by the website http://forecast.io which in turn relies on weather data providers, including Environment Canada.

I guess I could always look out the window, but I like my posse of weather-prediction products. I really like being able to see the expected conditions for later today and tomorrow. And for me, I think it most useful regardless of the computer or internet appliance I'm near.

It is with mixed emotions that I encourage you to try the Clear Outside website as well as the app for your portable device. Let it be known, I'm not stopping my use of Clear Sky Charts. If anything, Clear Outside is simply a new iron in the fire for us amateur meteorologists / amateur astronomers. ✶

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

John Percy's Universe

BRITE-Constellation: Canada's "Shoebox Satellites" for Variable-Star Research

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

Canada has a long list of achievements in astronomical research, ranging from leadership roles in megaprojects such as the Atacama Large Millimetre Array (ALMA), to imaginative "small science" initiatives. This column highlights one of the latter.

I hope that most (no pun intended) readers of this *Journal* have heard of *MOST*[1], properly called *Microvariability and Oscillations of STars*, (et en français, *Microvariabilité et Oscillations STellaires*) and colloquially called "Canada's humble space telescope" (Walker *et al*. 2003). This suitcase-sized satellite cost about 10 million dollars to build and launch. It was designed and built at the Space Flight Laboratory at the University of Toronto Institute for Aerospace Studies (UTIAS-SFL[2]), and went up on 2003 June 30. It was still gathering data as of late 2014, though its ownership was transferred at that time from the Canadian Space Agency to Microsat Systems Canada, formerly part of Dynacon, an industry partner in the development and operation of the satellite. As of now, *MOST* has contributed to about 100 scientific publications on stellar pulsation and other forms of variability.

MOST's claims to fame are its modest cost, its very precise photometry, and the fact that it was the first satellite devoted to variable-star research. In many ways, it was the pathfinder for the much more expensive European *CoRoT* and NASA *Kepler* satellites. Its success has been due to the vision of its proposers (initially Slavek Rucinski and subsequently him and Kieran Carroll, Jaymie Matthews, Tony Moffat, Dimitar Sasselov, and Gordon Walker), the leadership of Project Scientist Jaymie Matthews (University of British Columbia), technical advances such as reaction wheels and microtorquers to keep this low-mass satellite pointed precisely, and a Fabry microlens array to achieve sub-millimag photometry.

BRITE-Constellation[3] (*BRIght Target Explorer*, not the world's most imaginative acronym, but the best we could think of at the time) is "the spawn of *MOST*"—a set of six 7-kg, 20-cm, cube satellites, whose purpose is to study the photometric variability of the several hundred apparently brightest stars, ones that are too bright for satellites such as *Kepler* or *Hubble* (Weiss *et al.* 2014). At the same time, these bright stars are easily accessible to spectroscopic observation with modest-sized, ground-based telescopes, in support of the photometry. Incidentally: I like to think of *BRITE* as "shoebox satellites" but, given their cube shape, "car-battery satellites" is more appropriate. Technically, they are nanosatellites, or nanosats.

BRITE is studying micropulsations, wind phenomena, and other forms of variability—perhaps even exoplanet transits. *BRITE* target stars are intrinsically luminous—almost all more luminous than the Sun—and especially prone to variability. Although the target stars are rare per unit volume, they are extremely important in producing the chemical elements and recycling them in winds and supernovae. They are "laboratories" that help us to understand a wide range of astrophysical processes. Luminous hot stars tend to have massive, variable winds, as well as other forms of variability. Luminous cool stars are unstable to complex pulsations and mass loss. The brightest stars also include several dozen pulsating B stars[4], emission-line B stars (Be stars), delta Scuti pulsating stars, as well as eclipsing and rotating variables. *BRITE* may also identify stars that are not variable, which is astrophysically interesting in itself.

BRITE-Constellation was conceived, a decade ago, by Slavek Rucinski, now Professor Emeritus at the University of Toronto. I was involved in the project at that stage, but less so now, though I still have a few stars on the target list. Initial attempts to obtain funding in Canada were unsuccessful for several years, despite the merits of the project and the quality of the proposal. By the time Canadian funding materialized in 2011, Austria and Poland had joined the project as enthusiastic partners, and they quickly obtained funding for their participation in the project. The Canadian Project Scientist, and currently chair of the international *BRITE* executive scientific team ("BEST") is Tony Moffat (Université de Montréal).

BRITE-Constellation, like *MOST*, was designed at UTIAS-SFL. It is operated by a consortium of universities from Canada, Austria, and Poland. There are six satellites: *BRITE-Toronto* and *BRITE-Montreal*, *BRITE-PL1* and *2* (called Lem and Heweliusz) that are operated from Poland, and the Austrian satellites *UniBRITE-1* and *BRITE-Austria*. The latter is also known as *TUGSAT-1*, as it was built at the Technical University of Graz, using the UTIAS-SFL design, and is operated from TUG. Polish astronomer Heweliusz is better known to English-speaking astronomers as Johannes Hevelius (1611-1687). Lem is the great Polish science-fiction writer Stanislaw Lem (1921-2006).

Also like *MOST*, the *BRITE* nanosats incorporated several pioneering Canadian space technologies. These included advances in precise attitude control, which are absolutely essential to keep such a small, low-inertia satellite pointed accurately—not to mention the whole concept of operating several satellites as a "team." The 30-mm telescope has a field of view of 24 degrees, and the detector provides millimag precision per orbit. Much smaller signals can be detected, if periodic, using time-series analysis. Three satellites have blue filters, three have red. The constellation thus provides colour

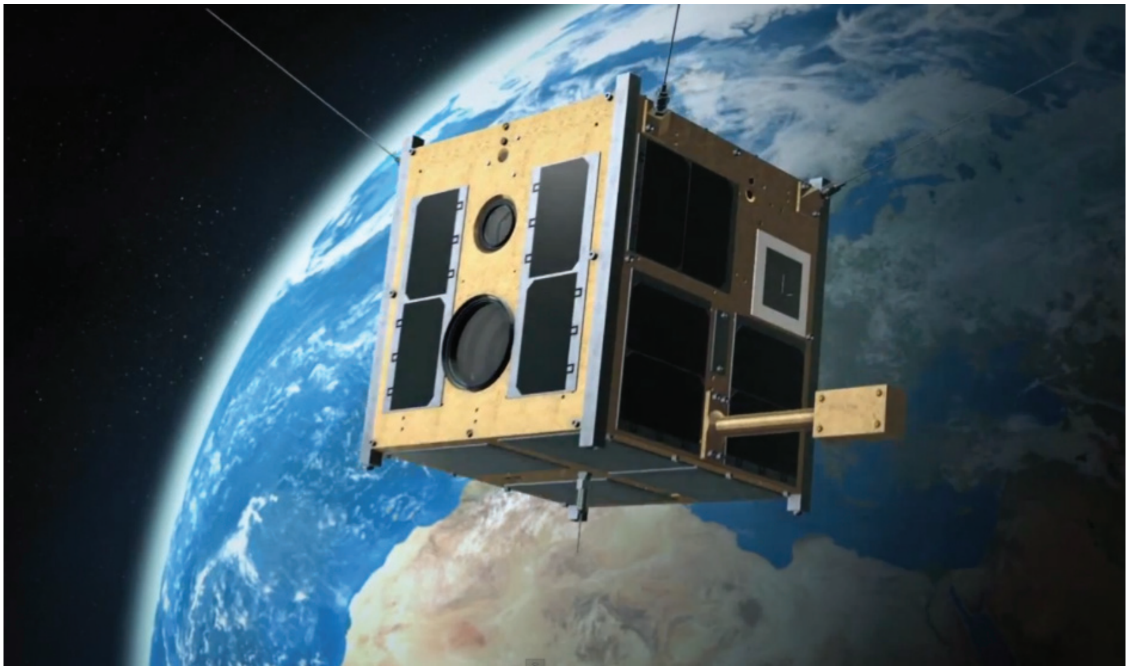

Figure 1 — An artist's concept of the BRITE *nanosatellite* Lem *in orbit. Image: BRITE-PL*

information, as well as superior time coverage, which leads to more precise period determination for periodic variables. It also provides more complete sky coverage. The optics for the *BRITE* nanosats (except *Heweliusz*) were designed and built by Ceravolo Optical Systems—a name familiar to many RASC members. The design of the nanosats is deliberately simple, in an effort to achieve effectiveness with less risk and less cost (Figure 1).

The Austrian satellites were launched in 2013 from India, *Lem* in 2013 from Russia, and *Heweliusz* in 2014 from China. The Canadian satellites were launched in 2014 from Russia, but *BRITE-Montreal* did not detach from its third-stage rocket, and is probably lost. The satellites are in polar, low-earth (600-800 km) orbits. Data are downloaded to ground stations in Toronto and in Europe but, beginning in October 2013, both *BRITE* ground stations in Europe began to suffer from severe UHF radio interference from an unknown (military?) source.

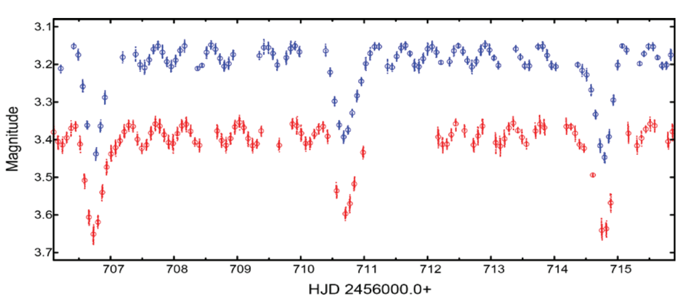

Figure 2 — A small portion of the BRITE *light curves (in blue and red light) of eta Orionis, a 7.989-day Algol-type eclipsing binary with a non-radially pulsating component with a period of about 0.43 day. Source: Andrzej Pigulski.*

As of February 2015, modifications of the UBC's *MOST* ground station, to support *BRITE* communication, are in progress.

The *BRITE* team issues a monthly report on the status and progress of the mission. The 2015 February 25 edition (the 2nd anniversary of the launch of *BRITE-Austria*) reported that the five nanosats were busy observing their target fields and that reduced data were beginning to flow to the Principal Investigators (Figure 2). Furthermore, the first *BRITE* science conference is scheduled for September 14-18 in Gdansk, Poland—sure signs that new and exciting science results are coming from this unique Canadian-born mission! ✶

Acknowledgements

I am grateful to Professor Tony Moffat (Université de Montréal) for his careful reading of a draft of this column and for his many useful suggestions, and to Professor Andrzej Pigulski for providing Figure 2.

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Publications of the Astronomical Society of the Pacific, 115, 1023-1035.

Weiss, W.W. *et al.* (2014). BRITE Constellation: Nanosatellites for Precision Photometry of Bright Stars. *Publications of the Astronomical Society of the Pacific, 126*, 573-585.

Endnotes

1 http://en.wikipedia.org/wiki/MOST (satellite)

2 http://utias-sfl.net/?page id=407

3 http://brite-constellation.at

4 B stars are hot stars in the spectral sequence OBAFGKM—hot to cool

Dish on the Cosmos

Gravitational Lensing

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

In my previous column, I discussed how the ALMA observatory recently overcame major engineering challenges and was now able to use large separations between the antennas to form an interferometer. These long baselines dramatically improve the angular resolution that the telescope can achieve, operating as a "zoom lens" for the radio telescope. Now, we are starting to see the scientific results of these new capabilities. One major result that came out this year is the imaging of the distant galaxy known as SDP.81.

While all galaxies are "distant," this particular system is of intense community interest, because it is imaged as part of a gravitational lens. This lensing takes advantage of a chance alignment of the distant SDP.81 with an anonymous foreground galaxy that acts as an immense, focusing telescope, billions of light-years long. This alignment allows astronomers to observe a star-forming galaxy 3/4 of the way across the visible Universe. Because the galaxy is so far away, and light travels at a large but finite speed, SDP.81 is a representative of systems found early in the course of the Universe's evolution. These gravitational lenses are one of the many consequences of Einstein's general theory of relativity. Specifically, the theory holds that massive objects will warp the space and time in their vicinity so that light will actually bend around them. The first predictive test of Einstein's theory was to observe this very distortion in the light paths taken by rays from stars as they pass near the Sun. Sir Arthur Eddington's 1919 observation of the predicted distortions in stellar positions during a solar eclipse was the first in a long line of exact confirmations of Einstein's theory.

Figure 1 illustrates the typical geometry of gravitational lensing. The solid line shows the curvature of the light ray in the gravitational well of the Sun. The key point in interpreting this distortion is to recognize how we view the Universe: we assume that light reaches our eyes having travelled along a straight path as a ray (the grey dashed line in the figure). We are unaware of the bent path the ray actually travelled, and so we see the image of the star in a different position than where it is actually located. Whenever our brains encounter light traveling along bent paths, we are confused about where the ray comes from: just think of sitting at the edge of a pool with your legs in the water. When you look down, your brain tells you that your legs appear to be broken! This assumption about the rays causes us to perceive this bending as a distortion in position. It is also important to note that one bent ray reaching us will produce one image of a background star.

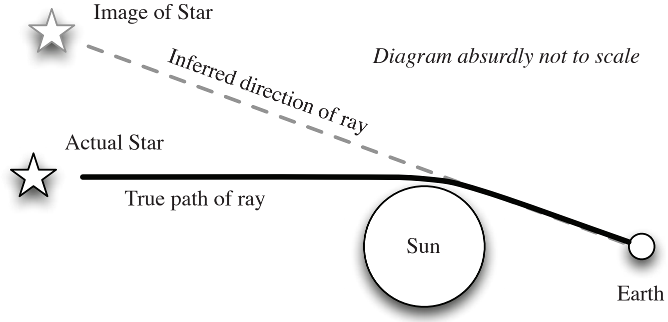
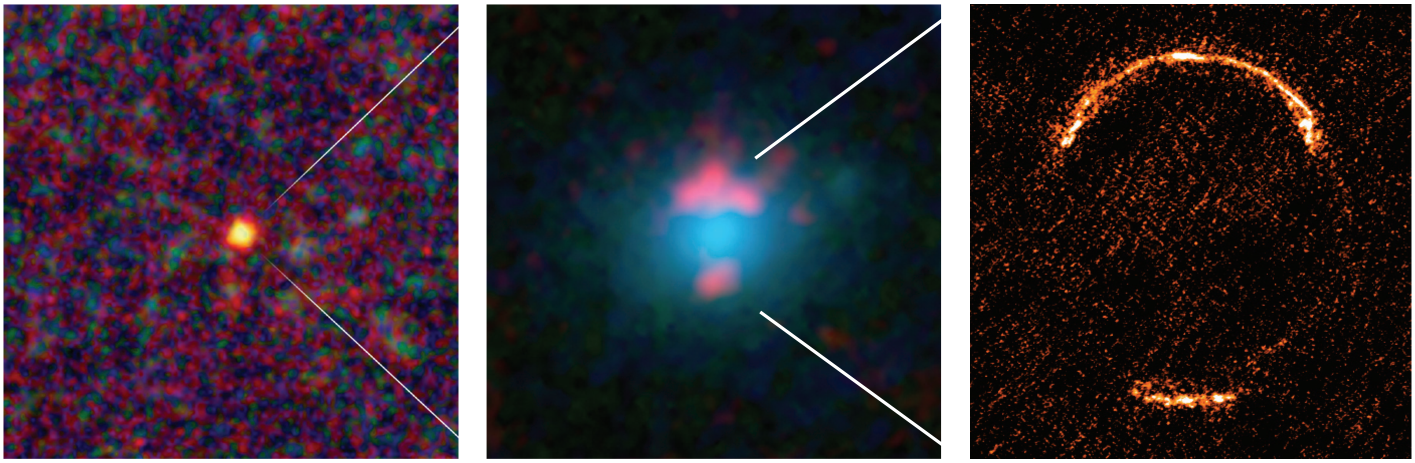


Figure 1 — A schematic diagram showing a ray of starlight undergoing gravitational lensing by passing near the Sun. The apparent location of the star is inferred by tracing the ray back along its path, assuming a straight line. Image Credit: E. Rosolowsky

Multiple rays can travel along different curved paths to arrive at the same point, leading to multiple images of the background object. The gravitational distortion of the Sun isn't enough to create multiple images of background stars, but other physical systems, like the anonymous lensing galaxy mentioned above, can create multiple images of the background target; in this case, SDP.81. Figure 2 shows SDP.81 as it was seen by several different telescopes. The left image shows the view from the *Herschel Space Observatory*, which had relatively poor resolution but amazing sensitivity to light in the far infrared part of the electromagnetic spectrum. While observing a seemingly empty part of the sky, the telescope found a bright source of light literally in the middle of nowhere. The observations were constructed to find these bright sources, since it was thought that the primary reason for them would be gravitational lenses magnifying the light from very distant galaxies. In fact, the scientists using the telescope at the time wanted to identify precisely this type of galaxy, because they represent a a dusty and primitive type of star system that is not seen in the local Universe today. Finding many such galaxies can contribute to research that is building up a picture of how such galaxies form and evolve.

The middle image of Figure 2 shows SDP.81 as seen in a combination from the Keck 10-metre optical telescope (blue image) and the Submillimetre Array (SMA), both located on Mauna Kea in Hawaii. The Keck 10-m telescope light reveals the foreground galaxy that is serving as a lens. These data allow astronomers to build up a model for how that galaxy magnifies and distorts the background light. The SMA is a telescope much like ALMA, but it is significantly smaller. The SMA made the original image of the lens, looking like an off-centre cross as seen in the red colours in the middle panel. Finally, the right-hand panel shows the image of SDP.81 as seen from ALMA, observing in the same wavelengths as SMA. The sharper vision of ALMA is a dramatic improvement on the SMA image. These beautiful arcs are the signature of multiple images created in passing through a gravitational lens.



Herschel Space Observatory | Submillimetre Array + Keck Telescope | ALMA

Figure 2 — Several views of the SDP.81 system. Image Credit: ESA / NASA / JPL-Caltech / Keck / SMA / ALMA.

The ALMA image looks nothing like a galaxy, even a particularly irregular one. This is because gravitational lenses, like glass lenses, both magnify and distort the background image. We are actually seeing two images of the galaxy, one in each of the top and bottom sections. The top lensed image is stretched out into a long, thin arc while the bottom is more compact. These two views of the galaxy can be used to understand how early galaxies differ from our own. We already knew that galaxies like our own Milky Way form many of their stars early in their formation process. If we look around the solar neighbourhood, many of the stars are very old. Star formation in our galaxy has taken place in an early burst that then mellowed into the relatively sedate pace of star formation that we see today.

SDP.81 is a galaxy undergoing its youthful burst of star formation and the question then becomes how, exactly, do these stars get formed out of gas? How long is the burst? Do neighbouring galaxies or clouds of gas get contaminated by the products of star formation in SDP.81? While ALMA cannot answer all these questions, the lensed images of SDP.81 indicate that the galaxy is dominated by the cold gas that goes on to form stars. Furthermore, this gas is concentrated into clouds that are far denser and more massive than the star-forming clouds seen in our own Milky Way. Pushing that much gas into a small volume should form stars exceptionally quickly, accounting for the burst of star formation we think has happened in the distant Universe.

ALMA observations fill out other pieces of the puzzle about what is happening in SDP.81. The gas appears to be warm, at least when compared to star-forming gas in the present day. The gas also appears to be moving at very different speeds in different parts of the system. These two pieces of evidence suggest that the burst of star formation is being powered by two smaller galaxies crashing into each other in the process of building up a larger system. We think these collisions are fairly common in the early Universe and SDP.81 is likely to be such a collision seen as it happened 11.6 billion years ago, a mere 1.9 billion years after the Big Bang. Using gravitational lenses with our most powerful telescopes is giving a resolved view of how galaxies assemble in the earliest phases of the Universe. ✶

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.

Imager's Corner

Star Fix

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

This edition continues a group of Imager's Corner articles that will focus on techniques that are useful in processing astrophotos. Over the next several editions of the *Journal*, I'll continue with a guide to several techniques I find most useful.

Ever have an otherwise great image with crappy stars at the edges, due to coma, that force you to crop more than you'd like? Here is a way to save a little more of that field of view that you worked so hard to capture. This process is intended to deal with mild coma, not pincushion distortion—that can be fixed with more standard functions in programs such as *Photoshop* or *PaintShop Pro*.

Take a look at this image of M100 captured by Scott Rosen from his dark-sky backyard in California. In the upper left corner, we can easily see what the coma from Scott's uncorrected SCT has done to the stars. They have a crescent look that usually dictates cropping to avoid spoiling the final image. What follows here is a technique that helps improve

Figure 2 — Stretching the image

the stars to the point where cropping may not be necessary.

The first step is to over-stretch the image to fill in some of the missing parts of the stars (Figure 2).

Once the stretch has been applied, it is time to use the stretched image to make a star mask. You can use your favourite tool or technique; here I'm using

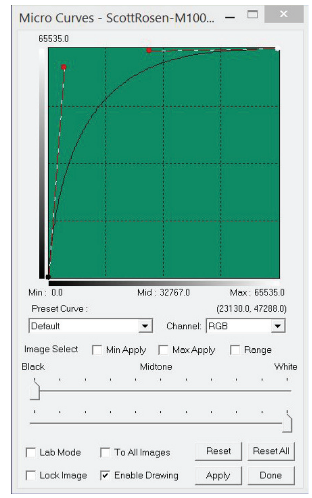


Figure 1 — M100 with coma. Note the star shapes in the upper corners.

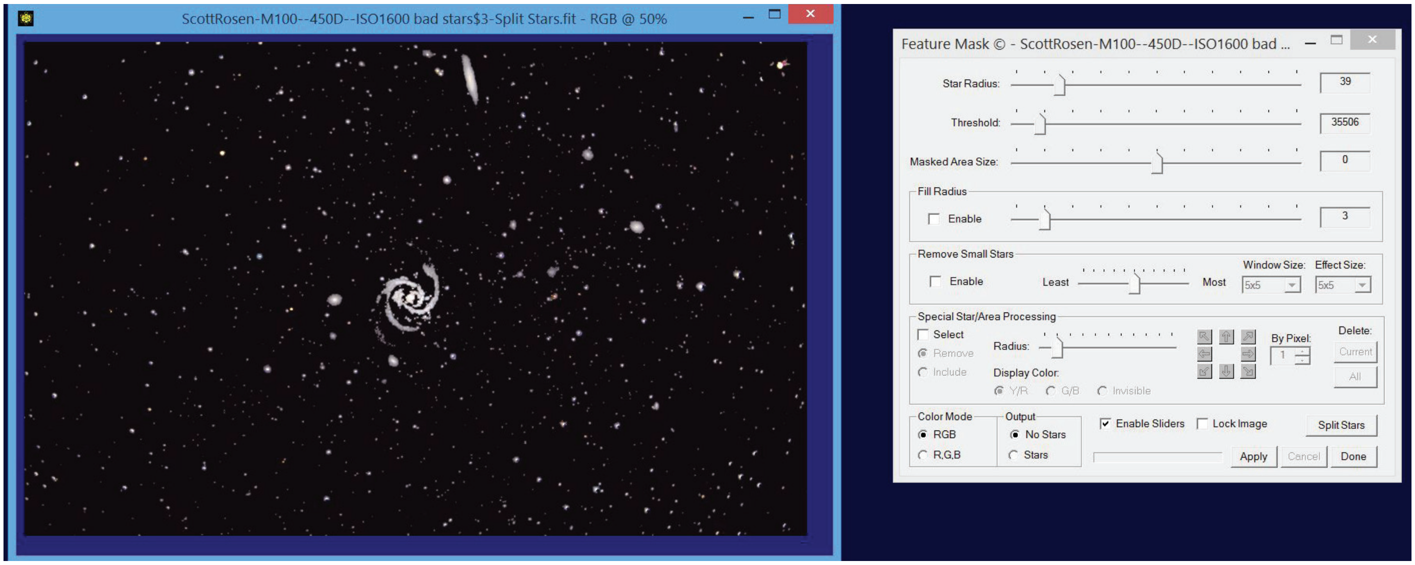


Figure 3 — Making the star mask

the feature mask tool in *ImagesPlus* to produce a star mask with a few clicks (Figure 3).

Now it's time to do a little creative painting to remove anything that is not a star, as the setting used with the feature mask still leaves a few details from the galaxy in the scene. After a little painting, we have the star mask with most of the middle, covering the galaxy, filled in with black. Making this mask is not an important step, as the final mask needs the centre removed anyway (Figure 4).

The star correction needs to be applied to the outer edges of the image while leaving the central regions untouched. This can be accomplished simply by painting the central area black, as we've done below, but the technique I like to use is to reduce the brightness using levels with a control-point mask in

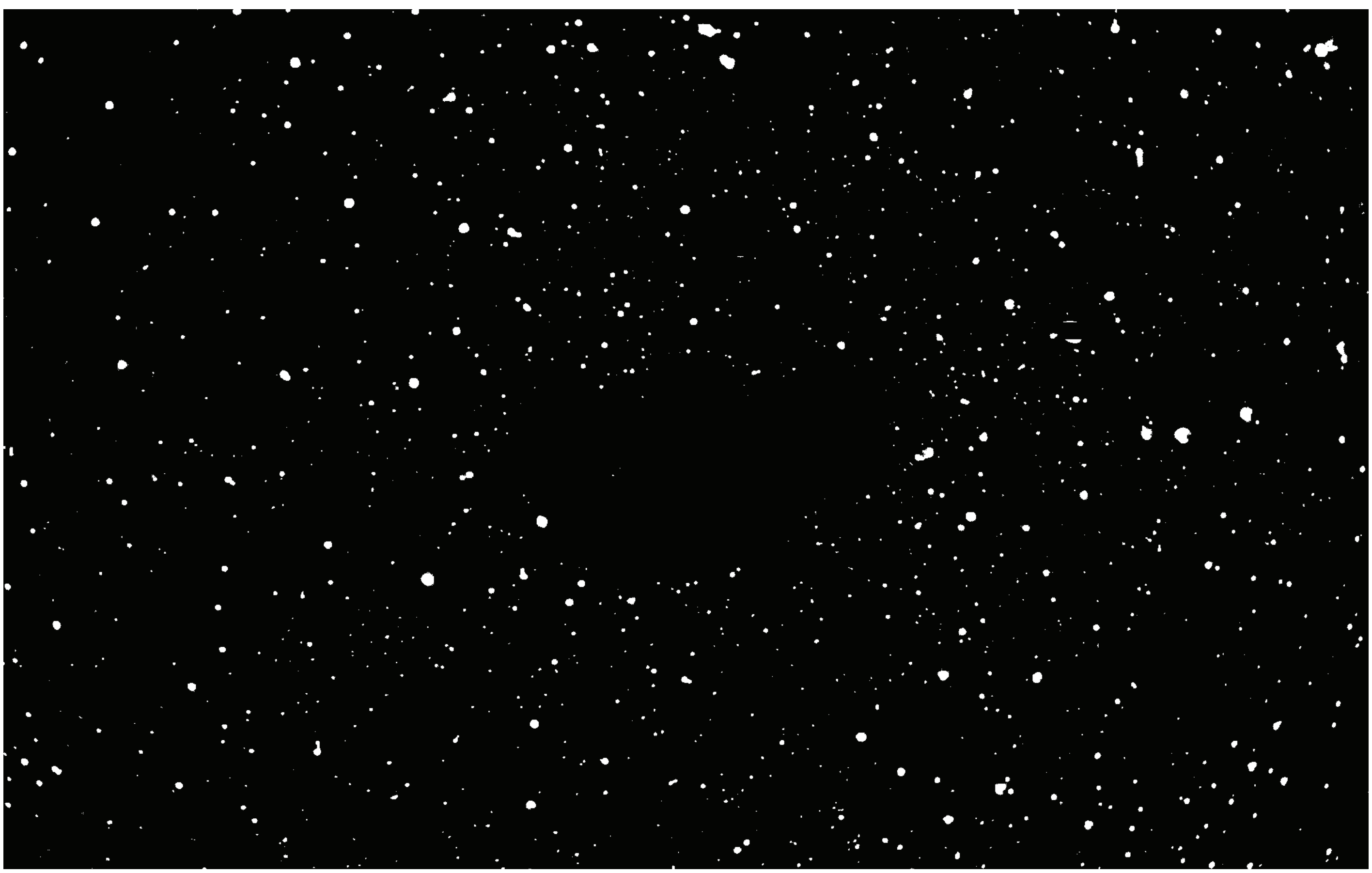


Figure 4 — Star mask after painting

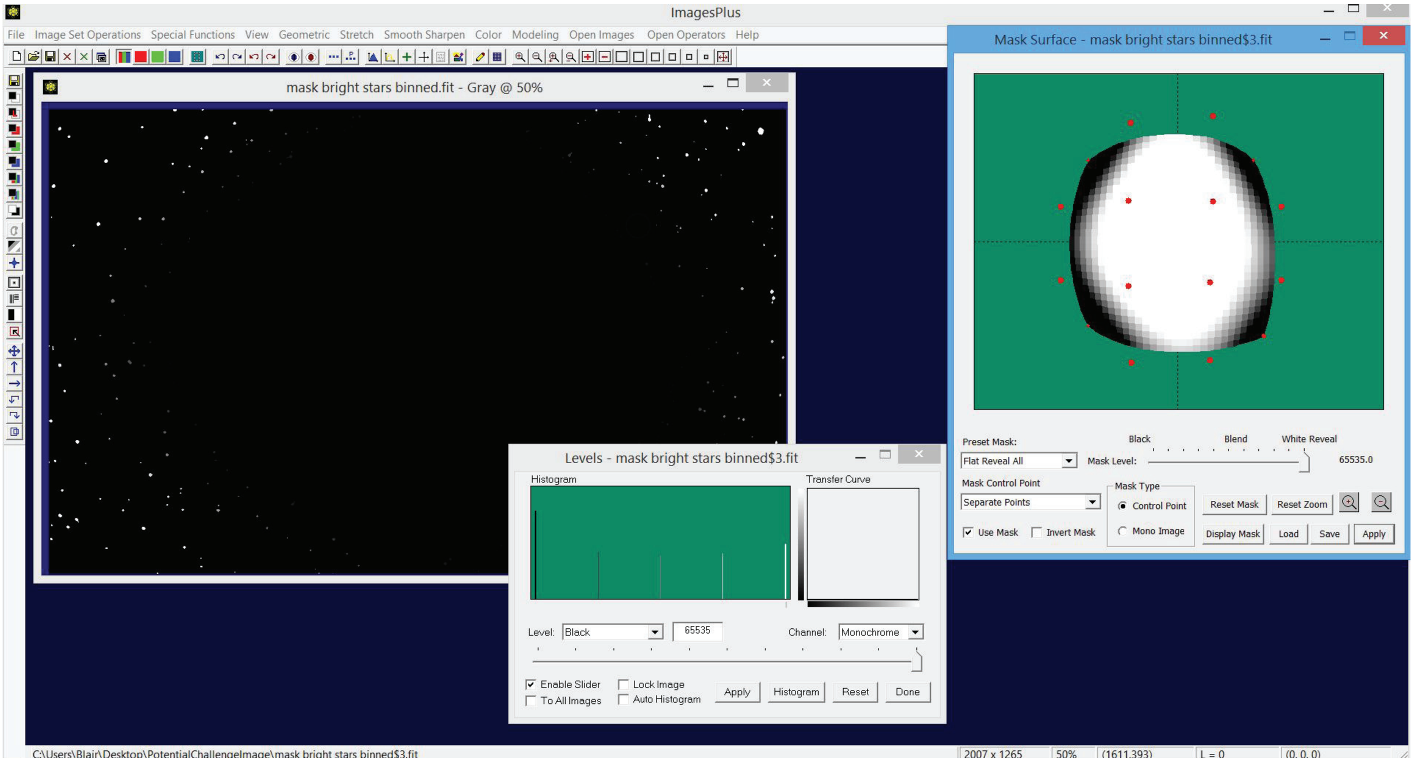


Figure 5 — Making the final mask

ImagesPlus. This has the advantage of blending the effect from "full" at the edges to "none" in the central part of the image, as shown in Figure 5.

With the mask complete, it is time to fix those stars. One method of doing this is to increase the brightness until the whole star appears white. With the mask applied, the effect will be limited to the edges, producing almost-round stars. The problem with this is that the star colour is removed. A better technique is to use some function that fills in the dim parts of the star while preserving the star colour. It turns out that there is just such a function available on most image processors: it's called dilation. Dilation fills dimmer pixels with the value of brighter surrounding pixels. When this is applied to the stars,

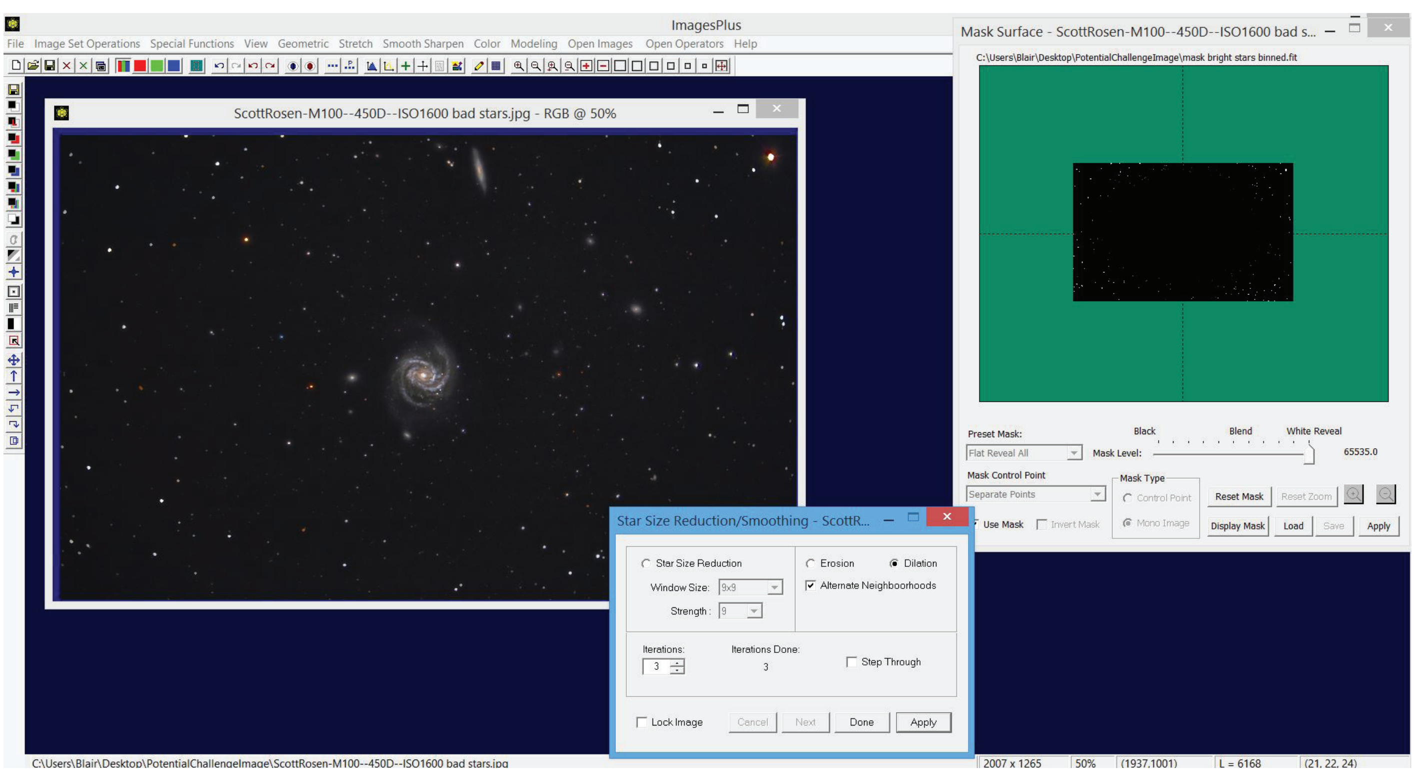


Figure 6 — Masked dilation

Figure 7 — Corrected but large stars

the bright area is blended into the dim area; the mask limits the effect to stars at the edges of the image (Figure 6).

This leaves an image with round, but somewhat large and abrupt stars at the edges as shown in Figure 7.

To fix these oversized stars, apply a star reduction or erosion with the same mask used for the dilation. To correct the abrupt edge left on the stars, use a simple small-radius Gaussian blur, again with the mask to limit the effect to the edge stars. This produces the image in Figure 8; the improvement in the star shape in the upper left corner is obvious.

While not perfect, the image is now good enough to avoid any extreme cropping while preserving star colour across the full field of view.

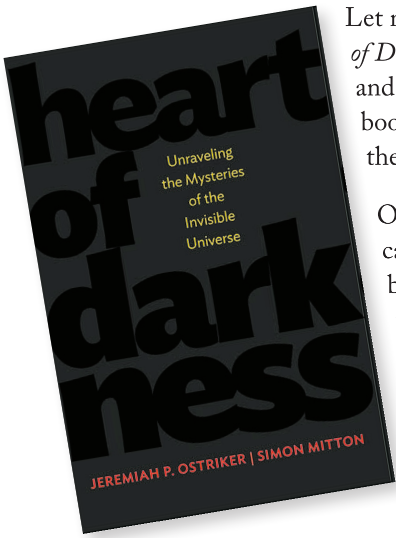
Remember, this column will be based on your questions so keep them coming. You can send them to the list at hfxrasc@lists.rasc.ca or you can send them directly to me at b.macdonald@ns.sympatico.ca. Please put "IC" as the first two letters in the topic so my email filters will sort the questions. ✶

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.

Figure 8 — The final image. Note the improved star shapes in the upper corners

Reviews / Critiques

Heart of Darkness, Unraveling the Mysteries of the Invisible Universe, by Jeremiah P. Ostriker & Simon Mitton, pages 299; 16 cm × 24 cm, Princeton University Press, 2013. Price $27.95 USD hardcover (ISBN 978-0-691-13430-7).



Let me begin by saying that *Heart of Darkness* is a fascinating read and a welcome addition to the bookshelf. There is little about the book that I did not like.

Ostriker and Mitton are both capable writers, the former being an accomplished theorist, and both are intimately familiar with the subject matter of *Heart of Darkness*. Ostriker himself was involved in some of the scientific discoveries highlighted in its contents.

Heart of Darkness is more than a dry narrative describing dark matter and dark energy. It is a walk through the history of where we came from, what we knew 100 years ago, and where we are today, who was involved, and when. In addition to the well-known early observers of the Universe around us—astronomers such as Copernicus, Tycho Brahe, Kepler, Galileo, and Newton—the historical description includes more recent scientists like Laplace, Simon Newcomb, and Michelson, then embraces Einstein, Hubble, Lemaître, Shapley, Hoyle, as well as a few little-known science figures that are studded like gems in the matrix of the story: Sandage, Bethe, Gamow, Alpher, Wilson and Penzias, and Tinsley. The book relates the discovery of the Universe as it grew larger and broader by leaps and bounds with each new insight. Every new instrument led to a new understanding of what was "out there." And each new insight led to better and better theoretical descriptions.

In describing the process by which Edwin Hubble "discovered" the expansion of the Universe, the authors give Georges Lemaître full credit for his earlier discovery, which, in turn, was based on examination of data from Vesto Slipher. Hubble refined the data with better and more accurate observations, but Lemaître discovered what is now called the "Hubble constant." Lemaître made the mistake of publishing in French in a journal that was largely overlooked by American astronomers. No matter, his published work increased our knowledge of the Universe.

In the middle chapters, the authors take us along a road of discovery, using simple math, that shows how and why the Universe is expanding, and how we can re-wind the cosmological clock to the beginning of time, 13.7 billion years ago. The important question early on was "Is there enough matter in the Universe to cause gravity to stop expansion and start a collapse?" One of Edwin Hubble's protégés, Allan Sandage, calculated that "deceleration pointed to a closed universe that would likely re-collapse…." However, numerous observational astronomers tried applying the concept to what they saw, and were surprised that they could not find enough matter in the galaxies to trigger collapse. "Much debate and head scratching ensued."

Thus began the idea that some form of matter and energy should exist that drives accelerated expansion, stuff we just cannot see and so call "dark matter" and "dark energy." We are still ignorant of what they actually are! There does appear to be ample proof, however, both theoretical and observational, for "the evolving, hot big bang universe." *The Cosmic Background Explorer* (COBE) satellite, launched in 1989, measured the background microwave radiation to high precision, giving the now-familiar image of blues, greens, and yellows showing fluctuations in the very beginning of time—fluctuations that ultimately resulted in stars, galaxies, and voids in the present day.

Ostricker and Mitten close with a summary of their arguments in support of dark matter and dark energy: "The eye of the beholder can thus judge success or failure, but it is surely obvious to all that the undertaking has succeeded beyond the wildest dreams of the early scientists who led the way, while leaving ample room for the discoveries by future generations of cosmologists."

And, for the math-deprived, the authors have omitted equations from the main body of the text, but provide clear explanatory appendices, followed by a glossary, bibliography, and an index—all welcome components of a complete discourse on such a highly technical subject.

Did they succeed? Yes, in spades! ✶

James Edgar

James Edgar is the RASC President, Assistant Editor of the Observer's Handbook, *and Production Manager of this* Journal.

The August *Journal* deadline for submissions is 2015 June 1.

See the published schedule at
www.rasc.ca/sites/default/files/jrascschedule2015.pdf

RASC Travel

Randy Attwood, Executive Director

The RASC is partnering with its sponsor MWT Associates, Inc. to run several astronomy-related tours in the next few years.

Trips to Los Angeles, Hawaii, Arizona, Yellowknife and Chile are planned, culminating with a national eclipse expedition to Wyoming for the 2017 total solar eclipse.

First up is a one-week trip to Los Angeles/San Diego with visits to various astronomy and space exploration related destinations.

The trip will take place 2015 November 3 - 9. See the itinerary. Includes daily breakfasts and three dinners.

PRICE – $2395 per person, double occupancy ($575 Single Supplement)

Deposit: 1st Deposit: $300 per person to reserve Final Payment due no later than 2015 August 1

If you are interested please email **attwood@rasc.ca** to get on the list. Space is limited for this tour.

ITINERARY:

Tuesday, November 3 – Arrival in Los Angeles

Wednesday, November 4 – Los Angeles

- A free morning to sightsee LA and Hollywood with an afternoon visit to Griffith Observatory
- Evening—dinner at the Magic Castle where the up-and-coming magicians train—magic shows in every room.

Thursday, November 5

- A free morning to visit other sights such as the Getty Museum with an afternoon visit to the California Space Science Center where the Space Shuttle Endeavour is on display.

Friday, November 6 – LA, Pasadena

- A guided tour of the famous Jet Propulsion Laboratory

Saturday, November 7

- A visit to the Mount Wilson Observatory

Sunday, November 8

- San Diego A visit to the famous Palomar Observatory

Monday, November 9 - Return home

Future RASC Tour Trips Planned

Hawaii, June 2016: A visit to the summit of Mauna Kea

Wyoming/Idaho, August 2017: Total Solar Eclipse Expedition

Arizona: Observatories, Meteor Crater, Grand Canyon, Dark-Sky Observing / Date: TBA

Chile: Observatories, Dark-Sky Observing / Date: TBA

Yellowknife, NWT: Aurora observing / Date: TBA

If you have any questions please contact Randy Attwood: **attwood@rasc.ca**

Great Images

James Edgar (RASC President) took this sequence while imaging the aurora on April 10, capturing the International Space Station threading the stars Alioth, Mizar/Alcor, and Alkaid in the handle of the Big Dipper. James used his Canon 60Da, with a Canon 8-15-mm zoom fisheye lens at 9-mm focal length, aperture ƒ/4 for 9 sec, each at ISO 2000

Notes from the National Secretary

by Karen Finstad, National Secretary
(nationalsecretary@rasc.ca)

This month, two more members of the Society's Board of Directors provided information about themselves and why they are willing to give up so many hours to help keep the Society running smoothly. These are the people who will be guiding our future for years to come, and decide how our membership fees are spent. So, please participate in the upcoming election for three open Board positions.

Currently serving a one-year term as Director, Robyn Foret is a long-time astronomy enthusiast and a life-long volunteer. Since joining the Calgary Centre in 1999, he has volunteered thousands of hours toward public outreach and RASC business, including running the public viewing program at the now-retired Calgary Science Centre, and serving on Calgary Centre Council for eight years as a Councillor, three years as a National Council Rep, four years as Centre Secretary, and now as the Calgary Centre President.

On the National level, in addition to his Director's role, Robyn is in his third year as Chair of the Education and Public Outreach Committee. He states "I love astronomy, I love volunteering and am honoured to be in a position to contribute to the greater good of the RASC." Astronomy, the sciences, and volunteering also make up a large part of the daily norm for his school-teacher wife and three science-minded daughters.

Craig Levine joined the Halifax RASC Centre 16 years ago after watching comet Hale-Bopp night after night. Astronomy quickly became a passion that eventually led him to Presidency of the Halifax Centre and, after his departure from his east-coast homeland, to long-time service as National Council Rep for the London Centre. Craig is currently a member of the Publications and the Membership and Development Committees in addition to being Chair of the IT Committee, a natural fit, as he is a long-time IT Professional. Plus, he is a Trustee of the Public Speaker Program.

Both Robyn and Craig are originally from Cape Breton Island. Craig now resides in a village just west of London, Ontario, where he shares his home with his wife Lynne, three Border Collies, and two cats. An avid reader, he has also collected several other hobbies along the way: meteorology, photography, cooking, running, and most recently (to his astonishment), golf. ✶

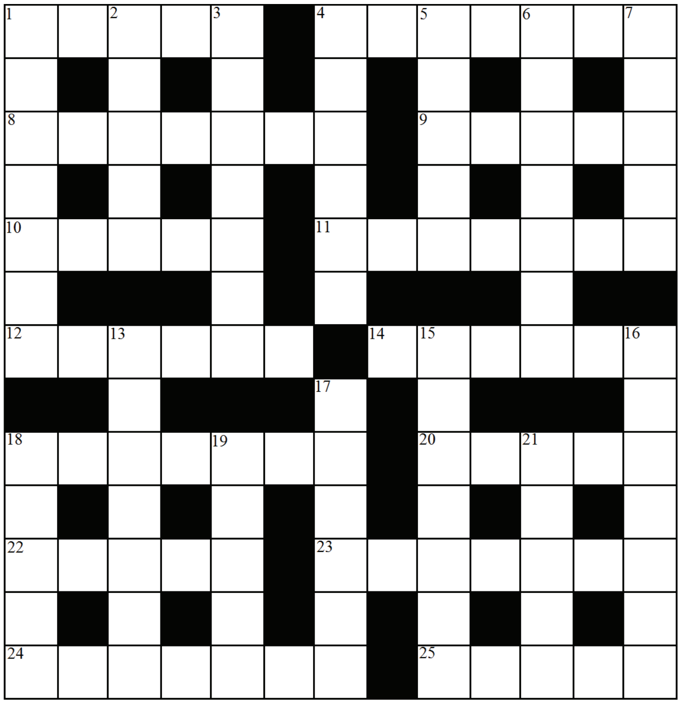
Erratum

In the February *Journal*, the note at the bottom of Andrew Pon's paper stated "This manuscript was derived from Dr. Pon's Northcott Lecture, delivered remotely from Scotland at the 2014 GA in Victoria, B.C. [Ed.]"

It should have read "This manuscript was derived from Dr. Pon's Plaskett Lecture, delivered remotely from Scotland at the 2014 GA in Victoria, B.C. [Ed.]"

Astrocryptic

by Curt Nason



ACROSS

1. Skewed shape of the Moon depends on it (5)
4. Countersink around Spanish gold on an asteroid (7)
8. Noisy CD spins according to planetary conjunctions (7)
9. Jewel Mrs. Kettle placed in the crown (5)
10. Curse about lithium detected in a planetary nebula (5)
11. Norton's editions made seas roil by the ocean (7)
12. Nurse in cozy home in a libration zone (6)
14. Magnitude man collected kids' bottle caps with no return (6)
18. Sky instrument seen in a Telrad (7)
20. Strange tales told of magnetic flux density (5)
22. I'm laughing inside after Bradley's first star in Pegasus (5)
23. He turned blind about backing Nagler but showed our galaxy is a spiral (7)
24. Aurora or light pollution? (7)
25. Sporer was angrier after losing his first payment (5)

DOWN

1. Auditor's great love for hydrogen emission lines (7)
2. Put an end to Luna rising around north (5)
3. I hear You Docs lead us to his model of planetary motion (7)
4. Bart moonwalks about half a dance with a polar guardian (6)
5. Large truck bumps the Spanish hunter's knee (5)
6. Hypothetical disruptive star has neon I mess around with (7)
7. Either way you look at it, the numbers are the same (5)
13. Wilson's mirror man came across never-itch eyepatches (7)
15. A month social workers set aside for position instruments (7)
16. Payne and Erfle own a lunar crater (7)
17. G star makes me scream in pain (6)
18. Hevelius's snake lost its three heads to a cryptic picture puzzle (5)
19. One beast leads another overhead (5)
21. Note argon is from the Sun (5)

Answers to April's Astrocryptic

ACROSS

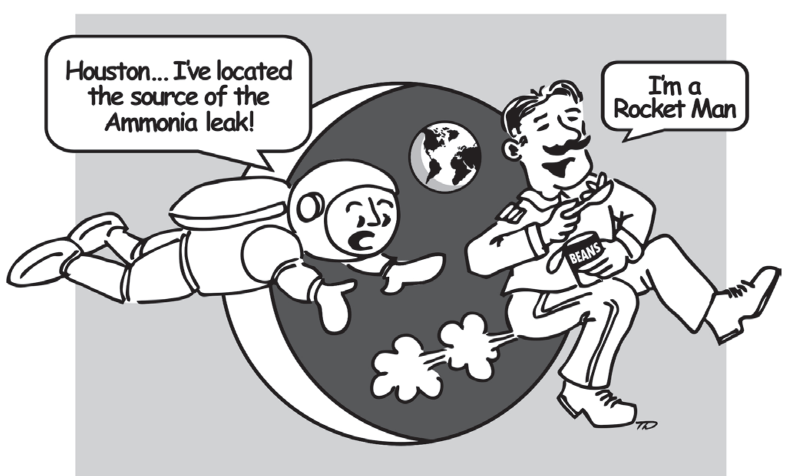
1 TELEVUE (Tu(elev)e); **5** MEADE (hidden); **8** SPONGES (2 def); **9** NIGHT (anag); **10** ORION (2 def); **11** ONTARIO (o(anag)o; **12** ISSUE (ISS+ u(niqu)e); **14** STONY (S+to+NY); **16** PUCCINI (Cup (rev)+c+in+1); **18** CUSPS (cus(p)s); **20** RIATA (Altair-1 (rev)); **21** NEUTRAL (anag+l); **22** NUNKI (nun+K+1); **23** ELEMENT (2 def)

DOWN

1 TASCO (anag); **2** LEONIDS (anag-o); **3** VEGAN (Vega+n); **4** EFSTONSCIENCE (anag); **5** MINUTES (m(Ni(rev)utes); **6** AUGER (2 def); **7** ENTROPY (anag); **12** IOPTRON (i(opt)ron; **13** ERIDANI (i(nadir)e (rev)); **15** OBSERVE (OBs+anag); **17** CHAIN (Mechain-me); **18** COUDE (co(u)de); **19** SPLAT (Alps(rev)+t)

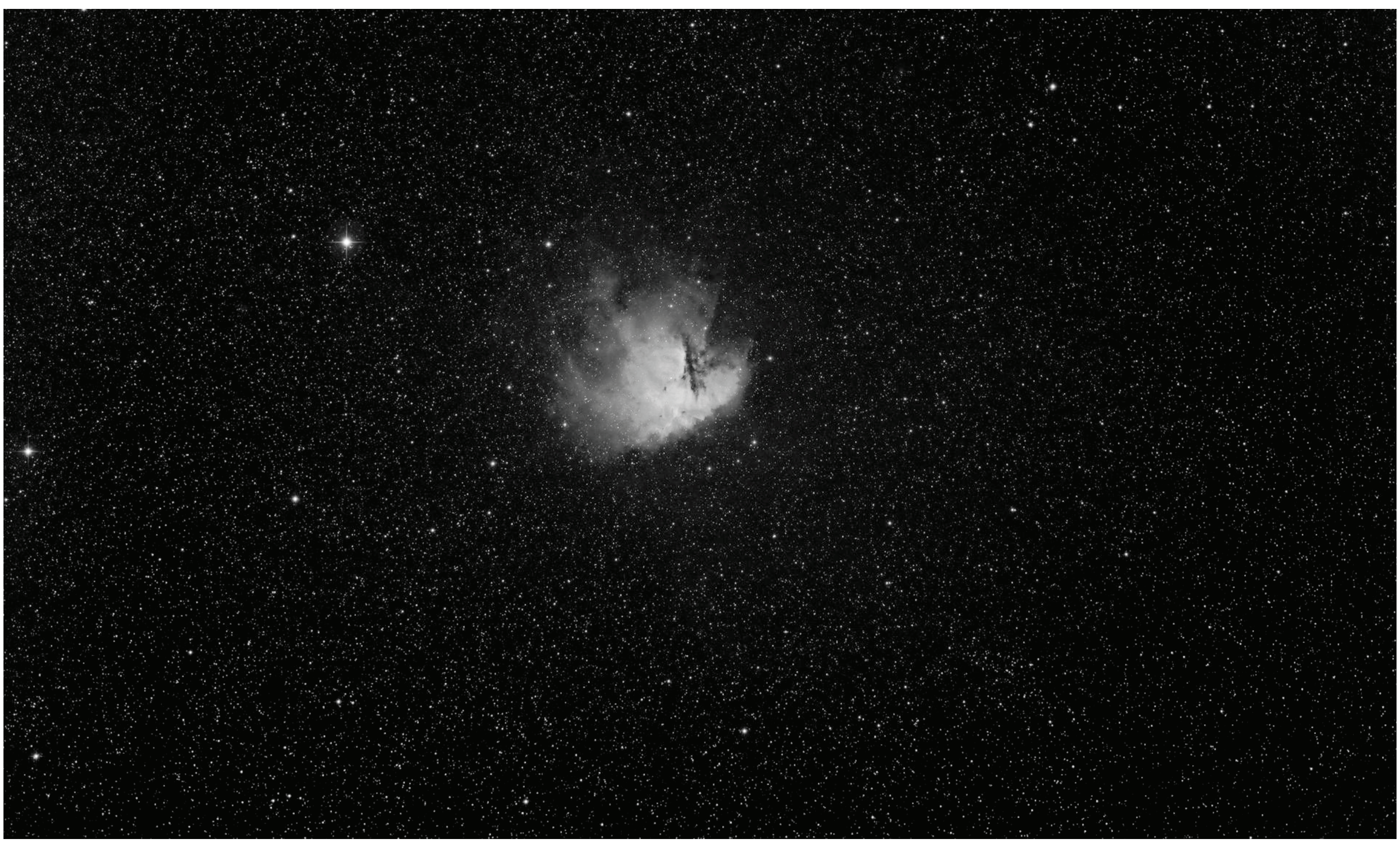
It's Not All Sirius

by Ted Dunphy

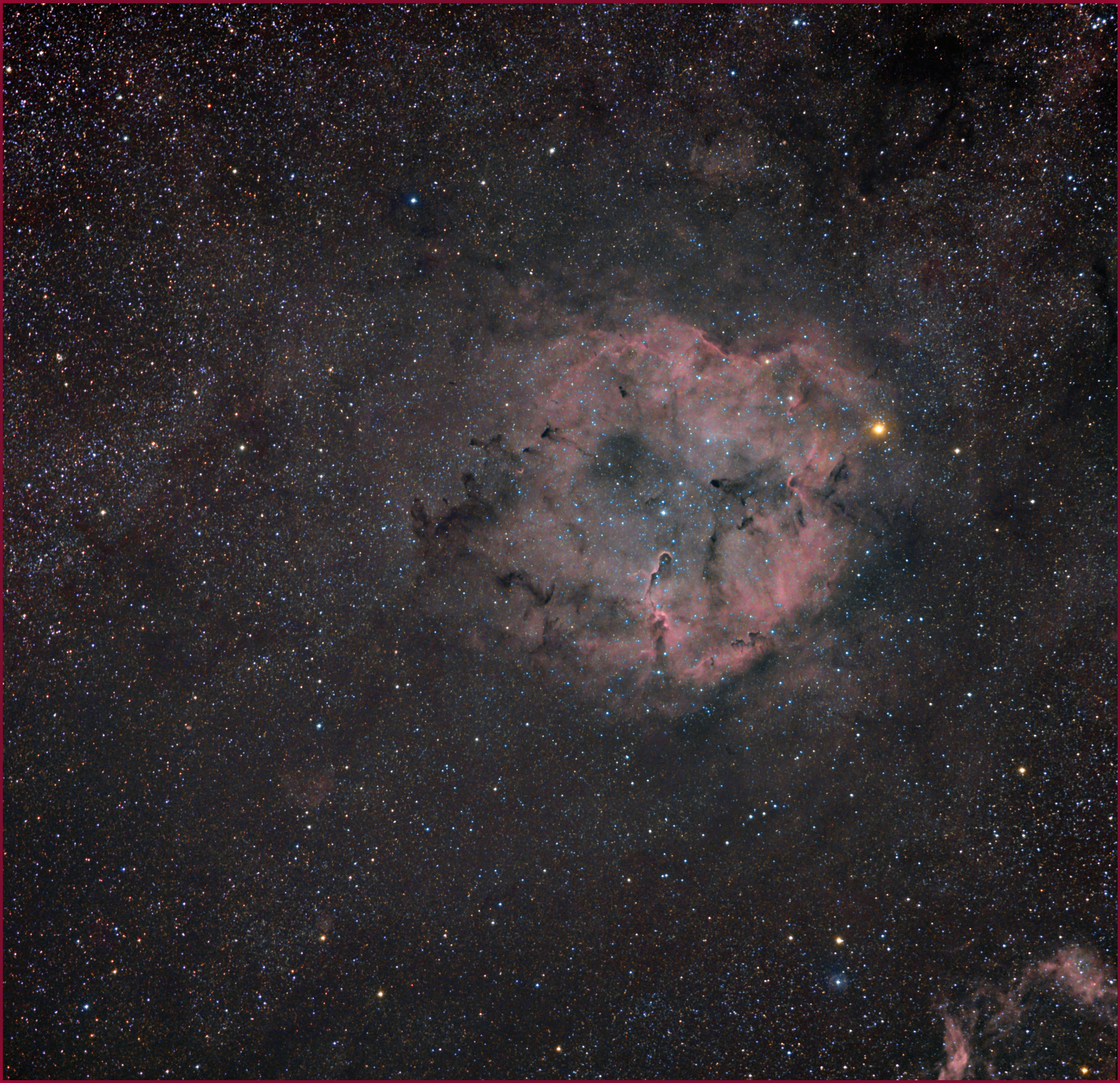


THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

Great Images



It's rare to find a nebula all by itself in the sky, as most seem to lie amidst a tangle of gaseous threads that connect them to similar members of our galaxy. One individual seems to be the Pac-Man Nebula, which lies alone among the generous star fields of Cassiopeia, about 9500 light-years from Earth. James Black took this Hα image from Light Waves Observatory in Pitt Meadows, B.C., using a Takahashi FSQ106ED and a Starlight Xpress SXVR-H36 camera.



Journal

Great Images

Steve Holmes captured the light for this delicate image of IC 1396 with the prominent dark dust lane known as the Elephant's Trunk Nebula. IC 1396 lies about 2400 light-years away in Cepheus; its bright rim is the ionized edge of a dense gas cloud, illuminated by young hot stars in the centre of the nebula. The bright orange star is Herschel's Garnet Star, otherwise known as μ (mu) Cephi. Steve noted, "This is 95-minute RGB with a Canon 5DII, unmodded, and a 90-minute Hα from 7-nm Baader Hα on QHY11 camera, both through Canon EF200mm ƒ2.8 at ƒ2.8...."