The Journal of The Royal Astronomical Society of Canada

Journal

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PROMOTING
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IN CANADA

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Inside this issue:

Lunar Exploration Part III

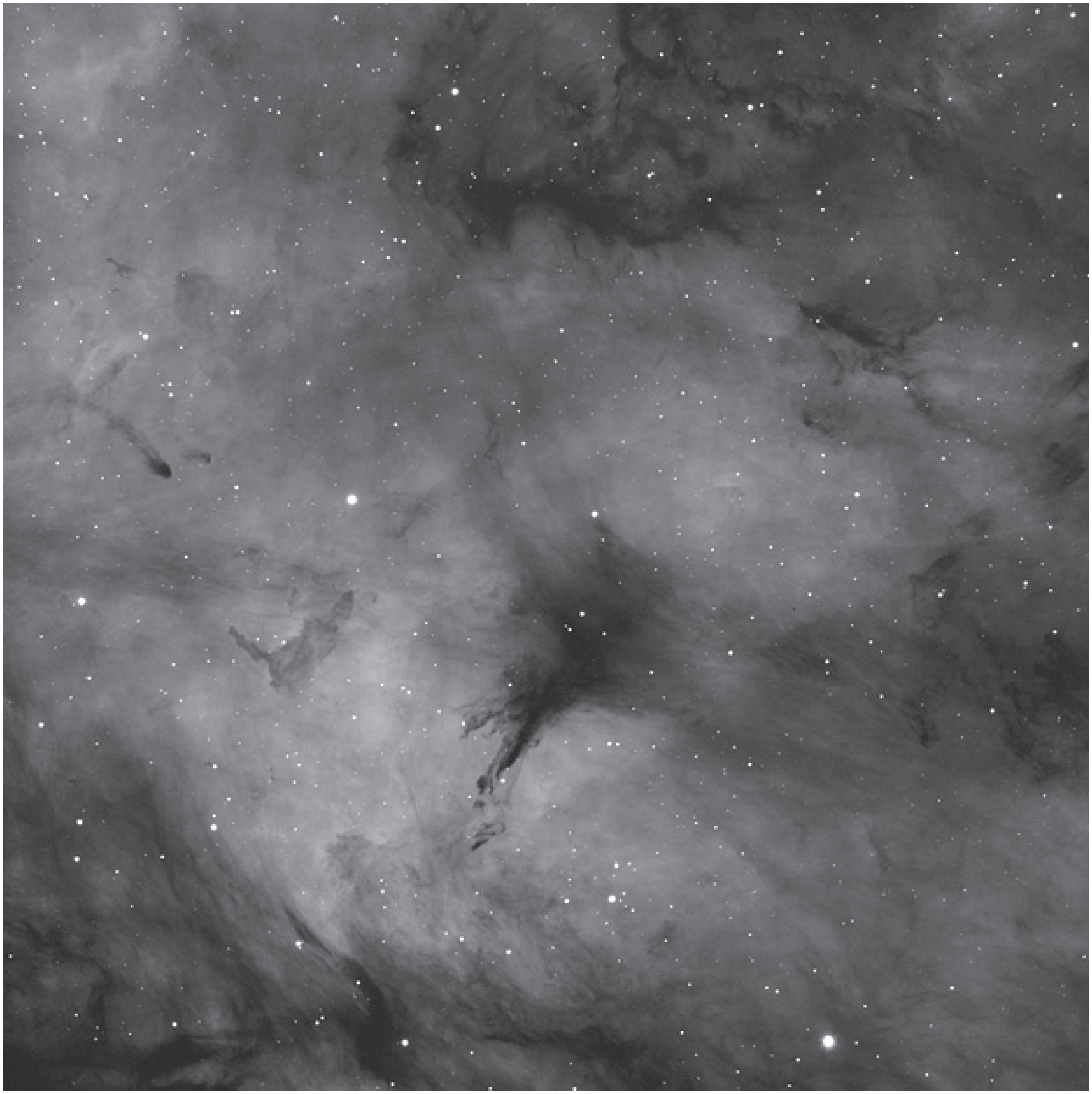
A New Year's Conjunction

Structure and Formation
of the Milky Way

The Cygnus "Great Wall"

The Best of Monochrome.

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



Andre Paquette took this image of IC 1318 in Hα using a 14" Celestron Edge HD, and an Apogee U16M on CGE Pro mount for a total of 3.7 hours. It was processed using Photoshop, Registax, and MaximDL.

Journal
October/octobre 2016 | Vol. 110, No. 5 | Whole Number 780

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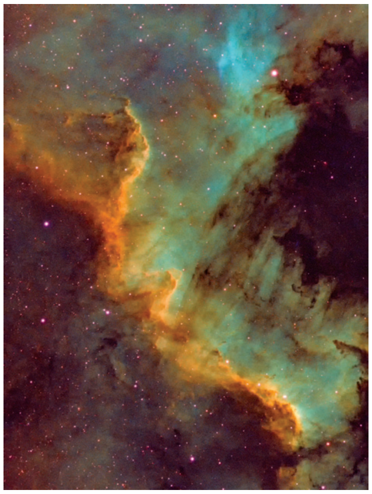
Société Royale d'Astronomie du Canada

contents / table des matières

Feature Articles / Articles de fond

Columns / Rubriques

Departments / Départements



Malcolm Park's image of the Cygnus Wall (details to follow in a later issue)

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.

Editor-in-Chief
Nicole Mortillaro
Email: editor@rasc.ca
Web site: www.rasc.ca
Telephone: 416-924-7973
Fax: 416-924-2911

Associate Editor, Research
Douglas Hube
Email: dhube@ualberta.ca

Associate Editor, General
Michael Attas
Email: attasm1@mymts.net

Assistant Editors
Michael Allen
Martin Beech
Dave Chapman
Ralph Chou
Ralph Croning
Dave Garner
Patrick Kelly

Editorial Assistant
Michele Arenburg
Email: mcarenburg@gmail.com

Production Manager
James Edgar
Email: james@jamesedgar.ca

Contributing Editors
Jay Anderson (News Notes)
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Proofreaders
Michele Arenburg
Ossama El Badawy
Margaret Brons
Angelika Hackett
Kim Leitch

Design/Production
Michael Gatto, Grant Tomchuk
Email: gattotomatto@eastlink.ca,
granttomchuk@eastlink.ca

Advertising
Julia Neeser
Email: mempub@rasc.ca

Printing
Cansel
www.cansel.ca

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

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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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President's Corner

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

This year marks my 15th in being involved with the RASC in some way in a supporting or leadership role, and being chosen by my peers to be President of this amazing Society is at once exhilarating and humbling. Exhilarating, because the RASC has given so much to me: lifelong friendships, a fellowship founded on a shared passion for the night sky, confidence in public speaking, and so much more; humbling because of the long history of the RASC and its place in Canadian astronomy. We are a truly national organization, 5000 members strong, with Centres in the Yukon, Victoria, Halifax, St. Johns, and all points and provinces in between.

As I read down the roll of past presidents, beginning with Daniel K. Winder, or Charles Carpmael, or Sir Robert Frederic Stupart (our history really is fascinating), and most recently James Edgar, I can't help but feel the weight of our history and many eyes staring at me and my Board colleagues from down the corridor of the ages. Being part of the team of stewards of the legacy of our forebears is at once daunting and exciting. Our challenge is to maintain the sustainability and health of our organization, and build on the solid foundation created by those who came before us.

We're about to take on the challenge of crafting a strategic plan that will carry our beloved RASC forward into the future. How do we broaden our appeal to be more welcoming and bring more diversity into the RASC—more youth, more women, more cultures? Which like-minded organizations can we partner with for mutual benefit? What do our Centres need to help them thrive and grow? How do we build and sustain a fundraising program that excites the greater community and brings real value to our membership? How do we grow and maintain our volunteer base at the local and national levels? These are just a few of the challenges that I'm excited to work on with the Board, staff and our membership over the coming year.

Underlying all of that is why we all joined the RASC: a passion for astronomy; for observing the wonders of the universe; for photographing the night sky; or sharing your passion with as many people as we possibly can. With events over the past year at work and with family (not to mention the weather in southwestern Ontario), I haven't had much time for a full night of actual observing. A recent evening at the London Centre's dark-sky site at the Fingal Wildlife Management Area brought back to me those feelings I had when I first joined the Halifax Centre all those years ago as a shy young person hoping to find welcoming and like-minded astronomy enthusiasts. Views through the various telescopes were shared, tips generously offered on how to use a piece of equipment or to find an object, that feeling of being part of a community when we all cheer simultaneously after a bright meteor flashes across our shared sky. The great conversations among friends with the Milky Way and sounds of nocturnal wildlife as the backdrop.

I'm hoping to have as many conversations with as many of you as I can (hopefully under clear, dark skies) as we work to strengthen the foundations that will sustain the RASC for the next 150 years. ✶

Editor's Note

by Nicole Mortillaro

Nine years ago I was going through a tumultuous time in my life. I was pleased to find an apartment in Richmond Hill, Ontario, just a few minutes away from the David Dunlap Observatory (DDO). I had had my first look through a telescope there when I was a teenager (Saturn, of course). The observatory meant a great deal to me.

However, just as I moved there, the University of Toronto announced plans to sell the grounds. I was incredibly saddened and worried about the future of the observatory.

On one of my forays up to the empty DDO to seek some peace, I was surprised to hear a vehicle making its way up the long drive. The occupant stopped to tell me that The Royal Astronomical Society of Canada, Toronto Centre, would be taking stewardship of the grounds. He introduced himself as Paul Mortfield, and then got out of his truck where we engaged in an hour-long conversation. He encouraged me to join the RASC. I didn't immediately, as I was terribly intimidated by the idea, but I did volunteer for the public nights. A year later, I joined the RASC and now, here I am.

Since then, the DDO has been the centre of controversy in Richmond Hill. (I won't get into the disputes, which were often clouded in ignorance.) But throughout those years, the volunteers were efficiently running the observatory and conducting extremely successful public nights, all of which have been sold out in recent years.

Throughout that time, there have been key people who have volunteered thousands of hours making the DDO what it is today. From ripping up carpets, to painting, to hosting private events, to re-aluminizing the mirror, to buying furniture, to mowing the lawn, to taking tickets on public nights, to directing traffic on busy nights, to everything and anything you can think of, blood, sweat, and tears went into not only making this a direct fulfillment of a core part of the RASC mandate—"to stimulate interest and to promote and increase knowledge in astronomy and related sciences"—but to also contribute financially to the Centre.

In July, Toronto Centre stepped away from negotiations with the Town of Richmond Hill, which was given the property by the developer (after the RASC was told it would be theirs). As well, in August, Paul Mortfield resigned from his role as Toronto Centre president as a result.

Both of these occurrences are terribly discouraging. While one member of the Toronto Centre Council shared in a Yahoo Group message his concerns (which were, of course, understandably financial), many Centre members and volunteers are dismayed that no other efforts were made to negotiate terms that would have been better suited to the Centre.

What is the future of the DDO? That is unclear. We—as members, as informed and educated astronomers—have a duty to continue to provide the public with as much of our knowledge as is possible. The DDO was a perfect medium with which to do that.

While many of you may not have an observatory to utilize, get out and educate. Set up your telescope on the sidewalk; offer to speak to students; volunteer whenever you can. We can provide the public with that "wow!" moment that I witnessed time and time again while volunteering at the DDO.

Personally, I want to thank Paul Mortfield for his enthusiasm and service to the Toronto Centre. That chance meeting changed my life for the better, opening up a whole new world—a whole Universe—to me. And I am better for it. ✶

News Notes / En Manchettes

Compiled by Jay Anderson, FRASC

Winnipeg's Jennifer West joins the ranks of Canadian astronomers

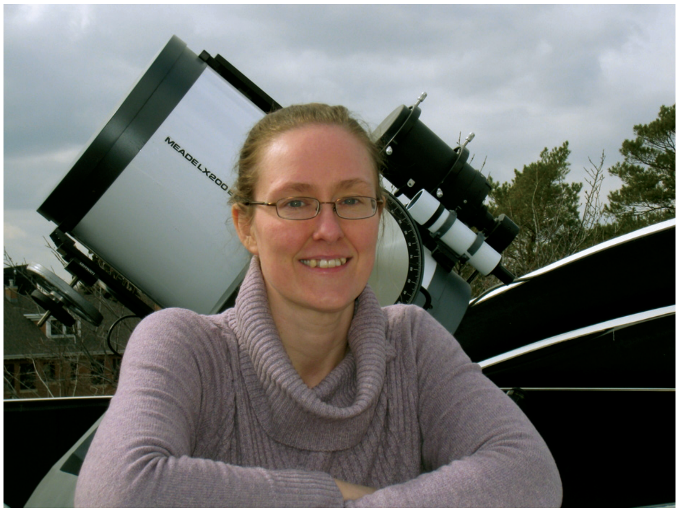


Figure 1 — Jennifer West.

Jennifer West, a member of the Winnipeg Centre and of the RASC's Education and Outreach Committee, has successfully defended her Ph.D. research on supernova remnants and is on her way to a post-doc in Toronto. The title of her thesis, *The connection between supernova remnants and the Galactic magnetic field,* relates a selection of radio images of axisymmetric or barrel-shaped supernova remnants (SNR) to the galactic magnetic field in their location. Her results supported the presence of an off-plane component to the galactic magnetic field and the importance of the overall field to the shape of the SNRs.

Jennifer has been a stalwart of the Winnipeg Centre since 1999, serving as a Councillor for many years and facilitating the relationship of the Centre with the University of Manitoba. Congratulations Jennifer!

The Andromeda Galaxy writ large

The National Optical Astronomy Observatory (NOAO) released a new high-resolution image of the Andromeda Galaxy in June captured by the Mosaic camera on the Mayall four-metre telescope at Kitt Peak National Observatory. The 585 megapixel mosaic of M31 was stitched together from 10 individual scenes, each one in five colours: U (violet), B (blue), V (cyan), I (orange), and H-alpha (red). The brilliantly coloured scene is a gem for galaxy explorers, showing a multitude of tiny globular clusters (which must be teased out with the help of a map), smudgy dark lanes and dust clouds, and open clusters embedded in intense red HII star-forming regions. The new mosaic is the largest and most detailed image of M31 ever completed that covers the entire galaxy.

Compiled with information provided by NOAO.

Milky Way rotation extends into its halo

Astronomers at the University of Michigan have discovered that the hot gas in the halo of the Milky Way galaxy is spinning in the same direction and at nearly the same speed as our galaxy's disk. "People just assumed that the disk of the Milky Way spins, while this enormous reservoir of hot gas is stationary—but that is wrong." says Edmund Hodges-Kluck, assistant research scientist. "This hot gas reservoir is rotating as well, just not quite as fast as the disk."

The galaxy's two-million-degree gaseous halo is several times larger than the disk—130,000 ly across—and composed of ionized plasma, along with individual old stars and scattered globular clusters immersed in an unknown amount of dark

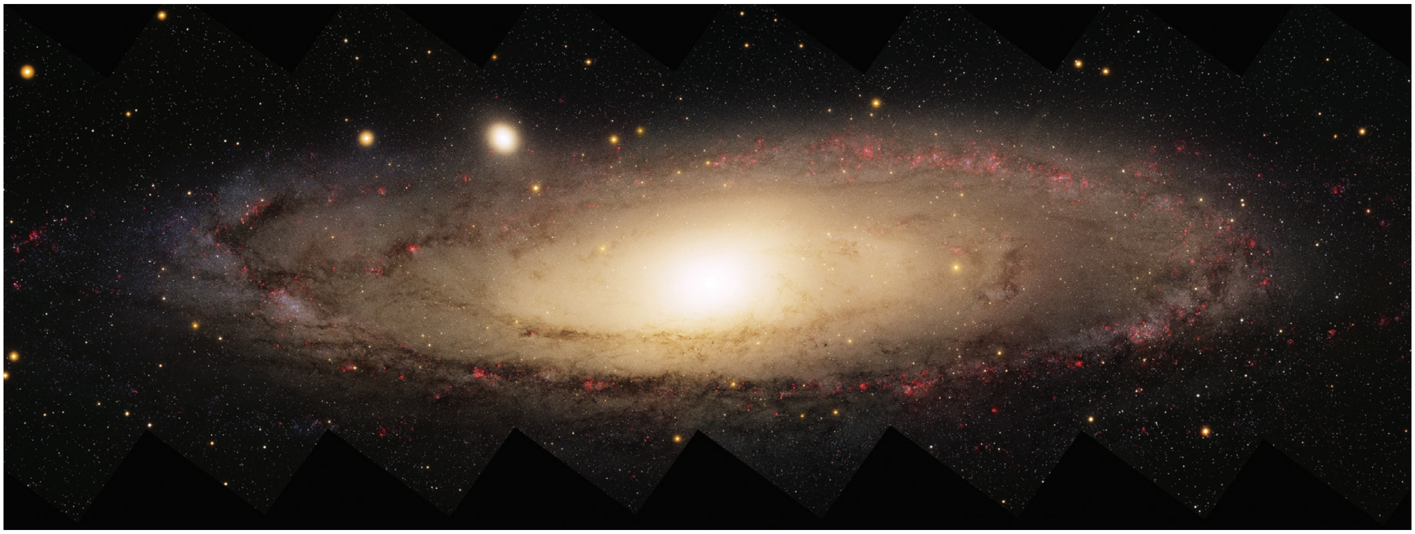


Figure 2 — The Mayall Telescope panoramic image of the Andromeda Galaxy. Image: Local Group Survey Team and T.A. Rector (University of Alaska Anchorage).

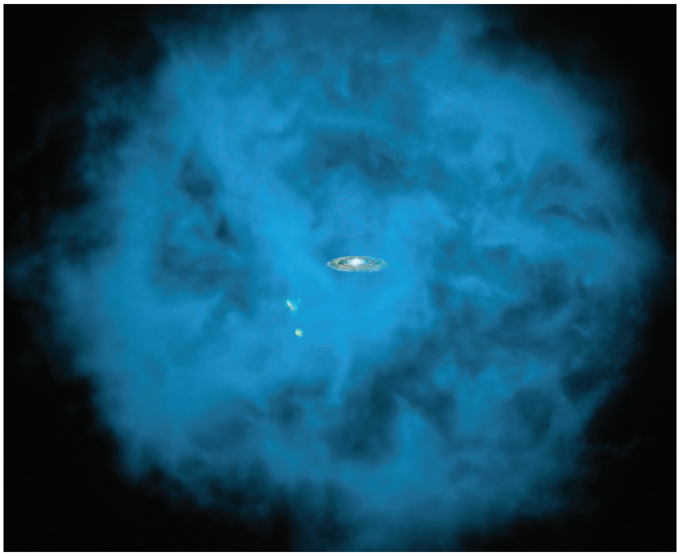


Figure 3 — The Milky Way Galaxy and the Magellanic Clouds are shown surrounded by a giant halo of million-degree gas (seen in blue in this artists' rendition) that is only visible to X-ray telescopes such as XMM Newton. *University of Michigan astronomers discovered that this massive hot halo spins in the same direction as the Milky Way disk and at a comparable speed. Image: NASA/CXC/M.Weiss/Ohio State/A Gupta et al.*

matter. The U-M researchers say that learning about the direction and speed of the spinning halo can help us learn both how the material got there in the first place, and the rate at which we expect the matter to settle into the galaxy.

The Milky Way's halo can be detected in both absorption and emission in a highly ionized oxygen spectral line (O VII) against the background emission from active galactic nebulae (AGNs). Using archival data obtained by *XMM-Newton*, a European Space Agency telescope, the research team was able to measure the Doppler shift in the oxygen spectral line around the sky in an ensemble of such AGNs. By modelling the dynamics of an extended spherical halo, they were able to fit a rotational velocity of 183 km/s from their data (versus 240 km/s for the disk). The work was published in the Astrophysical *Journal* in April.

"The rotation of the hot halo is an incredible clue to how the Milky Way formed," said Hodges Kluck. "It tells us that this hot atmosphere is the original source of a lot of the matter in the disk."

Partially compiled from material provided by the University of Michigan

Serious lack of large craters on Ceres

A team of scientists led by Southwest Research Institute (SwRI) in San Antonio, Texas, made a puzzling observation while studying the size and distribution of craters on the dwarf planet Ceres. Collision models predicted Ceres should have accumulated up to 10 to 15 craters larger than 400 km wide and at least 40 craters larger than 100 km wide. Instead, NASA's *Dawn* spacecraft found only 16 craters larger than 100 km, and none larger than 280 km across.

Crater size and distribution provide planetary scientists with important clues to the age, makeup, and geologic history of planets and asteroids. Ceres is believed to have originated about 4.5 billion years ago at the dawn of our Solar System, growing through a history of accretionary collisions of smaller bodies. It was expected that the planet would exhibit evidence of this violent history with a spectrum of crater sizes similar to other small bodies in the Solar System, in particular the asteroid Vesta, visited earlier by *Dawn*. Instead, images of the surface showed an abundance of small impact craters, but the largest well-defined crater is only about 280 km in diameter. In contrast, images of Vesta, only about half the size of Ceres, revealed huge craters, including one 500 km in diameter covering almost an entire side of that asteroid.

Dawn's images of Ceres reveal that the dwarf planet has at least three large-scale depressions called "planitiae" that are up to 800 km wide. These planitiae have craters in them that formed in more recent times, but the larger depressions could be left over from bigger impacts. One idea about Ceres's origins holds that it formed farther out in the Solar System, perhaps in the vicinity of Neptune, but migrated in to its present location. Nevertheless, scientists determined that even if Ceres migrated into the main asteroid belt relatively late in Solar System history, it should still have a significant number of large craters.

"We concluded that a significant population of large craters on Ceres has been obliterated beyond recognition over geological

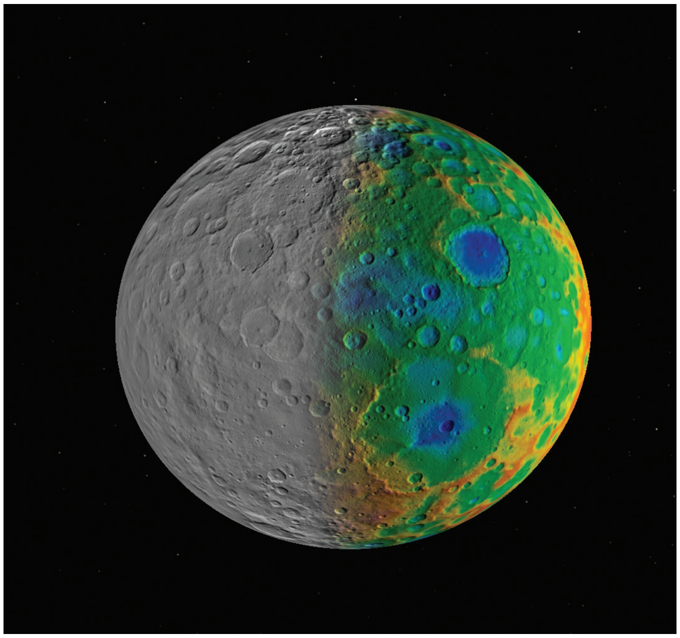


Figure 4 — This image of Ceres shows both visible (left) and topographic (right) mapping data from Dawn. *Credit: NASA/JPL-Caltech/SwRI.*

time scales, likely the result of Ceres's peculiar composition and internal evolution," said lead investigator Dr. Simone Marchi, a senior research scientist in SwRI's Space Science and Engineering Division. One reason for the lack of large craters could be related related to this interior structure of Ceres. There is evidence from *Dawn* that the upper layers of Ceres contain ice. Gravity data from the spacecraft reveal that the dwarf planet has a differentiated interior with low-density materials—likely ice—in the outer layers. Because ice is less dense than rock, the topography could "relax," or smooth out, more quickly if ice or another lower-density material, such as salt, dominates the subsurface composition. Recent analysis of the centre of Ceres's Occator Crater suggests that the salts found there could be remnants of a frozen ocean under the surface, and that liquid water could have been present in Ceres's interior. All of these observations lend credence to the relaxation hypothesis.

"Regardless of the specific mechanism(s) for crater removal, our result requires that large crater obliteration was active well after the late heavy bombardment era, or about four billion year ago. This conclusion reveals that Ceres's cratering record is inextricably linked to its peculiar composition and internal evolution," Marchi said.

Compiled in part using material provided by SwRI and NASA.

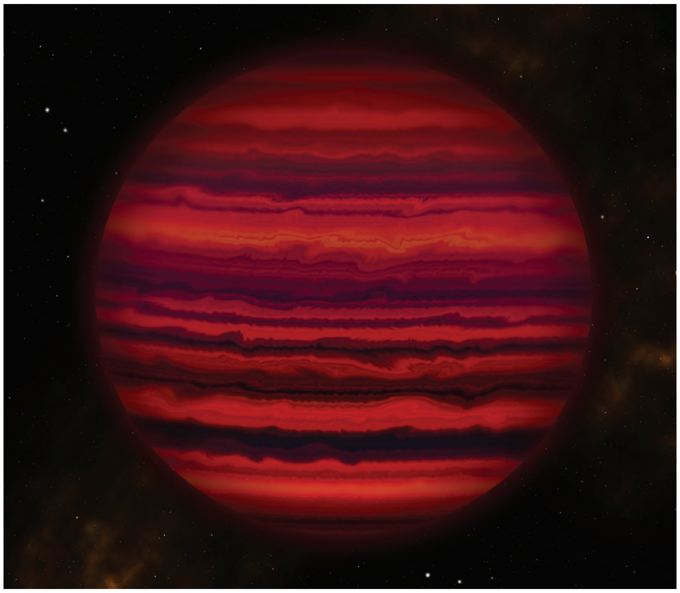


Figure 5 — Artist's conception of how WISE 0855 might appear if viewed close-up in infrared light. Artwork by Joy Pollard, Gemini Observatory/AURA.

Coldest brown dwarf is a close neighbour

Brown dwarfs are sub-stellar objects that occupy the mass range between stars and planets, approximately between 13 and 75-80 Jupiter masses, sometimes known as "failed stars." They lack the mass to fuse hydrogen into helium, and so cannot be classed as stars but may be able to fuse deuterium and burn lithium depending on their mass.

Now astronomers have determined that our fourth-closest neighbour, a brown dwarf known as WISE 0855, may be the coldest discrete world found outside our Solar System to date. Spectroscopic observations collected with the Gemini North telescope on Maunakea gave astronomers the best evidence to date of water vapour and clouds in the atmosphere of a distant body. The observations reveal temperatures of about −20 °C in 0855's cold atmosphere, giving the brown dwarf characteristics more in line with Jupiter than many exoplanets.

WISE 0855 was discovered by Kevin Luhman of Penn State in 2014 using data from NASA's *Wide-field Infrared Survey Explorer* (WISE) satellite. WISE 0855's relatively close proximity—it's only about 7.2 light-years away—provides an advantage in capturing the object's miniscule glow; however, it is still remarkably difficult to observe. The dwarf was too faint for spectroscopy at optical or near-infrared wavelengths, but could be observed in a window around 5 microns.

"It's five times fainter than any other object detected with ground-based spectroscopy at this wavelength," said Andy Skemer of the University of California Santa Cruz. "Now that we have a spectrum, we can really start thinking about what's going on in this object. Our spectrum shows that WISE 0855 is dominated by water vapour and clouds, with an overall appearance that is strikingly similar to Jupiter."

"I think everyone on the research team really believed that we were dreaming to think we could obtain a spectrum of this brown dwarf because its thermal glow is so feeble," said Andy Skemer of the University of California Santa Cruz. WISE 0855, is so cool and faint that many astronomers thought it would be years before we could dissect its diminutive light into a spectrum. "I thought we'd have to wait until the *James Webb Space Telescope* was operating to do this," adds Skemer.

The spectrum was obtained over a period of 13 nights (about 14 hours of data collection). "These observations could only be done on a facility like Gemini North. This is due to its location on Maunakea, where there is often remarkably little water vapour in the air to interfere with the sensitive observations, and the technology on the telescope, like its 8-metre, silver-coated mirror," says Jacqueline Faherty of the Carnegie Department of Terrestrial Magnetism. "We pushed the boundary of what could be done with a telescope here on Earth. And the result is spectacular." Gemini astronomer, and brown-dwarf researcher, Sandy Leggett, explains that the spectrum shows less phosphine than we see in Jupiter, "… suggesting that the atmosphere may be less turbulent, since mixing produces the phosphine seen in Jupiter's atmosphere." ✶

Compiled in part using material provided by Gemini North Observatory.

The Royal Astronomical Society of Canada

Vision

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

Mission

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

Values

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

Featured Articles / Articles de fond

A Brief History of Lunar Exploration: Part III

by Klaus Brasch
(krbrasch@earthlink.net)

Dedicated to the memory of my long-standing friend, Geoffrey Gaherty Jr.

The Moon was but a Chin of Gold
A Night or two ago—
And now she turns Her perfect Face
Upon the World below

Emily Dickinson

Introduction

Parts I and II of this brief history of lunar exploration encompassed the pre-telescopic era to the start of the space age (Brasch, 2015; 2016). Up till then, lunar exploration had been limited to mapping the Moon's visible or "near" side as accurately as possible with ground-based instruments. Although photography helped, it was still possible as late as the 1950s for observational cartographers to generate more detailed maps of the Moon than was possible with the grainy emulsions of that time (see e.g. Wilkins and Moore, 1955). Moreover, during the half century preceding the launch of *Sputnik I* in 1957, only a few professional astronomers were engaged in lunar research, notably Gerard Kuiper at Yerkes Observatory and collaborators. The majority of astronomers paid scant attention to the planets or our natural satellite, in favour of astrophysics and cosmology (Tatarewicz, 1990).

Amateurs filled that gap as best they could by sketching lunar surface features—particularly limb features visible under favourable libration—looking for elusive *transient lunar phenomena* (TLPs) and occultation timings. Though laudable, such efforts added only incrementally to our understanding of the lunar surface and topography. All that changed rapidly, however, with the launch of *Sputnik* and other artificial satellites, followed in 1961 by President Kennedy's announcement of the Apollo program. The ensuing "Moon race" between the United States and the Soviet Union necessitated not just far better rocket and related technological advances, but also an urgent requirement for better lunar maps than available heretofore. In 1959, the Soviet Union took a giant leap forward in that regard when Luna 3 successfully circled the Moon and took the first photographs from orbit and also obtained the first images of its far side (Kopal and Carder, 1974, and Figure 1). However, even more crucial for the planned U.S. manned missions to the Moon was a fuller understanding of its geology, surface topography, and compositional attributes.

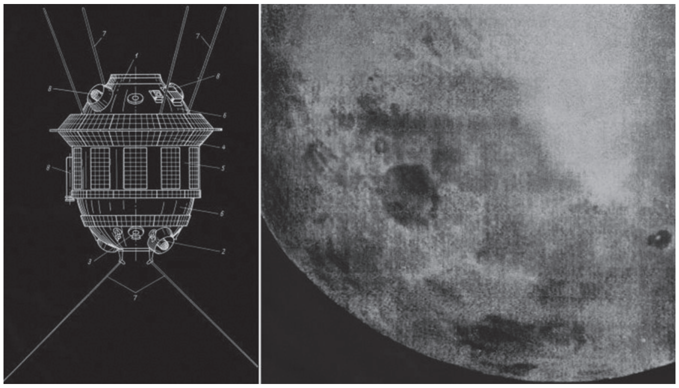


Figure 1 — Diagram of the Soviet space probe Luna 3 *and one of its images of the Moon's far side taken in 1959 (Wikimedia).*

The Measure of the Moon

Ever since Galileo's rudimentary attempts to estimate the height of lunar features, students of the Moon have over the years tried to develop and refine methods to determine both absolute and relative elevations of prominent mountains and crater walls using simple geometric methods. Figure 2a, adapted from Richmond (1999), illustrates one such method. The earliest measurements of this sort were fraught with uncertainty and inaccuracy, however, primarily due to observer and instrument limitations, and the fact that lunar relief is extremely variable and affected by libration and foreshortening effects. Consequently, observers like Nasmyth and Carpenter (1874) vastly overestimated vertical relief and elevation in constructing their magnificent plaster-of-Paris models of lunar landscapes (Figure 2b).

The geometric basis for estimating the relative elevations on the Moon was eventually refined and further developed in the 1950s and 1960s at the University of Manchester by Kopal and colleagues working at Pic du Midi Observatory in France,

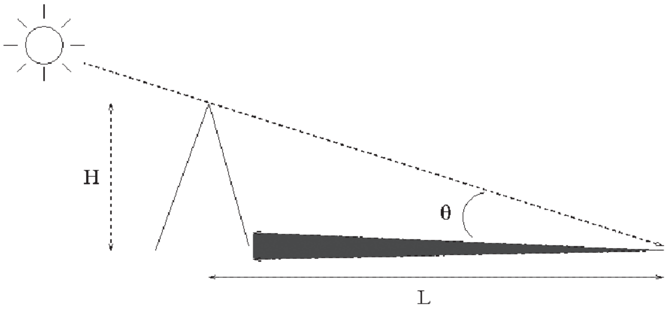


Figure 2a — Illustration how to measure the height (H) of a lunar feature based on the length of the shadow is casts in relation to the angle Θ subtended by the Sun at the time and date of observation. (from Richmond, 1999).

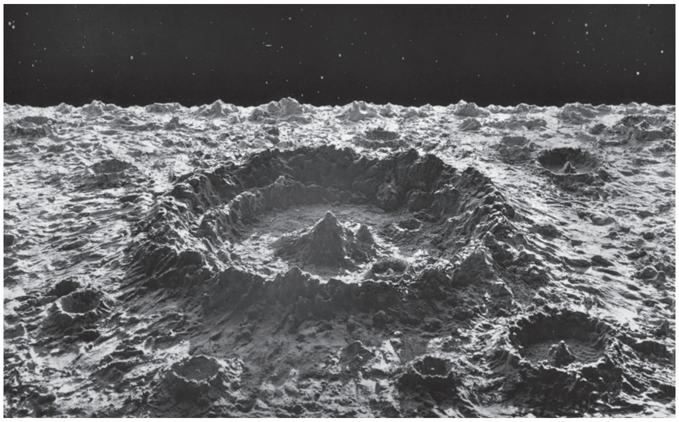


Figure 2b — Plaster-of-Paris model of a normal lunar crater as envisaged by Nasmyth and Carpenter in 1874, with overestimated vertical relief (Wikimedia).

Figure 3 — Aerial view of Meteor Crater, Arizona (north up) (Public Domain)

see e.g. Kopal and Rackham (1962). By combining microdensitometry of thousands of lunar photographs, with shadow measurements and rigorous mathematical analysis, investigators were able to determine relative heights and positional data with much improved accuracy (Kopal and Carder, 1974). Among other things, this work showed that the profiles of seemingly deep craters like Eratosthenes are in fact remarkably low and shallow, and that the impression of depth is greatly exaggerated when such features are close to the terminator. These methods could then be applied with confidence to Apollo era mapmaking efforts.

The Birth of Astrogeology

Eugene Merle Shoemaker (1928–1997), better known as Gene Shoemaker, was an American geologist and one of the founders of the field of planetary science. In later years he became best known in the astronomical community for the discovery of Comet Shoemaker–Levy 9 with his wife Carolyn S. Shoemaker and David H. Levy, when the comet crashed into Jupiter in 1994 (en.wikipedia 2015a). Shoemaker first gained distinction in 1960 for his seminal work showing once and for all that Arizona's famed Meteor Crater (Figure 3) and other similar structures on Earth were indeed created by meteoric impacts and not volcanism. He went on to show that Copernicus and the bulk of other lunar craters were also the result of extensive bombardments from space over geologic time (Shoemaker et al., 1962). As a result, Shoemaker became a leading figure in the emerging field of astrogeology (a field now referred to as planetary science) and the establishment of the USGS Astrogeology Research Program in Menlo Park, California, in 1960 and in 1965 in Flagstaff, Arizona (Levy, 2000; Marsden, 1997).

The modern era of lunar mapping and attendant geological studies of our satellite began in 1958 through establishment by President Eisenhower of the National Aeronautics and Space Administration (NASA), with involvement of the U.S. Army Map Service (AMS), the USAF Aeronautical Chart and Information Center (ACIC), the Lunar and Planetary Laboratory in Tucson, Arizona, and finally the U.S. Geological Survey's (USGS) Astrogeology Research Program. The Flagstaff location was chosen due to its suitability for lunar studies, both for telescopic observations at Lowell Observatory and due to the geologic similarities of various sites in the area and the surface of the Moon. This allowed for extensive Apollo astronaut training at nearby Meteor Crater and in the volcanic cinder fields in and around the Flagstaff region and the Navajo Nation (Sheehan and Dobbins, 2001; Schindler, 2016). A diverse group of talented scientists, technicians, cartographers and services were involved in these efforts, too many to highlight here, but a few groups deserve to be singled out. For an elegant and comprehensive scientific review of lunar geology and of the history of the pre-Apollo, Apollo, and post-Apollo era, see Wilhelms (1987) and (1993), respectively. For a history/timeline of the USGS Astrogeology program see Schaber (2005).

In 1958, the U.S. Army Map Service (AMS) embarked on an ambitious program to compile a modified stereographic projection map of the Moon based on the best available Earth-based telescopic photographs. This 1:5,000,000 two-sheet map would indicate 1000-metre contours and was headed by AMS photogrammetrist Albert L. Nowicki (Kopal and Carder, 1974). The AMS was uniquely equipped for stereographic mapping of this kind; however, its usefulness was severely limited by the resolving power of the various telescopes whose photographs were used.

This was followed by the U.S. Air Force lunar-mapping efforts in collaboration with Gerard Kuiper then of Yerkes Observatory, who compiled the best available photographs from Mt. Wilson, Lick, McDonald, Yerkes, and Pic du Midi observatories into the first *USAF Lunar Atlas* in 1960. A commercial version, known as the Kuiper Atlas was also published through the University of Chicago Press, eventually leading to the *USAF Lunar Reference Mosaic* (Figure 4) and the *Orthographic Atlas of the Moon*, by David Arthur and Ewen Whitaker (1960).

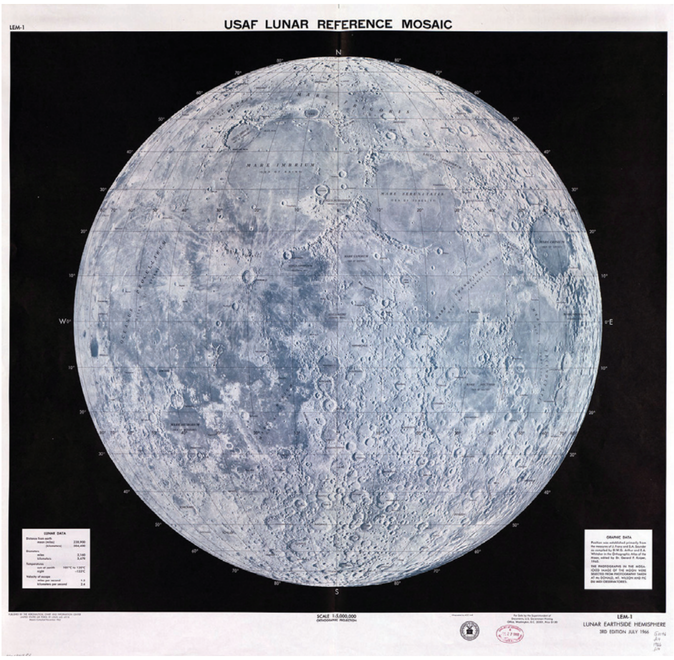


Figure 4 — United States Air Force Lunar Reference Mosaic (1966) (Public Domain)

As mentioned in Part II of this series (Brasch, 2016), production of the Lunar Aeronautical Chart (LAC) series marked the culmination of Earth-based lunar-mapping efforts in the pre-Apollo and early spacecraft era. It also marked the beginnings of proper geologic mapping of our natural satellite. Geologic mapping entails far more than cartographic elevations and contour tracing, but also includes geologic and compositional information of the terrain being mapped, for example, crater ejecta, secondary impact material, breccia (sedimentary rock composed of lithified fragments), talus (rock debris at base of a cliff), faults (breaks in rock mass where movement has occurred), volcanic flows, and so forth (en.wikipedia, 2016a). Since relatively little was known about lunar geology in the pre-Apollo era, geologic mapping was based on a combination of telescopic information, interpretation of features by trained geologists, informed guesswork and eventually images from spacecraft like the *Ranger* missions (1967), the *Surveyor* lander missions, and the *Lunar Orbiter Program* (1967-1968) (Kopal and Carder, 1974).

Among the early pioneers working on lunar geology at that time were Gene Shoemaker, Robert J. Hackman, C.H. Marshall, Arnold Mason, Henry J. Moore, Annabel Brown Olson, and Richard E. Eggleton. Their job was quite daunting.

In addition to producing accurate geologic maps of the Moon based almost exclusively on Earth-based observations, they were also tasked with constructing high-resolution charts to help plan future landings and surface traverses. This required great expertise in geology and accurate map making, and all before any person, spacecraft, or scientific instrument had actually landed on the Moon. For example, it was not known whether the lunar surface was solid enough to support the weight of a manned spacecraft or whether there was a real risk it might sink deep into dust or regolith. Alternately, each potential landing site had to be evaluated for both scientific interest and whether it was suitable for landing or so rough as to endanger the mission. Consequently, the earliest geologic maps had to be not only as accurate as possible, but also provide the best possible deduction as to what type of physical and compositional conditions lunar landers and Apollo astronauts might encounter at their respective target sites.

Pre-Apollo geologic mapping efforts were of necessity limited since no bona fide lunar samples were available to provide at least some direct information about its chemical composition and absolute age (Spudis, 2013). While we now know that several meteorites recovered on Earth are of lunar origin, at the time only tektites were theorized to be that. The overwhelming consensus today among Earth and planetary scientists, however, is that tektites are not of lunar origin but consist of terrestrial debris that was ejected during the formation of an impact crater (en.wikipedia 2016b). In spite of the limitations they faced, Gene Shoemaker and his colleagues set out to apply the basic principles of geology in 1960 to the Lunar Atlas Chart (LAC) maps entirely based on photographic and visual work from Earth (Spudis, 2013).

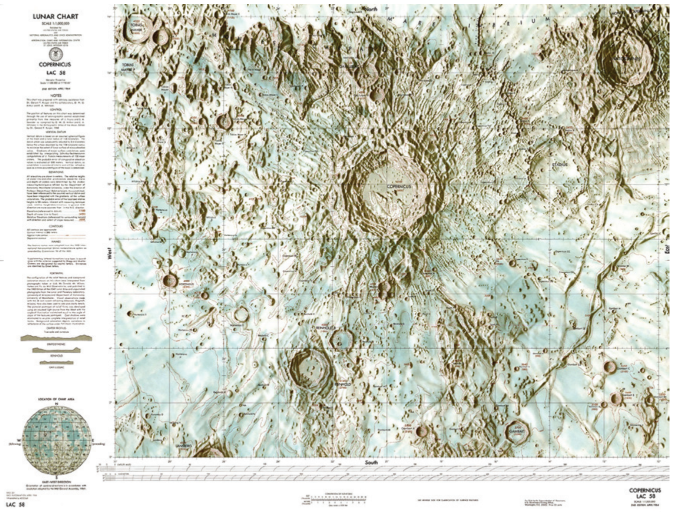


Figure 5 — Copernicus region map (LAC 58) by G. Shoemaker and R J. Hackman (1964) NASA

The very first such "photogeologic" USGS map was produced by Mason, Hackman, and Brown-Olson (Portee, 2013). Though pioneering, this map proved of limited use and did not accurately portray the Moon's history, as most features identified as volcanic turned out to be due to impact processes.

The fundamental premise of basic geological principles is that younger rocks and formations lie over or intrude into older rocks. Among other measures, this is illustrated by the relationships between the morphologies of lunar craters, their diameters and postulated ages (Trask, 1969, Eggleton, 1970). Figure 6a shows a refinement of this technique, which relies on modifications of crater shapes and degrees of degradation. The vertical axis shows the relative age of craters with the youngest at the top, plotted against their diameters on the horizontal axis. Larger, younger craters in the Copernicus class are characterized by sharp rims, well-preserved interiors, distinct ejecta blankets, and persistent ray systems. The level of crater degradation depends on size and length of time since formation. Hence a crater like Eratosthenes, for example, is more degraded and therefore older than Copernicus.

Five initial regions (quadrangles) of the Moon were selected for geologic mapping. Shoemaker and R.J. Hackman generated the spectacular Copernicus region map, published in 1960 (Figure 5). The Kepler and Apennine Mountain regions were also assigned to Hackman, the Letronne region to C.H. Marshall, and the Riphaeus Mountains region to R.E. Eggleton.

The author is fortunate to have actually met and befriended one of these pioneering Apollo-era geologists, Richard Eggleton. Now long retired from the USGS, Eggleton nevertheless maintains an active interest in the geology of major Solar System objects, including the Moon, Mars, outer Solar System moons, and, most recently, the highly unusual Pluto/Charon system as revealed by the *New Horizons* spacecraft.

Between 1960 and 1963, Eggleton mapped the geology of the Riphaeus Mountains region of the Moon based on the USAF chart (LAC-76) compiled from the photographs obtained from various observatories and augmented by his telescopic observations with the 24-inch and 36-inch refractors at Lowell and Lick Observatories, respectively. Enlargements of the Fra Mauro region from LAC-76, named after the prominent walled plain partly and eventual *Apollo 14* landing site in 1971, are shown in (Figure 6b). The area was subsequently analyzed in greater detail by Eggleton and after *Lunar Orbiter* data became available (Figure 7).

In 1966-1967, NASA launched its *Lunar Orbiter Program* (LOP), which consisted of five unmanned space probes. Along with the Apollo missions, this program revolutionized our understanding of the Moon's surface, composition, geology, and likely evolution (en.wikipedia, 2016c, NASA History Program, 2016). Although all lunar images obtained at the time were taken on 70-mm film, they provided an unparalleled

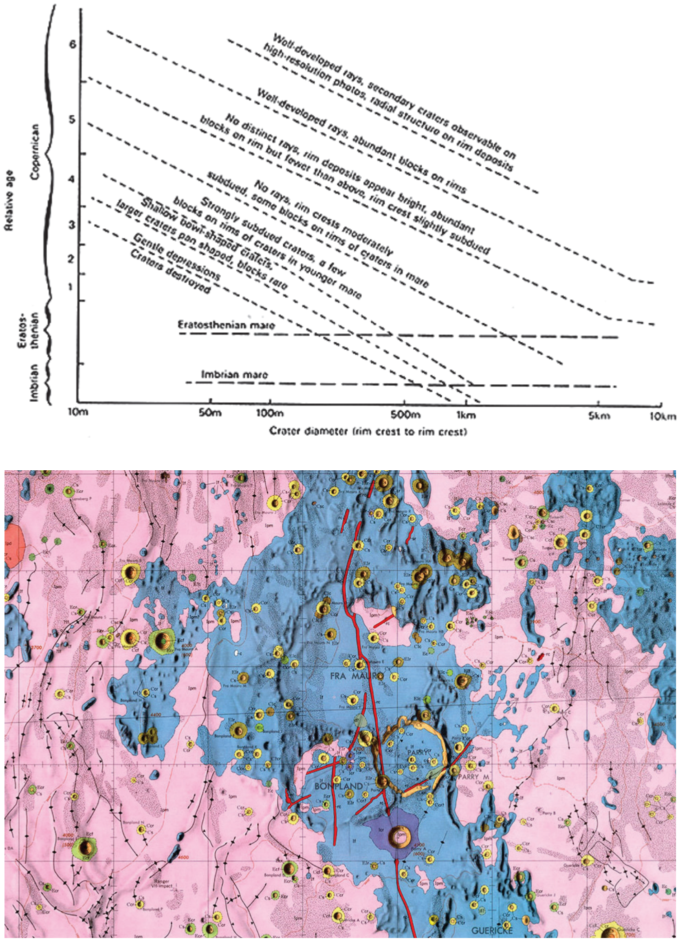


Figure 6a and 6b — Top: Plot of the relative age of lunar craters as a function of their diameter Bottom: Enlargement of the Montes Riphaeus (LAC-76) Lunar Aeronautical Chart, showing the eventual landing site of Apollo 14. Topographic features were based on the best available telescopic imagery and geologic features as mapped by R. Eggleton in 1965. Pink denotes mare material, blue the inferred ejecta from the Imbrium multi-ring impact basin, and stippling as ray material.

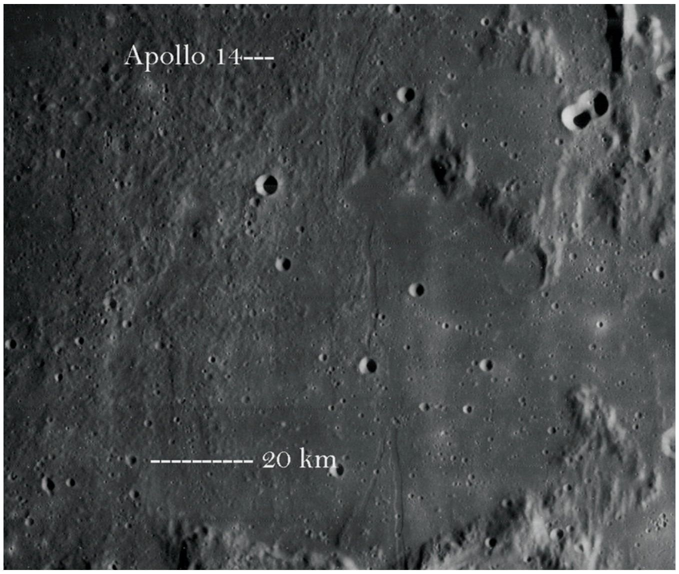


Figure 7 — Lunar Orbiter image of the Fra Mauro region showing the eventual Apollo 14 *landing site. (USGS/NASA)*

level of detail. The iconic oblique image of Copernicus taken by *Lunar Orbiter 2* and dubbed "Picture of the Century" says it all (Figure 8). The original film images were developed and scanned aboard the *Lunar Orbiter* spacecraft and then relayed to Earth to be recorded on magnetic tape, projected unto film strips, and assembled into an image mosaic. More recently NASA's Lunar Orbiter Lunar Orbiter Image Recovery Project Project (LOIRP), has reprocessed many of LPO images, including the Copernicus one to reveal even more detail. Many of the original film strips have also been scanned and reassembled into mosaics by the USGS. These are available online at http://astrogeology.usgs.gov/LunarOrbiterDigitization and assembled into a global *Lunar Orbiter* mosaic of the Moon.

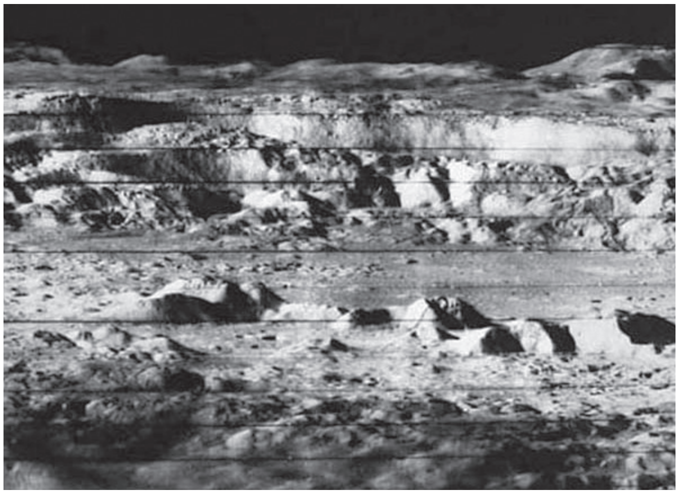


Figure 8 — Mosaic of Copernicus by Lunar Orbiter 2 *popularly termed "Picture of the Century." The central peaks are in the foreground and the north wall in the back. Note mosaicking lines between 70-mm film strips.*

Lunar Mapping Today

The LOP ushered in an entirely new capability for mapping and analyzing the Moon, a trend that continues to the present day. While a comprehensive review of all lunar-orbital and lander-based mapping programs since the LOP are too numerous to treat here, a near-complete review may be found in *Space Probes* (Séguéla, 2010), which also covers a wide range of Solar System space probes. Between 1959 and 1971, the then-Soviet Union launched an ambitious series of lunar-orbiter and lander missions named *Luna 1* to *Luna 22*. While not fully successful, this program nonetheless provided a wealth of information about the Moon's surface, plus physical and compositional properties. With the launch of *Hiten-Hagoromo* in 1990, Japan became the third nation to actually send a space probe to the Moon.

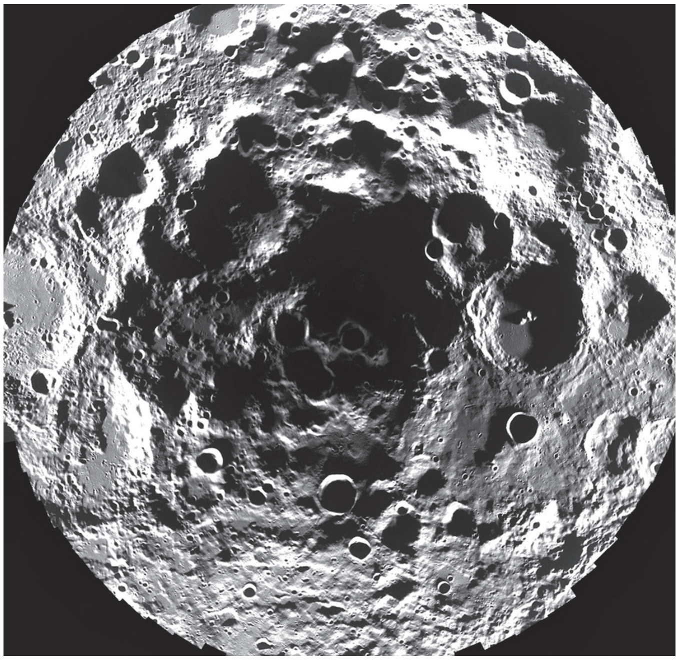
Undoubtedly, however, in 1994 the NASA/DOD mission *Clementine*, which marked NASA's first return to the Moon after the Apollo programs, was without precedent (Spudis, 2013). Also known as the Deep Space Program Science Experiment, this undertaking was an offshoot of the Strategic Defense Initiative (SDI) and a test of new sensors and light-weight spacecraft components designed to withstand extended exposure to the space environment while embarking on a mission of extensive new scientific observations of the Moon (NASA, 2016). Among other instrumentation, this sophisticated orbiter was equipped with UV/visible/near- and long-wavelength IR cameras, high-resolution cameras, star-tracker cameras, a laser altimeter (LIDAR), and a charged-particle telescope. Spacecraft tracking data was used to create an improved gravity model of the Moon. Radio signals from *Clementine* reflected off the lunar surface were also received by the NASA Deep Space Network as part of the bistatic radar experiment.

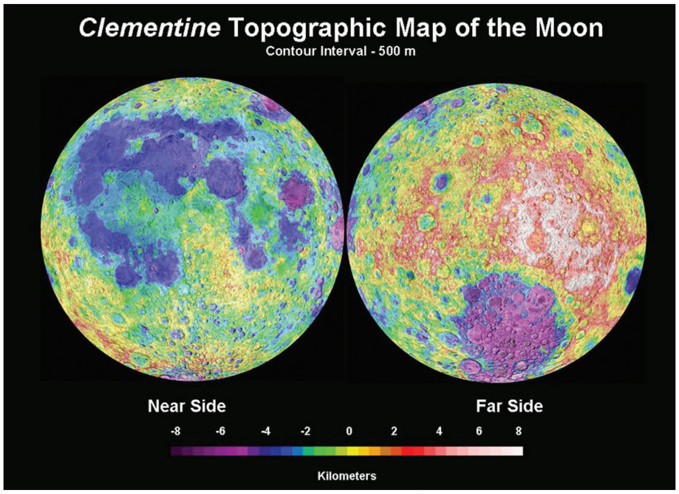
After entering orbit over a period of about two months, *Clementine* gathered the first data on the large-scale petrological properties of the lunar surface, high-resolution surface mapping, altimetry and relief mapping (Figure 9), density distribution of the Moon's crust, and the first hint that polar areas in perpetual shadow might contain water ice (Figure 9). To quote American geologist and lunar expert Paul D. Spudis, "*Clementine* was a watershed, the hinge point that forever changed the nature of space policy debates. A fundamentally different way forward is now possible in space—one of extensibility, sustainability, and permanence. Once an outlandish idea from science fiction, we have found that lunar resources can be used to create new capabilities in space, a welcome genie that cannot be put back in a bottle" (Spudis, 2014).

The spectacular success of *Clementine* was followed by a sequence of other sophisticated robotic missions to the Moon, including Lunar Prospector in 1998, SMART-1, the first European lunar space mission in 2004, the Japanese probe *Kaguya* (SELENE) in 2007, three Chinese craft, *Chang'e 1* in 2007, *Chang'e 2* in 2008, and *Chang'e 3* in 2013, and an

Indian probe, *Chandrayaan-1*, in 2008 (Séguéla, 2011). All these spacecraft contribute significant new information about the Moon and new images. The *Chang'e 3* mission included a lander and a rover, the first landing since *Apollo 17* in 1972.

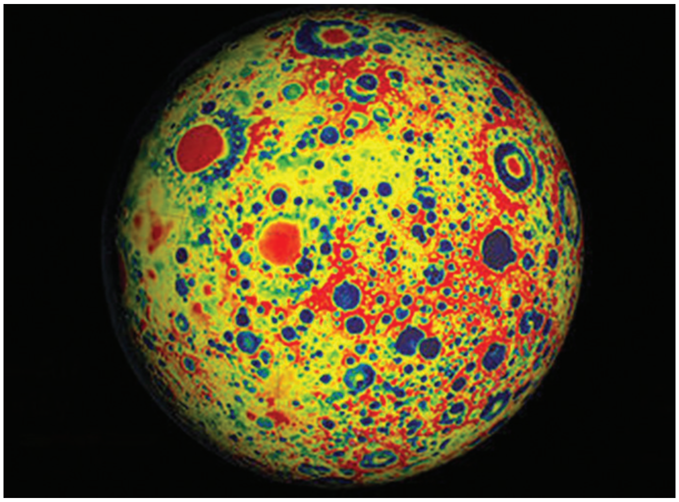
Perhaps most notable among these findings were gravity relief maps showing numerous gravitational variations beneath the lunar surface. The *Gravity Recovery and Interior Laboratory* (GRAIL) was an American lunar science mission in NASA's Discovery Program that used high-quality gravitational field mapping of the Moon to determine its interior structure. Launched on September 2011 with a single launch vehicle, two small spacecraft *GRAIL A* (Ebb) and *GRAIL B* (Flow) separated after launch and orbited the Moon in tandem. Each probe transmitted and received telemetry from the other and, by measuring the change in distance between them, information on the gravity fields and corresponding lunar features was obtained. In this way, the gravitational field of the entire lunar globe was mapped in unprecedented detail; see: NASA/GSFC/JPL (2015) and NASA/JPL (2013) and Figure 10.





Figures 9a and 9b — Top: Clementine *mosaic of the lunar South Pole showing dark regions likely containing water ice (NASA); Bottom: Topographic map of the Moon based on* Clementine *altimetry in mid-latitudes and stereo images near the poles. NASA*

Without doubt, however, the most sophisticated and productive robotic mission to the Moon to date is the *Lunar Reconnaissance Orbiter* (LRO) and *Lunar Crater Observation and Sensing Satellite* (LCROSS) combination. Launched in 2009, as the only mission of NASA's Lunar Precursor Robotic Program, LRO continues to be highly productive to the present day. The pair of probes had two major missions. The primary objective was to gather surface mapping and compositional information essential for future robotic and human missions to the Moon. For this purpose, the LRO spacecraft was equipped with an array of instruments that collectively has provided more new data and information about our natural satellite than any prior mission. On-board instrumentation includes a cosmic-ray detector to characterize the lunar radiation environment, radar, radiometer, and neutron and Lyman-Alpha detectors to look for water ice and near-surface ice deposits, a laser altimeter (LOLA), and *Lunar Reconnaissance Orbiter Camera* (LROC), including a wide-angle camera (WAC), and a pair of very-high-resolution, narrow-angle cameras (NAC) (en.wikipedia, 2016d).



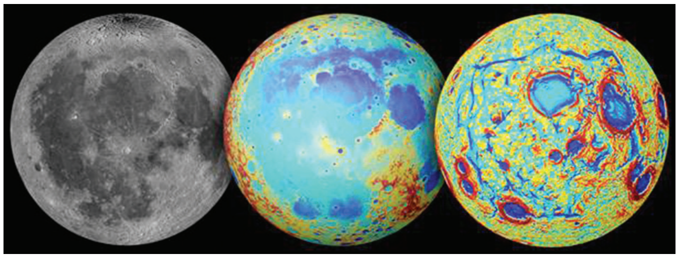


Figure 10a — This image shows the variations in the lunar gravity field as measured by GRAIL*, with red denoting mass excesses and blue mass deficiencies. (NASA-Colorado School of Mines)*

Figure 10b — The Moon in visible light (left), topography (centre), showing red as high and blue as low, and the GRAIL *gravity gradients (right). Copernicus is at centre, and the Oceanus Procellarum (left) is a broad region of low topography covered in dark mare basalt. The gravity gradients reveal a giant rectangular pattern of structures surrounding the region. (NASA-JPL-Caltech)*

The mission's other important objective was to seek additional evidence for water ice on the Moon. Turning first to LCROSS, its main function was to guide the fourth stage of the Centaur launch rocket to a crash landing into the crater Cabeus. The latter is permanently shadowed near the lunar south pole, and the goal of the impact was to verify evidence of water ice and hydroxyl ions in the resultant debris cloud, as originally indicated by *Clementine* and subsequently by *Chandrayaan-1* (en.wikipedia, 2016d). The cumulative evidence to date as obtained by the LRO mission indicates that the LCROSS Cabeus crater impact site is unlikely to contain large slabs of water ice, but that water is most likely present as small pieces of ice mixed withlunar regolith. On the other hand, the LRO's laser altimeter's examination of the Shackleton crater at the lunar south pole suggests up to 22% of the surface of that crater is covered in ice (en.wikipedia, 2016e).

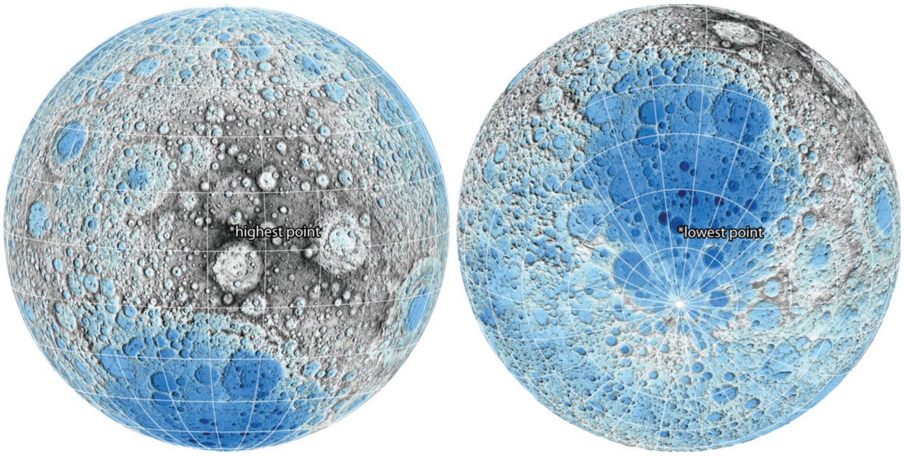


Figure 11 — Topographic Map of the Moon showing the highest spot (near 200° east longitude, +6° latitude) and lowest spot (near 188° east longitude, -70° latitude based on data from the Lunar Orbiter Laser Altimeter. Photo Credit: GSFC/NASA/ASU

Given its technical sophistication and huge amounts of data generated by LRO, numerous investigators, analysts, and instrument specialists are involved in the program. Once again, the author is fortunate to count one among his friends. Brent Archinal is a research geodesist at the USGS Astrogeology Research Program in Flagstaff, Arizona. He and several other USGS scientists are responsible for development and application of digital photogrammetric methods to improve geodesic control of lunar and planetary surfaces for production *of* cartographic maps and navigational information to assist in determining the structure of planetary interior and surface features (see http://astrogeology.usgs.gov/people/brent-archinal).

Among other duties, Archinal was involved in the Lunar Mapping and Modeling Project (LMMP). This entails production of image mosaics, digital elevation models, hazard assessment and slope maps, and gravity maps, all in support of ongoing lunar research and exploration. The project uses data derived primarily from LRO but also historical and international data, including *Apollo*, *Lunar Orbiter*, *SMART-1*, *Kaguya*, *Chang'e*, and *Chandrayaan-1* (Kirk et al., 2012).

Two recently published maps of the entire Moon (Hare et al., 2015) are available from USGS. One is a topographic map based on data from the *Lunar Orbiter* laser altimeter (LOLA), representing more than six billion measurements obtained between 2009 and 2013. The different shades of colour indicate elevation values above or below the lunar reference radius of 1737.4 kilometres (Archinal et al., 2011). Similar views of the topography are shown in Figure 11. The other map is a global mosaic of the Moon based on LRO WAC images taken under similar illumination angles.

Since the Moon's poles are likely repositories of significant quantities of water ice, much attention has naturally been focused on high-resolution mapping of those regions. A recent example of such efforts is illustrated in Archinal et al (2015). The research team's stated goal is to create geodetically controlled high-resolution (1 m/pixel) *Lunar Reconnaissance Orbiter* (LRO) narrow angle camera (NAC) polar mosaics of the lunar north and south polar caps, from ±85° to ±90° latitude. Interim examples are shown in Figure 12.

How might such water-ice deposits have originated? At least two mechanisms have been suggested. One might be the result of water-bearing comets (and other bodies) striking the Moon in the permanently shaded regions, and a second source may be in situ production. It has been hypothesized that the latter may occur when hydrogen ions (protons) in the solar wind chemically combine with the oxygen atoms present in the lunar minerals (oxides, silicates, etc.) to produce small amounts of water trapped in the minerals' crystal lattices or as hydroxyl groups, potential water precursors (en.wikipedia 2016e).

Perhaps nothing about the LRO project has captured the public's imagination more than its ability to actually image *Apollo*-mission landing sites. These images clearly show the lunar landers, astronaut footsteps, assorted equipment, and yes, the flags (Figure 13). Given various conspiracy theories that these landings did not actually take place, but were staged as implied in the 1970s movie *Capricorn One* about a faked manned landing on Mars, these superbly detailed LRO images should put the whole issue to rest once and for all. Sadly, but perhaps not surprisingly, there is now a new slate of websites and publications claiming the well over a million LRO images themselves are fakes!

The Future of Lunar Cartography?

This question was addressed directly by scientists from the USGS Astrogeology Science Center at the 2012 congress of

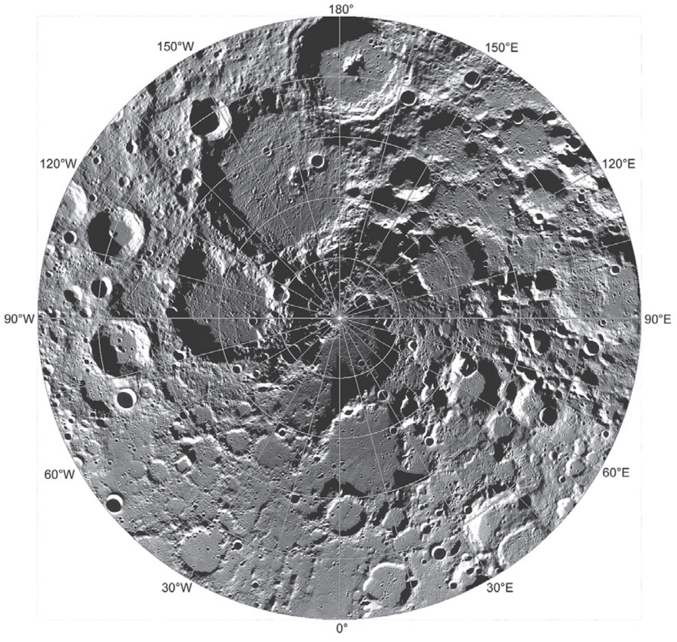


Figure 12 — Interim high-resolution map of the lunar North Pole based on LRO data (USGS/ASU/NASA)

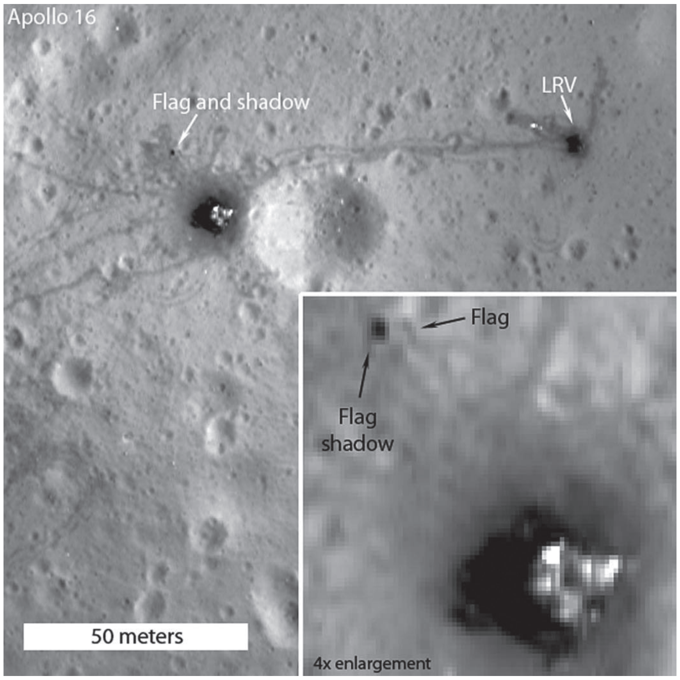


Figure 13 — LROC images of the Apollo 16 landing site showing resolution to less than 1 metre (NASA. Public domain)

the International Society for Photogrammetry and Remote Sensing (Kirk et al., 2012). The authors call for concerted efforts to unify existing data from all relevant sources: "To obtain maximum value for science and exploration, the lunar remote sensing data…must be co-registered in a common coordinate frame. Only such an effort will ensure the proper calibration, registration, and error analysis of the data, which in turn will permit the full comparative and synergistic use of the datasets." This is to ensure that detailed and accurate mapping is obtained to assist with identification of such key factors as safe landing sites, characterization of the ambient radiation environment, and the localization of potential lunar resources for future manned missions.

Similarly, at the International Lunar Development Conference in Toronto, in 2015, an "International Lunar Decade Declaration" was released that called for the establishment of "an International Lunar Survey Working Group (ILSWG) to be responsible for sharing of lunar exploration data and to integrate mapping data from national lunar missions through a common geodetic registration to produce increasingly accurate and comprehensive maps of the Moon's surface within the context of the ISECG [International Space Exploration Coordination Group]. All countries and commercial entities should have access to these nationally gathered data to facilitate scientific exploration, research, commercial activities, the location and utilization of lunar resources, and general economic lunar development in a rapidly expanding Earth-Moon economic system" (ISDC, 2015).

Along these lines, after a long hiatus, NASA has recently restarted lunar and planetary mapping planning with creation of a new NASA "analysis group," the Mapping and Planetary Spatial Infrastructure Team (MAPSIT). This group's primary goal is to develop a planetary mapping "roadmap" to help guide NASA's future lunar and planetary mapping efforts (Lawrence et al., 2016).

Where, amid this immense and growing expanse of data and information about our beloved Moon, can the amateur astronomer play a useful role? Clearly from the perspective of all lunar observers, imagers, and those monitoring for possible creation of new craters and TLPs, modern mapping and cartographic data are of major interest (see for example Cudnik, 2009; Woods, 2012). In addition, never before have amateurs had access to better telescopes, imaging technology, computational power, and software than at the present time and most likely the foreseeable future. Digital cameras and webcams, combined with dedicated capturing and processing software, now make it possible to generate diffraction-limited lunar images with modest-aperture backyard telescopes that far supersede anything professionals with much larger telescopes were able to do during the last century. Figure 14 illustrates that most emphatically.

Clearly, as well, these technological advances make it possible for backyard observers to engage in innovative and potentially novel research efforts. For example, three members of the Lunar Section of the British Astronomical Association have studied polarimetry of moonlight using single polarizing filters, monochrome CCD webcams, and typical amateur Maksutov and Schmidt-Cassegrain telescopes, to measure and compare the refractive indices of lunar regolith over extended regions of the Moon. They have shown this way that the Aristarchus plateau and Marius Hills regions both contain materials

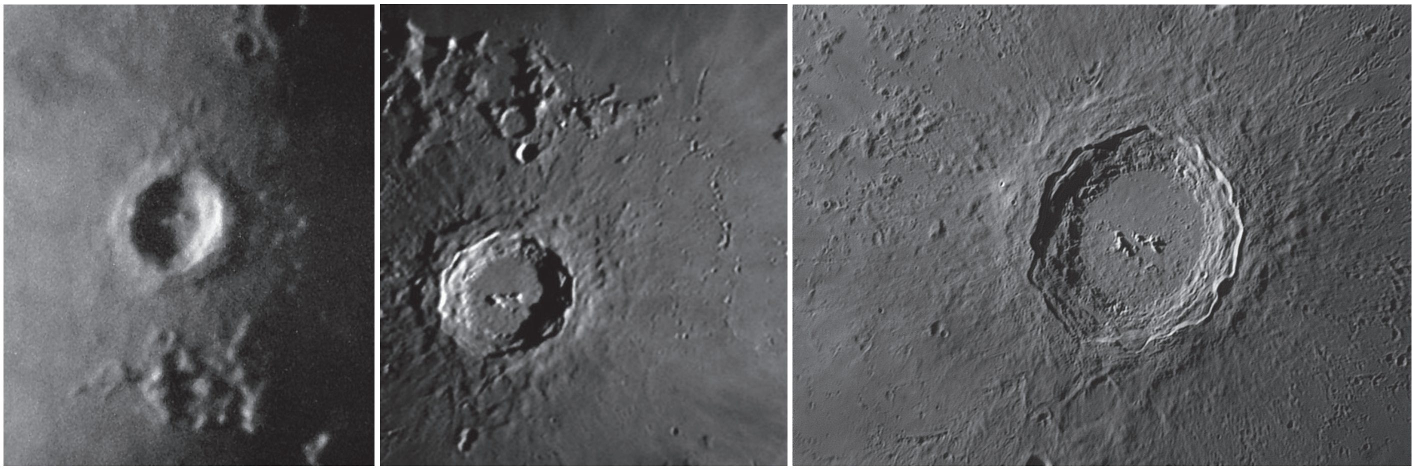


Figure 14 — The author's first photo of Copernicus (left) taken ca. 1962 with a 6-inch refractor on Kodak Tri-X Pan film; his first digital image taken in 2005 with a C14 and Nikon Coolpix 995 (centre). Copernicus by master imager Leo Aerts taken in 2014 (right) with a C14 and a high-resolution webcam. This superb diffraction-limited image rivals those taken from space.

of unusually low refractive index, similar to those of lunar highlands (Fearnside et al., 2016). These results were published in the prestigious journal *Icarus* (Fearnside et al., 2015). Anyone equipped and interested in participating is urged to contact the British Astronomical Association (BAA) Lunar Section at www.britastro.org/lunar. Another fine principally amateur research organization is the Association of Lunar and Planetary Observers (ALPO) at www.alpo-astronomy.org.

Whether imagers, researchers, or simply Moon enthusiasts, most amateur astronomers still enjoy nothing better than perusing the lunar surface visually through a good telescope, looking for unusual shadow and libration effects, perhaps spotting an infrequent or apparent TLP, or simply testing the limits of how small a craterlet can be resolved with a backyard telescope. For them nothing more than a good lunar atlas is needed, like the ever-popular *Atlas of the Moon* by Antonin Rükl (1990) and in revised and updated form (2004), both listing accurate feature diameters and elevations, or the splendid photographic *New Atlas of the Moon*, by Thierry Legault and Serge Brunier, among many other contemporary references. For those seeking wider information about all aspects of the Moon to access on your computer, see https://sourceforge.net/projects/virtualmoon ✶

Note: The author is greatly indebted to Leo Aerts, Brent A. Archinal, Richard E. Eggleton, Andrew Fearnside, and William Leatherbarrow, for providing images, literature, and special insights for this article.

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

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Mars and Neptune: A New Year's Conjunction

by Murray Paulson

I love planetary observing, but planetary conjunctions are the best! This coming New Year's Eve, we have a spectacular close conjunction of Mars and Neptune. But first I would like to relate an observation from many years ago.

Log book: 1999/02/23
One Hell of a Star Hop

You wouldn't normally be concerned about star hopping to such bright planets, but this was no ordinary star hop. The star I was hopping from was the Sun on this cold but sunny February 23. I had brought my 94-mm Brandon refractor to work, so at lunch hour, I could set up and hunt for the elusive pairing of Jupiter and Venus, which would be at closest approach at this time. My plan was to hop to Mercury, which was 15° from the Sun, then on to Venus and Jupiter 27.7° from the Sun. I had really underestimated how difficult it would be to do this with no accurate north reference on which to line up my equatorial. My Chinese copy of a Great Polaris mount was not computerized and had barely useable setting circles. This was going to be a challenge, no doubt. One hour of fruitless searching moved me to the point of total frustration and I almost gave up. The people walking by were giving me odd glances and questioning my sanity. By this time I was wondering, too!

Then I gave it that "one more last try." I was down to attempting a "Sun shot" to figure out where the heck south was. My antique 386 laptop was running *Earth Centered Universe* in my van, so I could find out where exactly the Sun was supposed to be in the sky. Using this information, I managed to guesstimate a north reference accurately enough to get into the ballpark—ice arena? Did I mention I was on an icy south-sloping parking lot that was threatening to dash me into the tripod at any minute? Did I also mention that I attempted this at lunch hour? I finally managed to find Mercury at around 1:45 p.m., after 45 minutes of sudden-death overtime. About five minutes later, I finally had Venus and Jupiter looming in my eyepiece. It was a beautiful sight. Brilliant gibbous Venus on top and the large pale disk of Jupiter 7.7′ below it.

Quite a few people from work came out to see it, and all of them were impressed at the sight. I really enjoyed the beauty and the significance of this juxtaposition. Jupiter and Venus on the far side of the Sun, widely separated in space, but in the tiny high-power field of my eyepiece! I marvelled at how well the plane of the planets lined up and I could see the equatorial belts on Jupiter. Awesome! I can only imagine what the image would be like if Venus had been on this side of the Sun. We would have had a large crescent of similar or larger size than Jupiter, and it would have been much brighter. On my way home at 6:30 p.m., I watched the pair again, now farther apart and in the twilight sky. They were beautiful at 120 power with the added treat of Jupiter's moons.

Now, back to the future. In this coming 2016–2017 New Year's Eve, we have an opportunity to witness a much closer conjunction of Mars and Neptune. As I mentioned in last year's *Observer's Handbook*, Mars passes Neptune in an extremely close conjunction on the night of December 31 to January 1 where they pass only 70″ apart at 6:53 UT. Mars will shine at mag. 0.9 and Neptune will be seven magnitudes fainter at mag. 7.9. Their disks will be diminutive at 5.7″ for Mars and 2.3″ for Neptune. This will merit some high powers at the eyepiece.

We are in a period of close conjunctions and this is the first of three over the next eight years. All of them are 2.1′ to 1.0′ at closest approach. Then nothing closer than 10′ for the next 50 years. The closest approach this year will be visible in the Hawaiian islands where they sit 20° above the horizon. Hawaii, what a way to welcome in the New Year! Two days later, a five-day-old Moon occults Mars only 3.5° above the horizon and 20 minutes before they set.

Back to our cold, hard reality here in Canada. We will see the pair set 10.5′ apart in Halifax and, in the West Coast, they are 3.6′ apart. Two days later, we miss the Moon/Mars occultation as they set before closing together here in North America. Now, this looks like a good plan to deal with those air miles that we have been promised we will lose. ✶

Murray Paulson is an enthusiastic planetary observer and refractorphile from way back. When not dodging clouds at an eclipse or while meteorite hunting, he often seeks the company of the planets in his 130-mm refractor. Murray also writes the Planets section of the Handbook.

Guide 9.0 data and Illustration

Elongation from Sun 58.69° (evening sky) Position source: JPL DE-406

Mars mag. 0.9

Right ascension: 22h45m37.906s

Declination: –08 48′ 44.08″

Dist from home planet:
1.64248469 AU
(245,712,212 km)

90.14% illuminated

5.70″ angular diameter

Position angle of the north pole:
344.41 degrees

Tilt of north pole toward home planet: –25.0735 degrees

Central meridian: 303.31

Neptune mag. 7.9

Right ascension: 22h45m35.678s

Declination: –08 47′ 41.71″

Dist from home planet:
30.45091653 AU
(4,555,392,273 km)

Position source: JPL DE-406

99.98% illuminated

Elongation from Sun 58.69°
(evening sky)

2.24″ angular diameter

The Structure and Formation of the Milky Way

by Randy Boddam, Belleville Centre
(dr__druid@msn.com)

The Milky Way Galaxy (MWG) is a barred, spiral galaxy (Freedman et al., 2014) as shown in Figure 1. Figure 2 shows a cross sectional, schematic view. MWG components, as outlined below, differ in terms of their composition (e.g. varied metallicities), anatomy, stellar ages, densities, kinematics (Buser, 2000; Wyse 2009), and elemental isotopic distributions (Kobayashi et al., 2011). In the following sections many of these components are described. Their formation history is also discussed.

Figure 1 — NGC 6814 is a barred spiral galaxy that showcases the structure of the Milky Way Galaxy. Credit: NASA

In The Beginning…

Within the first billion years after the Big Bang, cold, dark matter accreted or clumped into larger structures (Freeman and Bland-Hawthorn, 2002; Finkbeiner, 2012). Low metallicity gas was gravitationally attracted into these clumps. The MWG likely began as a spherical collection of metal-poor gas that contracted anisotropically within the gravitational potential well of this dark matter toward its centre of mass (Buser, 2000; Finkbeiner, 2012). Clusters and individual stars would form during this contraction (Buser, 2000). Significant mass of gas contracted into the centre and developed into a supermassive black hole (Freeman and Bland-Hawthorn, 2002). Concurrently, smaller sub-halos of dark matter facilitated the contraction of gas into dwarf galaxies that spiraled into the proto-MWG adding to its mass and structures (Finkbeiner, 2012; Hou et al., 2014).

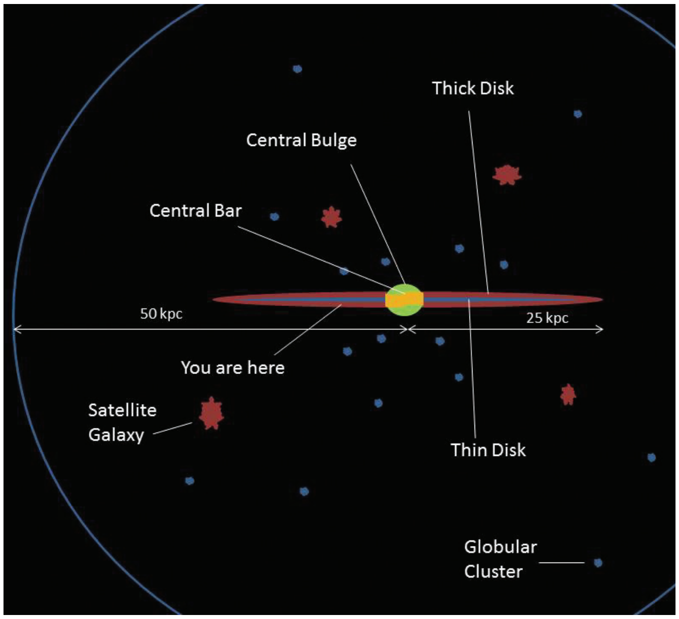

Figure 2 — A cross sectional view of the Milky Way Galaxy.

Thin Disk

The thin disk (Figure 2) contains about 95% of the disk stars (Sparke and Gallagher III, 2007) and is comprised of stars formed from the merger of gas and dwarf galaxies into the galactic plane very early on (Wyse, 2009; Finkbeiner, 2012). This region has relatively high mean rotational velocities about the centre of the MWG (Buser, 2000). Mean stellar age varies from 3 Gy to 6 Gy moving from periphery towards the centre of the thin disk (Wyse, 2009). Metallicities are higher than those of the thick disk or halo (Buser, 2000). The regions further out formed stars later as gas with higher angular momentum merged later onto the disk (Wyse, 2009). Older stars found in this region are likely either accreted from sources external to the MWG such as satellite galaxies or they represent stars formed in situ from earlier times (Wyse, 2009). Accretion continues. Streamers from the Magellanic Clouds suggest, for example, that their future is accretion with the MWG (as a consequence of dynamical friction with the MWG halo). Similarly, multi-object spectroscopy has revealed stellar streamers deriving from the Sagittarius Dwarf Spheroidal Galaxy, providing evidence for a future accretion of it with the MWG (Freeman and Bland-Hawthorn, 2002).

Thick Disk

Less dense than the thin disk (scale height of about 1 kpc versus 300–400 pc for the thin disk (Buser, 2000; Freeman & Bland-Hawthorn, 2002; Sparke & Gallagher III, 2007)), the thick disk surrounds it. Its stellar composition shows distinct kinematics with slower rotational velocities and higher vertical velocities over those of the thin disk (Buser, 2000).

Continues on page 198

Pen & Pixel

Figure 1 — Ian Donaldson took this image from the Carr Astronomical Observatory in Thornbury, Ontario, on 2016 August 3, using a Canon 5D at ISO 1600 for 30 seconds at ƒ/5.0.

Figure 2 — This stunning mosaic of the Milky Way and Comet 252/P Linear over Muskoka was taken by Wesley Liikane using a Sony A7s, with a Rokinon 35-mm t1.5 cine at ƒ/2 and ISO 6400. Each image was 13 seconds (3 images per panel × 9 panels).

Figure 3 — Ed Hitchcock photographed the Andromeda Galaxy (M31) near Meaford, Ontario. He used an Orion Starshoot Pro Colour on a William Optics 10th Anniversary Edition 80-mm fluorite doublet. The stacked image is comprised of 19 200-second subs for a total of 63 minutes and was processed using MaximDL *and* Photoshop.

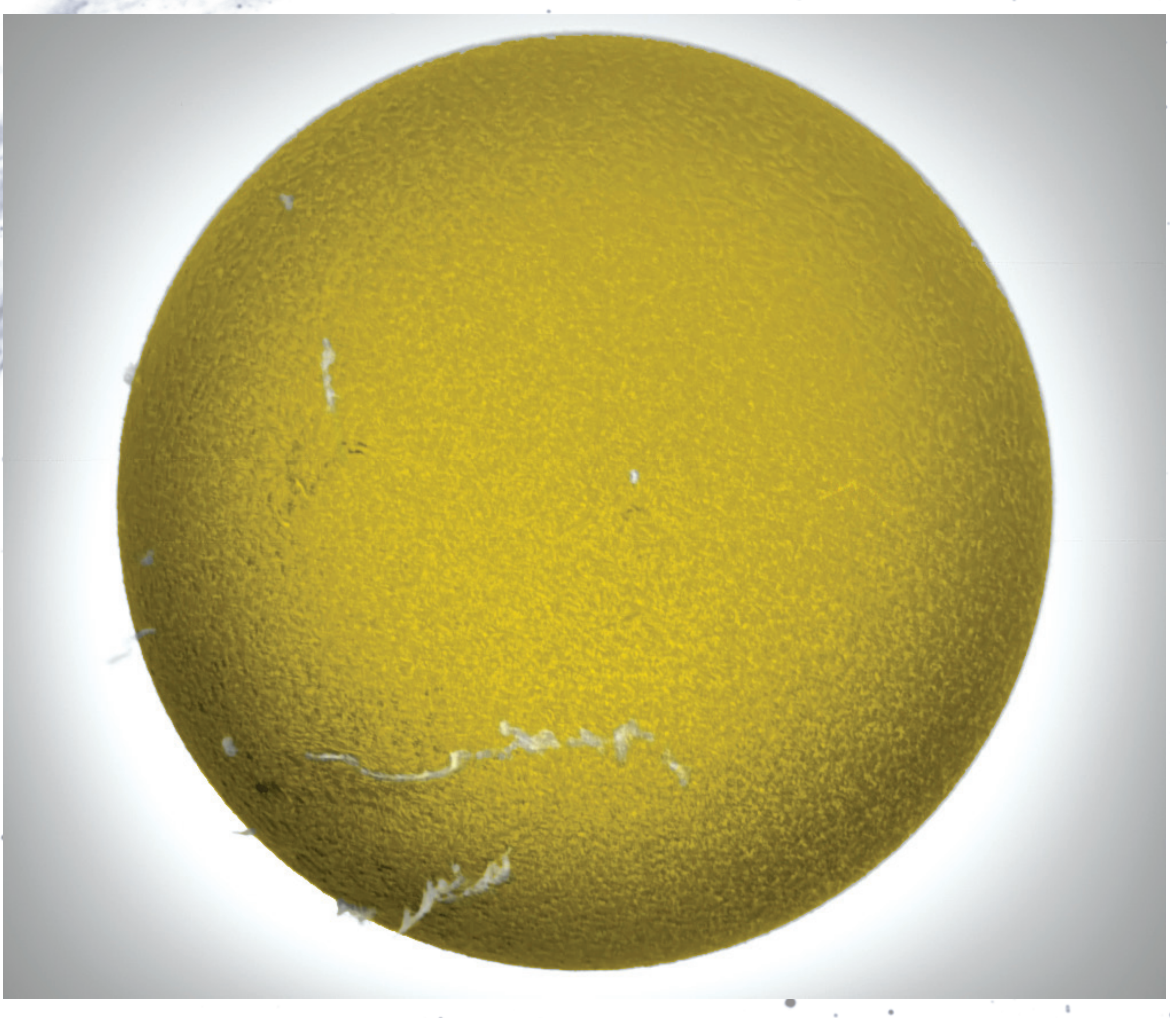

Figure 4 — A beautiful photograph of our nearest star imaged by Jim Chung, who used a double-stacked Coronado 40-mm Solarscope and a Grasshopper Express CCD.

Continued from page 195

Main-sequence turnoff ages (Wyse, 2009) and metallicities (Buser, 2000) suggest thick-disk stars are older than thin-disk stars. Higher metallicity globular clusters (GCs) probably also belong to this structure (Buser, 2000). Examining the age of these GCs suggests that it is 11.4 ± 0.8 Gy old (Buser, 2000). These stars are not as old as halo GCs (Buser, 2000). Chemically, they are spectroscopically found to be more α-enhanced (α enhancement means that there are more alpha elements—elements built by alpha-particle capture) at comparable metallicities than similar thin-disk stars (Schlaufman et al., 2011). One formation model suggests significantly smaller satellite galaxies merged with the MWG disk (Buser, 2000).

Simulations involving the accretion of a single satellite with 10–20% of the mass ratio of the thin disk have shown that heat coming from these mergers moves stars to form the thick disk (Buser, 2000; Wyse, 2009). Haywood et al., (2015) alternatively suggested that the thick disk formed "all at once" as a sort of "closed box." Observing the relatively constant distribution of α elements throughout the thick disk, they showed that the absence of a gradient suggests a uniform formation history resulting from uniform gas distribution and subsequent star formation throughout the thick disk (Haywood et al., 2015). Earlier work by this group (Snaith et al., 2014) suggested a similar mechanism in the formation of both thick and thin disk. Spectroscopically analyzing a small subsample of stars in the solar neighbourhood, they derived a star-formation history of the stars in this region. Both papers suggested that the development of the disk was not dependent upon a constant inflow of gas from outside of the MWG as has been previously thought but rather had all the necessary gas early on (Snaith et al., 2014; Haywood et al., 2015). They also challenged the proportionality of mass in thick and thin disks suggesting an equal distribution of luminous mass.

Central Bulge

This region, about 2–8 kpc in diameter (Gerhard, 2000; Freedman et al., 2014) and having a mass of $2 \times 10^{10} M_{\odot}$ (WebMass) (see Figure 2), formed as the result of mergers of material with the MWG that either migrated toward the centre as a consequence of dynamic friction or due to centrally directed gas flow resulting from transfers of angular momentum with the material being merged (Wyse, 2009). Younger stars are located in the plane of the disk while older stars lie above and below (Wyse, 2009). Wyse (2009) has suggested that either the bulge formed as a consequence of the last major merger occurring about 10 Gy ago with the MWG and consequential burst of star-forming activity or that it was formed of gas ejected as a consequence of star formation occurring early in the halo, as bulge and halo have similar angular momenta.

At the centre of the bulge is a 2–4 kpc bar of young stars and a massive, central black hole (Finkbeiner, 2012). Bars develop possibly triggered by an interaction between galaxies (Okamoto et al., 2015) or possibly as a density wave impacting on central stars of the disk (WebBar). Okamoto et al., (2015) simulated bar development using MWG-sized galaxies. Bars tended to get larger and slower as time goes on (Okamoto et al., 2015), as found in their model, resulting from transfer of angular momentum to the outer disk and, especially, the dark-matter halo. Renaud et al., (2015) have demonstrated that bars are also a site of star formation. Bars rotate faster than their surrounding disk, which induces molecular clouds to form at the point where the bars interact with the disk. These molecular clouds become a bed of star formation (Renaud et al., 2015).

Shen et al. (2010) challenged the presence of the central galactic bulge. Citing infrared imaging that shows a parallelogram or peanut-shaped central density, they developed a numerical model of galactic evolution. In this model they started with a flat disk and found that a central bar develops over time and buckled vertically—appearing like a bulge. This model fits COBE infrared observations well, as they demonstrated. Adding a pre-existing bulge to their model produced worse-fitting results, suggesting the absence of a central bulge in the MWG. Given that central bulges are thought to be the result of galactic accretion events, the absence of a bulge, if their model is correct, calls into question much of what has been understood to have involved in the growth and development of the MWG. More recently this group (Kunder et al., 2016), spectroscopically examining RR Lyrae stars within 1 kpc of the galactic centre have found kinematics suggesting that there may well have been a classical bulge at least in the early MWG's history. Which model is the most accurate? The jury is clearly out!

The Halo

Existing as a spheroidal region of diameter 100 kpc surrounding the MWG (Figure 2) the halo consists of field stars, about 170 GCs (Buser, 2000) and low density gas (Finkbeiner, 2012). This low-density gas likely extends beyond the boundary of the halo and may be an important reservoir supporting stellar birth in our galaxy (Finkbeiner, 2012). Field stars likely derived from the accretion of a few massive (Wyse, 2009) and possibly several dwarf (Freeman & Bland-Hawthorn, 2002; Finkbeiner, 2012) satellite galaxies very early on in the history of the MWG or were formed in situ (Buser, 2000). Distant halo stars orbit the MWG with highly eccentric and inclined orbits moving into and out of the galactic disk (Buser, 2000). Schlaufman et al. (2011) spectroscopically analyzed a class of stars that they call "ECHOS" (Elemental Cold HalO Substructure) and found that these stars, existing in the inner halo, are chemically distinct from other field stars in the inner halo. Schlaufman et al. (2012) spectroscopically studied metallicities of halo stars up to a galactocentric distance of 17.5 kpc. They determined that stars closer than 15 kpc were likely the result of galactic mergers early in the life of the MWG (that is, at high redshift), whereas more distant stars derive from the accretion of smaller, satellite galaxies.

The absence of a metallicity gradient, that would be expected were the halo comprised of stars that formed solely with the contraction of the gas cloud that became the MWG, also supports an accretion origin for these stars (Buser, 2000). Inner field stars rotate in the same direction as does the MWG, whereas the outer field stars are older Population II stars that rotate in the opposite direction (Finkbeiner, 2012). The halo has subpopulations of stars and is a testament to the formation history of the MWG.

There are two populations of GCs in the halo differentiated by kinematics, distribution, structure, and metallicity (Freeman & Bland-Hawthorn, 2002). Older GCs are believed to have coalesced out of the primordial gas cloud that developed into the MWG (Krauss & Chaboyer, 2003). These are believed to be of the oldest visible structures of the MWG (Freeman & Bland-Hawthorn, 2002; Krauss & Chaboyer, 2003) having an age of approximately 12-13 Gy (Buser, 2000; Freeman & Bland-Hawthorn, 2002). They show a lower metallicity than stars such as our Sun (Krauss & Chaboyer, 2003), suggesting little stellar turnover since their formation. Parenthetically, estimation of their ages has been used by Krauss and Chaboyer (2003), in comparison to the age of the Universe as shown by the Cosmic Microwave Background to demonstrate the presence of dark energy in the Universe. As such, they are of interest to cosmologists. Younger GCs may, in fact, represent the tidally disrupted remains of the accretion of dwarf galaxies into the MWG (Freeman & Bland-Hawthorn, 2002).

Dark Matter

Dark matter can only be detected through its gravitational effects. The MWG exists within a halo or sphere of dark matter that accounts for 90% of its mass extending out to a radius of at least 100 kpc (Freeman & Bland-Hawthorn, 2002). This is the only plausible explanation to account for the observed rotational characteristics of its disk (Oppenheimer et al., 2001; Freedman et al., 2014). The MWG disk rotates at relatively constant speed with radius contrary to what would be expected were all the mass concentrated at the galactic centre (Freedman et al., 2014). Oppenheimer et al. (2001) searched for previously unidentified white-dwarf stars, too cool to have been detected earlier, to determine if these could account for the missing mass, but found that only 2% (as a lower limit) of this mass could be accounted for.

The dark-matter halo is likely not smooth. In fact, it has been suggested that dark-matter subhalos with relatively shallow gravitational wells were responsible for the formation of the dwarf galaxies surrounding the MWG (Hou et al., 2014). It is likely that the lumpy distribution of dark matter still influences the development of the MWG (Freeman & Bland-Hawthorn, 2002).

Summary

There are morphologically distinct regions within the MWG. Past understanding of hierarchical structuring of these different regions within a sphere of dark matter is being challenged by newer data suggesting different mechanisms of galactic development. Is there a central bulge? Did the disk form all at once? Does accretion have a role in the development of the MWG structure? The MWG is still far from having revealed all of her secrets! ✶

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CFHT Chronicles

Planets, Big and Dwarf, Abound

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

Summer 2016 may be remembered as the summer of planets at CFHT. Well, at least until SPIRou arrives… Let us take a look at two discoveries from last summer that are really fascinating and big news. What I have done is taken the press releases for both discoveries and added additional information that clarifies and expands upon the details for the reader. Bonus, Canadian astronomers were actively involved in both.

First, we need to talk a bit about how astronomers hypothesize that planets form. Stars and planets form inside stellar nebulae.

Each part of a nebula exerts a gravitational pull on other parts, leading to contraction of the nebula. The highest concentration of material occurs in the centre of the cloud, forming the star. As the star grows, rotation within the cloud ensures that not all the material in the cloud falls into the star. This remaining material ultimately forms planets. As the cloud spins, particles within it begin to collide. Clumps of material form, collide, merge, and reform into larger clumps—ultimately creating larger masses called protoplanets. As the collisions occur, the motion of the protoplanets becomes less random and the cloud flattens. A spinning disk during planetary formation explains the orderly motions that we see in our Solar System today.

Now we have the seeds of planets within the disk. The protoplanets closest to the forming star are too warm for condensation of hydrogen compounds to occur, resulting in rocky and metal-based planets: the terrestrial planets in our Solar System. Further away from the star, the temperature in the nebula is cold enough for hydrogen compounds to condense. With a greater supply of materials, i.e. rocks, metals, and hydrogen compounds, protoplanets can grow bigger. Once they have enough gravity, they begin to attract gaseous hydrogen and helium, creating the gas-giant planets we see today. Different models exist for how the Jovian planets ended up in their exact location within our Solar System.

For the last 20 years, the giant planets known as "hot Jupiters" have presented astronomers with a puzzle. The formation model described above does not entirely explain hot Jupiters—Jupiter-sized planets that settled into orbits 100 times closer to their host stars than our own Jupiter is to the Sun. Astronomers ask: If the planets form in the outer regions of the nebula, when and how do they move closer to the star?

In June, a team of astronomers, many of whom are working on SPIRou, announced the discovery of a hot Jupiter planet orbiting the star V830 Tau that just might shed some light on the question above. The discovery of a newborn hot Jupiter, orbiting an infant sun V830 Tau—only two million years old, the stellar equivalent of a week-old human baby—starts to give astronomers a clue to the answer of where and when Jupiter-sized planets can form. The discovery that hot Jupiters can already be present at such an early stage of star-planet formation represents a major step forward in our understanding of the formation and evolution of planetary systems.

The team monitored the two million-year-old infant star V830 Tau, located in the Taurus stellar nursery, some 430 light-years away. Over the one-and-a-half months of the observing campaign, a regular 4.9-day "wobble" in the velocity of the host star revealed a giant planet almost as massive as Jupiter, orbiting its host star at a distance of only one-twentieth that of the Sun to the Earth distance. "Our discovery demonstrates for the first time that such bodies can be generated at very early stages of planetary formation, and likely play a central

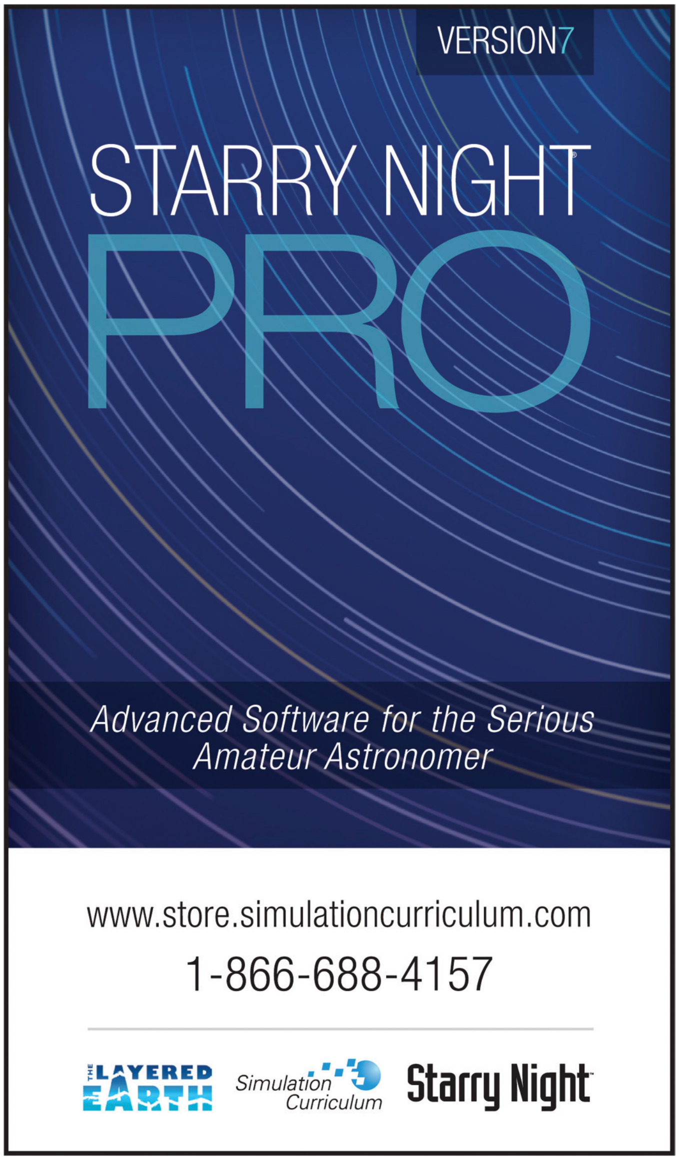


Figure 1 — Artist's view of V830 Tau and the newly discovered hot Jupiter. Infant stars are very active, making the detection of planets around them challenging. Photo Credit: Michael Ho

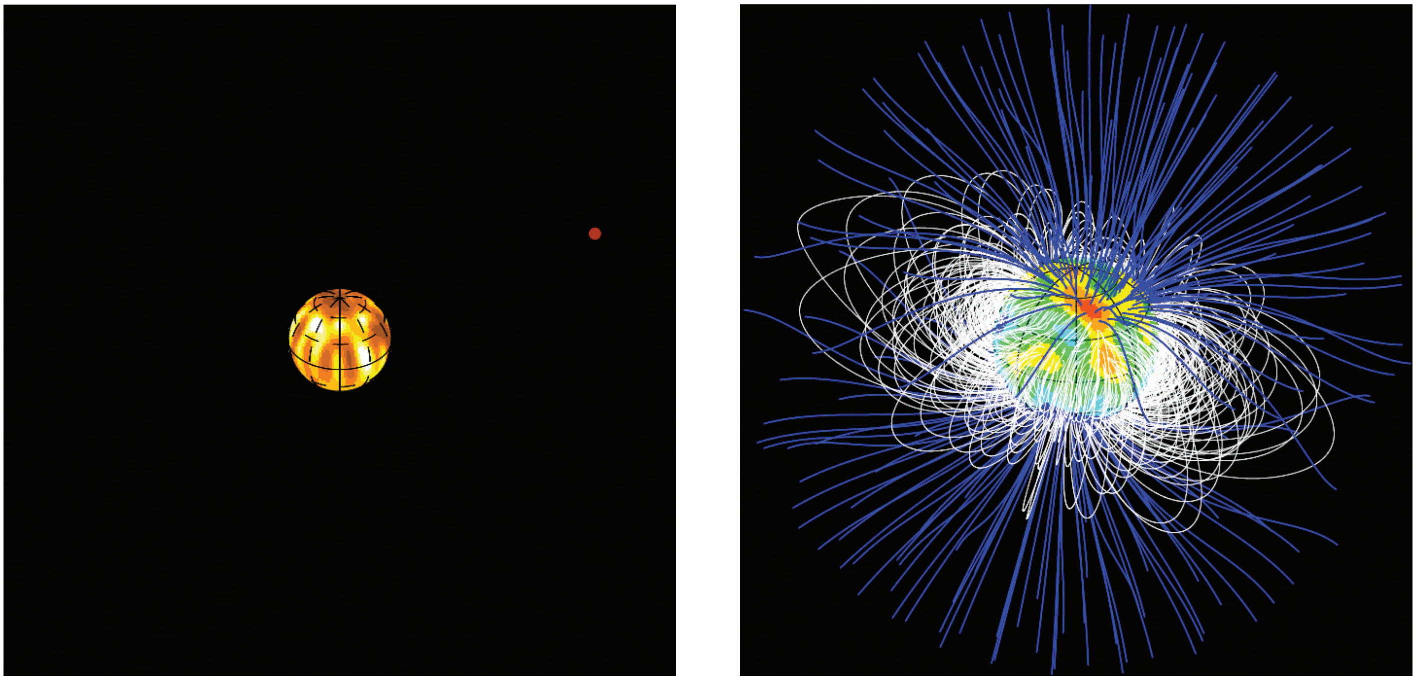
role in shaping the overall architecture of planetary systems," explains Jean-François Donati, CNRS astronomer at IRAP / OMP2 and lead author of a new paper published in the journal *Nature*.

The team used the twin spectropolarimeters ESPaDOnS and Narval to monitor V830 Tau for a total of 47 hours. ESPaDOnS, as you may recall, is mounted at CFHT. ESPaDOnS can be fibre-fed from either CFHT itself, or via GRACES, a 300-metre optical-fibre link from the nearby eight-metre Gemini North telescope. The team used ESPaDOnS in both modes, providing the opportunity to monitor the star using light from the Gemini North telescope when the instrument was unavailable at CFHT. The team also used Narval, mounted at the two-metre Télescope Bernard Lyot (TBL) atop Pic du Midi in the French Pyrénées. "Using all three telescopes was essential for regularly monitoring V830 Tau throughout our campaign and for detecting its giant planet," stresses Lison Malo, CFHT astronomer, a co-author of the study and leader in coordinating the observations.

In our Solar System, small rocky planets like Earth are found near the Sun, whereas gas giants like Jupiter and Saturn orbit much further out. "The discovery in 1995 of a giant planet flying very close to its host star took us by surprise and revolutionized the field," recalls Claire Moutou, CNRS astronomer at CFHT and a co-author of this new study. As mentioned above, theoretical work indicates that such planets can only form in the cold and icy outer regions of the protoplanetary disk in which both the central star and surrounding planets are born. Some, however, migrate inwards without falling into their host star, thus becoming hot Jupiters.

"Planet formation models offer two competing explanations of how and when this migration of hot Jupiters occurred. Either it happened early while these planets were still forming, or much later, with some planets being kicked closer to their stars due to the interaction of multiple planets, or both," explains Clément Baruteau, CNRS astronomer at IRAP / OMP and a co-author of this study. "Our discovery demonstrates that the first, earlier option is taking place; it revives the long-running debate about how and when this migration occurs, and brings us one step forward in our understanding of how planetary systems form."

Among the known hot Jupiters, some feature strongly tilted or even upside-down orbits, suggesting they were knocked into close orbits by gravitational interactions with other planets or neighbouring stars. Others orbit above the host star's equator, hinting at a more gentle formation process in the form of an inward drift through the disk. "The young hot Jupiter we just detected comes as the first evidence that early disk migration is also happening," says Andrew Collier Cameron of the University of St Andrews, a co-author of the study.



Figures 2 and 3 — Star surface and planet (left) and magnetic field lines (right) at the surface of V830 Tau as reconstructed from ESPaDOnS data

"SPIRou and SPIP, the twin new-generation instruments built for CFHT and TBL by our team and scheduled for first light in 2017 and 2019 respectively, will offer vastly superior performances for such programs, and will soon allow us to explore the formation of new worlds with unprecedented sensitivity," adds Louise Yu, a co-author of the study and Ph.D. student in observational exoplanet science at IRAP / OMP.

The V830 Tau discovery sheds light onto the formation and migration of hot Jupiters.

Our other discovery explores the effects of those large planet migrations on smaller bodies by studying our own Kuiper Belt. The Outer Solar System Origin Survey (OSSOS) team studies the Kuiper Belt with the aim of detecting small icy worlds to test models of Solar System formation and evolution.

In July, the OSSOS team announced the discovery of new dwarf planet orbiting the Kuiper Belt. The new object is roughly 700 kilometres in size and has one of the largest orbits for a dwarf planet. Designated 2015 RR245 by the International Astronomical Union's Minor Planet Center, it was found using CFHT.

"The icy worlds beyond Neptune trace how the giant planets formed and then moved out from the Sun. They let us piece together the history of our Solar System. But almost all of these icy worlds are painfully small and faint; it's really exciting to find one that's large and bright enough that we can study it in detail," says Dr. Michele Bannister of the University of Victoria in British Columbia, who is a postdoctoral fellow with the survey.

National Research Council of Canada's Dr. J.J. Kavelaars first sighted RR245 in February 2016 in the OSSOS images from September 2015. "There it was on the screen—this dot of light moving so slowly that it had to be at least twice as far as Neptune is from the Sun," says Bannister.

The team became even more excited when they realized that the object's orbit takes it more than 120 times further from the Sun than Earth. The size of RR245 is not yet exactly known, as its surface properties need further measurement. "It's either small and shiny, or large and dull," says Bannister.

The vast majority of the dwarf planets like RR245 were destroyed or thrown from the Solar System in the chaos that ensued as the giant planets moved out to their present positions: RR245 is one of the few dwarf planets that has survived to the present day—along with Pluto and Eris, the largest known dwarf planets. RR245 now circles the Sun among the remnant population of tens of thousands of much smaller trans-Neptunian worlds, most of which orbits are unseen.

Worlds that journey far from the Sun have exotic geology with landscapes made of many different frozen materials, as the recent flyby of Pluto by the *New Horizons* spacecraft showed.

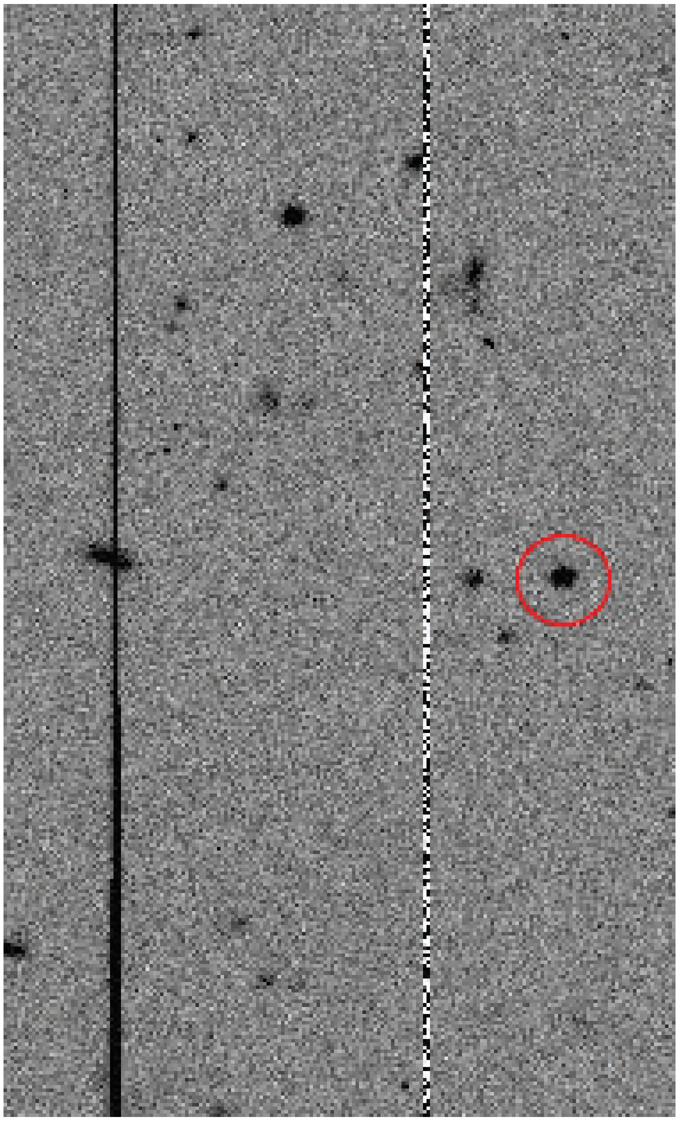


Figure 4 — *Discovery image of RR235. The red circle surrounds RR245. Credit: OSSOS team*

After hundreds of years further than 12 billion km or 80 astronomical units (AU) from the Sun, RR245 is travelling toward its closest approach at 5 billion km (34 AU), which it will reach around 2096. RR245 has been on its highly elliptical orbit for at least the last 100 million years.

As RR245 has only been observed for one of the 700 years it takes to orbit the Sun, where it came from and how its orbit will slowly evolve in the far future is still unknown; its precise orbit will be refined over the coming years, after which RR245 will be given a name. As discoverers, the OSSOS team can submit their preferred name for RR245 to the International Astronomical Union for consideration.

"OSSOS was designed to map the orbital structure of the outer Solar System to decipher its history," says Professor Brett Gladman of the University of British Columbia in Vancouver. "While not designed to efficiently detect dwarf planets, we're delighted to have found one on such an interesting orbit."

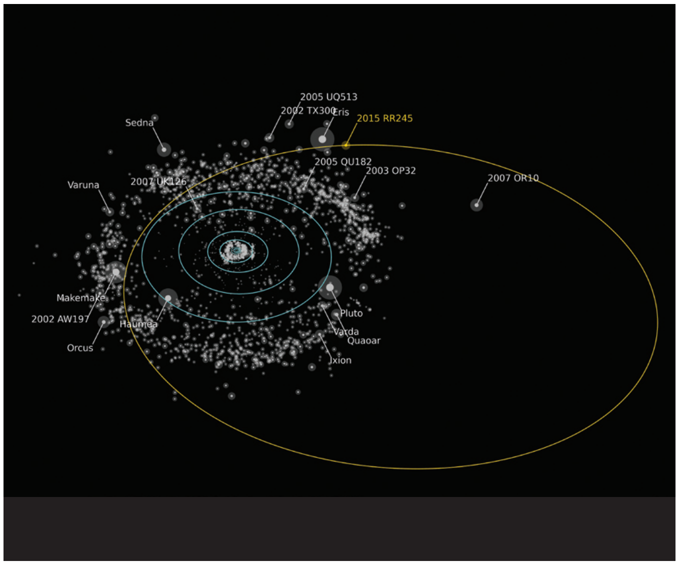


Figure 5 — Rendering of the orbit of RR245 (orange line). Objects as bright or brighter than RR245 are labelled. The blue circles show the projected orbits of the major planets. The Minor Planet Center describes the object as the 18th largest in the Kuiper Belt. Credit: Alex Parker, OSSOS team

RR245 is the largest discovery and the only dwarf planet found by OSSOS, which has discovered more than 500 new trans-Neptunian objects. "OSSOS is only possible due to the exceptional observing capabilities of the Canada-France-Hawaii Telescope. CFHT is located at one of the best optical observing locations on Earth, is equipped with an enormous wide-field imager, and can quickly adapt its observing each night to new discoveries we make. This facility is truly world leading," says Gladman.

Previous surveys have mapped almost all the brighter dwarf planets. 2015 RR245 may be one of the last large worlds beyond Neptune to be found until larger telescopes, such as LSST, come online in the mid 2020s.

After the OSSOS team's initial announcement of the discovery of RR245, the Pan-STARRS1 survey released data related to the position of RR245 yielding an additional six opposition points for the object. With the new data, the OSSOS team calculated a more precise orbit for RR245, discovering it lies in a 9:2 resonance with Neptune centred at a semi-major axis near 82 AU (for reference, Pluto's semimajor axis is 39.5 AU and Eris's is ~67 AU). In layman's terms, for every 9 orbits that Neptune makes, RR245 makes 2. RR245 is the first object discovered in a 9:2 resonance with Neptune. In their OSSOS:IV paper, the team concludes "residence in the 9:2 or other resonances can temporarily shield TNOs from scattering, but eventually their orbital evolution will lead such TNOs to leave the resonance and resume active scattering." We will continue to follow the adventures of the OSSOS team and RR245 and give updates as they are available. ✶

Binary Universe

Planning on a Mac

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

I like to think I am an equal opportunist with operating systems. I regularly use Windows and Android devices; for a time, I had more Macintosh computers than PCs. I was a big fan of Psion's EPOC. And I dabble with Linux.

It is a fact, sad for some perhaps, that the Macintosh is not supported to nearly the same degree, compared to the Windows platform, for astronomy applications. And that is certainly true with planning software.

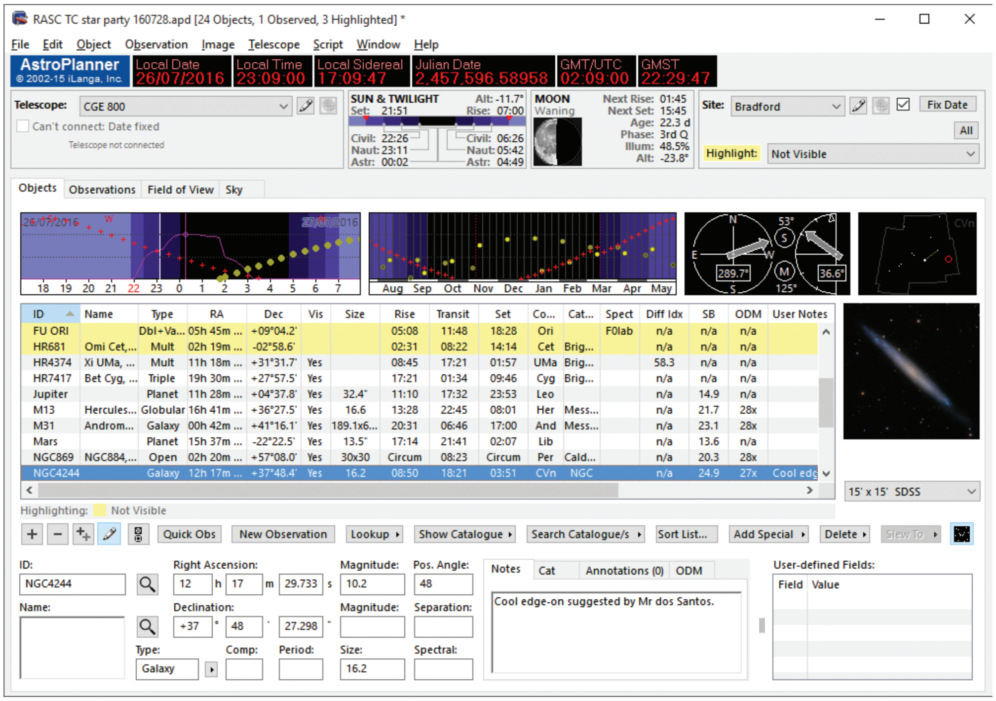
Happily, there is a very good astronomical planning application available for the Apple Mac platform. In fact, *AstroPlanner* runs on both Mac and Windows. I installed an evaluation copy of the app, version 2.2 (released in 2015), on Windows 10, Windows XP, and Mac OS X computers.

Planning tools are a different kettle of fish. When people think about astronomy computer applications, they typically consider software that shows (or rather simulates) the night sky, in varying degrees of realism, lets you select a displayed object, zoom in, show some details of the object, and perhaps slew a connected telescope to that spot. Those types of apps I would lump under the banner planetarium software—*Stellarium*, *SkySafari*, *Cartes du Ciel*, and *Starry Night* all fall into this category.

Planning apps like *AstroPlanner*, *SkyTools*, *Deep-Sky Planner*, however, show lists or tables with target objects, sorted in a useful way, so that you may view or image objects in a good sequence. These session plans can be prepared well in advance with content provided automatically with sophisticated algorithms, manually added, or copied from other plans. If the astronomer does not intend to take the computer out under the stars, forms and charts and lists can be printed. During an observing session, with a computer at the telescope, items essentially can be ticked off, and marked as observed, not unlike a paper checklist. If the computer is connected to a compatible mount, a target can be selected and then the telescope can be made to slew to the object.

On first running *AstroPlanner*, the user is guided through the setup process by a software wizard. It prompts for location details, telescope and eyepiece particulars, and then asks which catalogues you might like to use. With these key resources in place, the wizard then helps you build your first session plan list. It suggests the Messier list, different sets of interesting clusters or galaxies, or a mixture of 100 assorted objects. An abbreviated manual (with fewer than 50 pages) is provided to help you get up and running quickly. This is particularly useful if you want to make your own plan from scratch. The full user manual is over 400 pages!

The main screen (see Figure 1) is a busy place and takes a bit of time getting used to it.



RASC TC star party 160728.apd [24 Objects, 1 Observed, 3 Highlighted] *

Local Date 26/07/2016 | Local Time 23:09:00 | Local Sidereal 17:09:47 | Julian Date 2,457,596.58958 | GMT/UTC 02:09:00 | GMST 22:29:47

Telescope: CGE 800

☐ Can't connect: Date fixed

Telescope not connected

SUN & TWILIGHT Alt: -11.7°
Set: 21:51 Rise: 07:00
Civil: 22:26 Civil: 06:26
Naut: 23:11 Naut: 05:42
Astr: 00:02 Astr: 04:49

MOON Waning
Next Rise: 01:45
Next Set: 15:45
Age: 22.3 d
Phase: 3rd Q
Illum: 48.5%
Alt: -23.8°

Site: Bradford ☑ Fix Date

Highlight: Not Visible

ID	Name	Type	RA	Dec	Vis	Size	Rise	Transit	Set	Co...	Cat...	Spect	Diff Idx	SB	ODM	User Notes
FU ORI		Dbl+Va...	05h 45m ...	+09°04.2'			05:08	11:48	18:28	Ori		F0Iab	n/a	n/a	n/a	
HR681	Omi Cet,...	Mult	02h 19m ...	-02°58.6'			02:31	08:22	14:14	Cet	Brig...		n/a	n/a	n/a	
HR4374	Xi UMa, ...	Mult	11h 18m ...	+31°31.7'	Yes		08:45	17:21	01:57	UMa	Brig...		58.3	n/a	n/a	
HR7417	Bet Cyg, ...	Triple	19h 30m ...	+27°57.5'	Yes		17:21	01:34	09:46	Cyg	Brig...		n/a	n/a	n/a	
Jupiter		Planet	11h 28m ...	+04°37.8'	Yes	32.4"	11:10	17:32	23:53	Leo			n/a	14.9	n/a	
M13	Hercules...	Globular	16h 41m ...	+36°27.5'	Yes	16.6	13:28	22:45	08:01	Her	Mess...		n/a	21.7	28x	
M31	Androm...	Galaxy	00h 42m ...	+41°16.1'	Yes	189.1x6...	20:31	06:46	17:00	And	Mess...		n/a	23.1	28x	
Mars		Planet	15h 37m ...	-22°22.5'	Yes	13.5"	17:14	21:41	02:07	Lib			n/a	13.6	n/a	
NGC869	NGC884,...	Open	02h 20m ...	+57°08.0'	Yes	30x30	Circum	08:23	Circum	Per	Cald...		n/a	20.3	28x	
NGC4244		Galaxy	12h 17m ...	+37°48.4'	Yes	16.2	08:50	18:21	03:51	CVn	NGC		n/a	24.9	27x	Cool edg

15' x 15' SDSS

Highlighting: Not Visible

ID: NGC4244

Name:

Right Ascension: 12 h 17 m 29.733 s

Declination: +37 ° 48 ' 27.298 "

Type: Galaxy

Comp:

Period:

Magnitude: 10.2

Magnitude:

Size: 16.2

Pos. Angle: 48

Separation:

Spectral:

Cool edge-on suggested by Mr dos Santos.

User-defined Fields:

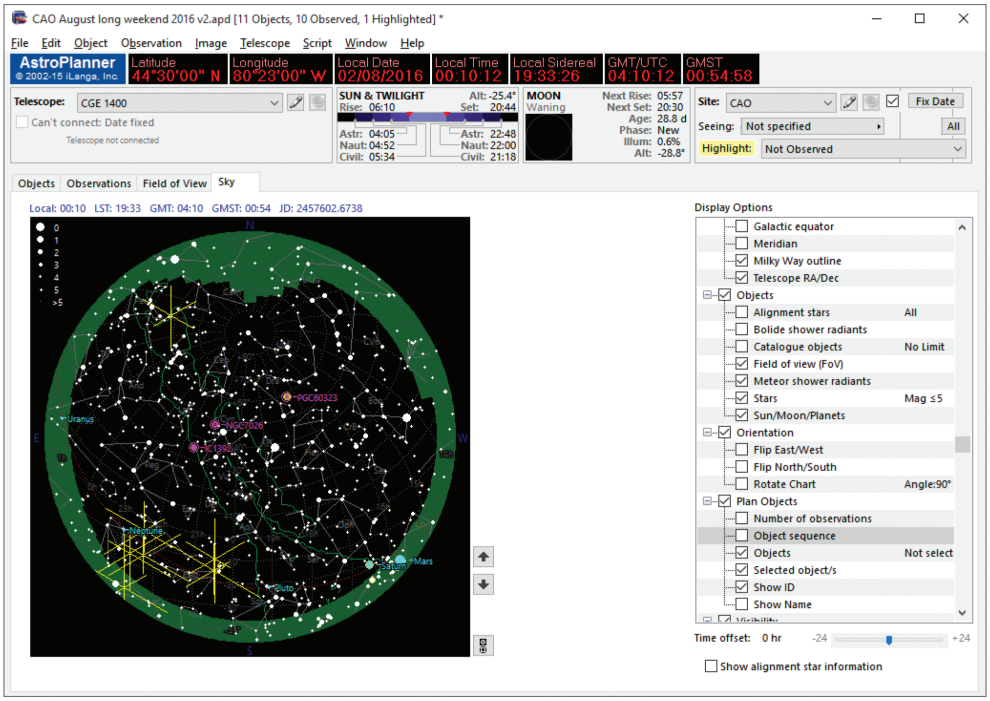
Field	Value

Figure 1 — The main window of AstroPlanner *with an observing plan list with various Objects showing. Galaxy NGC 4244 selected. DSS image and Object Editing Fields shown.*

A traditional menu appears at the top of the monitor (on a Mac) or just inside the window's top edge (er, for Windows users) with many obvious choices. The File menu lets you make new plans and save them. The Plan Creation Wizard is found here for letting the software automatically generate a list of target objects. Catalogue management is also accessed here. The Object menu is used to add more objects or slew to the currently selected one. The Observation menu lets you capture your log entries. And so on. Right-click menus are heavily used in this application.

At the top of the Plan Document Window is a section the author calls the "LED" area. This includes boxes with the local date and time, sidereal time, Julian Date, and Universal Time (UTC). This will reflect the current time unless you have set the app to use a specific period with the Fix Date option. If connected to a Go To mount, the Telescope RA and Dec boxes show. You may configure this bar.

The area below has a number of information boxes starting with the Telescope Control, Sun & Twilight, the Moon panel, the Site box with Highlight option, and the Date/Time section. The Telescope box helps determine the field of view when simulating through an eyepiece and is used to drive a connected mount. The Sun & Twilight shows the Sun's altitude and the calculated twilight times. You can quickly note the sunset. The Moon panel shows the phase, notes the Age, and timings. The Site option allows one to choose the observer's location, which will impact the visibility of targets and activate any configured horizon lines. The selected telescope and site also get transferred into log notes.



Latitude 44°30'00" N

Longitude 80°23'00" W

Local Date 02/08/2016

Local Time 00:10:12

Local Sidereal 19:33:26

GMT/UTC 04:10:12

GMST 00:54:58

Telescope: CGE 1400

☐ Can't connect: Date fixed

Telescope not connected

SUN & TWILIGHT Alt: -25.4°
Rise: 06:10 Set: 20:44
Astr: 04:05 Astr: 22:48
Naut: 04:52 Naut: 22:00
Civil: 05:34 Civil: 21:18

MOON
Waning
Next Rise: 05:57
Next Set: 20:30
Age: 28.8 d
Phase: New
Illum: 0.6%
Alt: -28.8°

Site: CAO
Seeing: Not specified
Highlight: Not Observed

Local: 00:10 LST: 19:33 GMT: 04:10 GMST: 00:54 JD: 2457602.6738

☐ Galactic equator
☐ Meridian
☑ Milky Way outline
☑ Telescope RA/Dec
☑ Objects
- ☐ Alignment stars All
- ☐ Bolide shower radiants
- ☐ Catalogue objects No Limit
- ☑ Field of view (FoV)
- ☑ Meteor shower radiants
- ☑ Stars Mag ≤5
- ☑ Sun/Moon/Planets

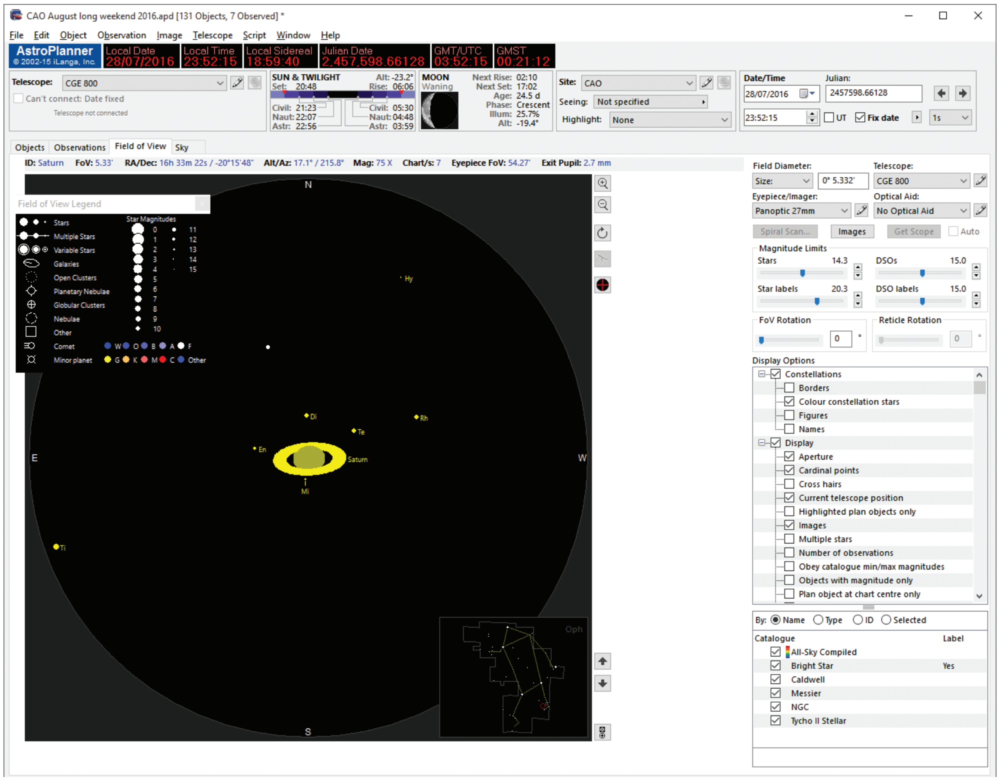
☑ Orientation
- ☐ Flip East/West
- ☐ Flip North/South
- ☐ Rotate Chart Angle:90°

☑ Plan Objects
- ☐ Number of observations
- ☐ Object sequence
- ☑ Objects Not select
- ☑ Selected object/s
- ☑ Show ID
- ☐ Show Name

Time offset: 0 hr -24 +24

☐ Show alignment star information

Figure 2 — The all Sky tab. The fuchsia dots represent three selected targets from the Objects list. The yellow sprites indicate meteor shower radiants.



Local Date 28/07/2016

Local Time 23:52:15

Local Sidereal 18:59:40

Julian Date 2,457,598.66128

GMT/UTC 03:52:15

GMST 00:21:12

Telescope: CGE 800

☐ Can't connect: Date fixed

Telescope not connected

SUN & TWILIGHT Alt: -23.2°
Set: 20:48 Rise: 06:06
Civil: 21:23 Civil: 05:30
Naut: 22:07 Naut: 04:48
Astr: 22:56 Astr: 03:59

MOON
Waning
Next Rise: 02:10
Next Set: 17:02
Age: 24.5 d
Phase: Crescent
Illum: 25.7%
Alt: -19.4°

Site: CAO
Seeing: Not specified
Highlight: None

Date/Time 28/07/2016 Julian: 2457598.66128
23:52:15 ☐ UT ☑ Fix date 1s

ID: Saturn FoV: 5.33' RA/Dec: 16h 33m 22s / -20°15'48" Alt/Az: 17.1° / 215.8° Mag: 75 X Chart/s: 7 Eyepiece FoV: 54.27' Exit Pupil: 2.7 mm

Field Diameter: Size: 0° 5.332'
Telescope: CGE 800
Eyepiece/Imager: Panoptic 27mm
Optical Aid: No Optical Aid

Magnitude Limits
Stars 14.3 DSOs 15.0
Star labels 20.3 DSO labels 15.0

FoV Rotation 0° Reticle Rotation 0°

Display Options
☑ Constellations
- ☐ Borders
- ☑ Colour constellation stars
- ☐ Figures
- ☐ Names

☑ Display
- ☑ Aperture
- ☑ Cardinal points
- ☐ Cross hairs
- ☑ Current telescope position
- ☑ Highlighted plan objects only
- ☑ Images
- ☐ Multiple stars
- ☐ Number of observations
- ☐ Obey catalogue min/max magnitudes
- ☐ Objects with magnitude only
- ☐ Plan object at chart centre only

By: ● Name ○ Type ○ ID ○ Selected

Catalogue	Label
☑ All-Sky Compiled	
☑ Bright Star	Yes
☑ Caldwell	
☑ Messier	
☑ NGC	
☑ Tycho II Stellar	

Figure 3 — Saturn and its bright moons in the Field of View display, for an 8-inch telescope with a 27-mm ocular.

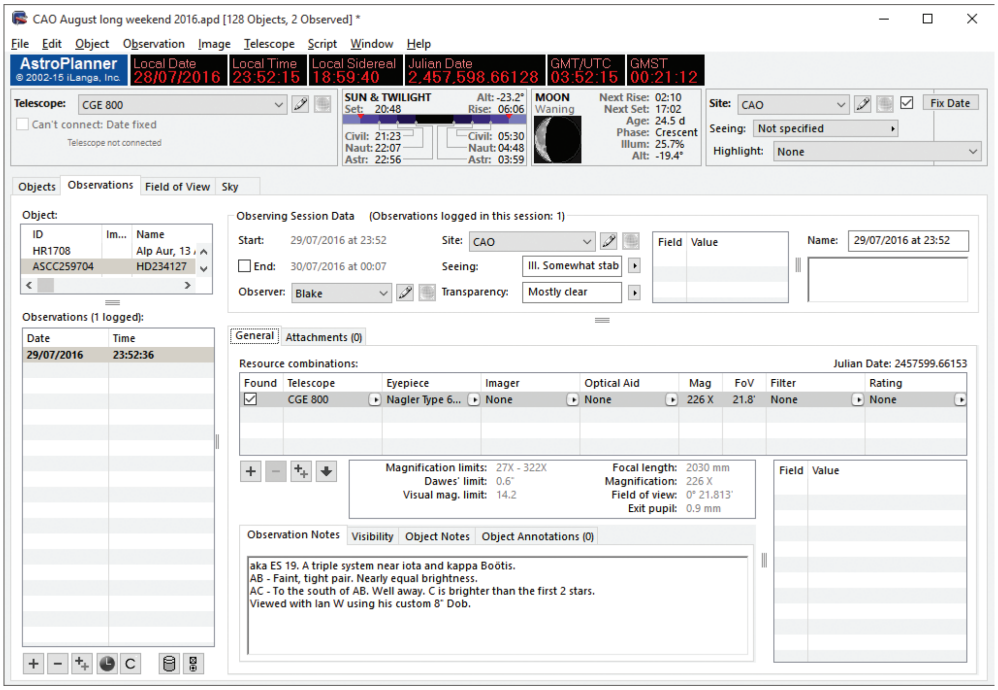
AstroPlanner has four main modes and the tabs or buttons (Objects, Observations, Field of View, and Sky) allow rapid switching.

The Objects mode shows the list of targets. When you select a specific target from the plan, the graphical panels above update. The left-most panel is the Short-Term Visibility Indicator. It plots a path for the selected object with red plus symbols. This panel, centred on midnight, illustrates how the object will rise and fall over the course of the evening. The Moon is noted with yellow discs. If hunting faint fuzzies visually or planning an imaging run, you want the target as high as possible in the darkest times. The best time is shown at the intersection of the vertical and curved purple Observability Value lines.

How an object may be seen over the course of the entire year is gleaned from the Long-Term Visibility Indicator. Again, very helpful when chasing faint and dim objects. The Alt/Az Indicator essentially points to the selected object. If the arrows show as red, the object is not currently visible. Perhaps it has not yet risen over the horizon and should be viewed later.

And, finally, a small Constellation Indicator shows you roughly where your quarry is located. A plethora of columns are available in the tabular area, over 60. You can pick and choose the ones you want to see. Column sets are specific to each observing plan.

Below the table is a button bar to let you perform various actions quickly, like add new objects to the plan, make a Quick Observation, Sort the object List, etc. Again, right-clicking in the table area offers an extensive menu to issue many commands.



Local Date 28/07/2016
Local Time 23:52:15
Local Sidereal 18:59:40
Julian Date 2,457,598.66128
GMT/UTC 03:52:15
GMST 00:21:12

Telescope: CGE 800
☐ Can't connect: Date fixed
Telescope not connected

SUN & TWILIGHT Alt: -23.2°
Set: 20:48 Rise: 06:06
Civil: 21:23 Civil: 05:30
Naut: 22:07 Naut: 04:48
Astr: 22:56 Astr: 03:59

MOON Waning
Next Rise: 02:10
Next Set: 17:02
Age: 24.5 d
Phase: Crescent
Illum: 25.7%
Alt: -19.4°

Site: CAO ☑ Fix Date
Seeing: Not specified
Highlight: None

Object:

ID	Im...	Name
HR1708		Alp Aur, 13 A
ASCC259704		HD234127

Observations (1 logged):

Date	Time
29/07/2016	23:52:36

Observing Session Data (Observations logged in this session: 1)

Start: 29/07/2016 at 23:52
☐ End: 30/07/2016 at 00:07
Observer: Blake
Site: CAO
Seeing: III. Somewhat stab
Transparency: Mostly clear
Name: 29/07/2016 at 23:52

General Attachments (0)

Resource combinations: Julian Date: 2457599.66153

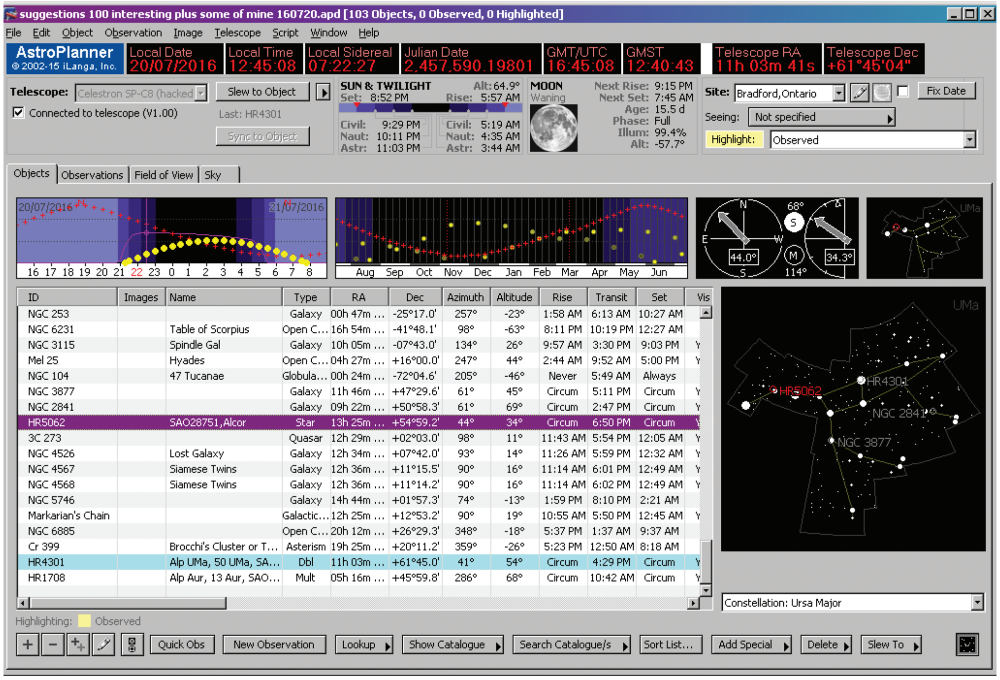
Found	Telescope	Eyepiece	Imager	Optical Aid	Mag	FoV	Filter	Rating
☑	CGE 800	Nagler Type 6...	None	None	226 X	21.8'	None	None

Magnification limits: 27X - 322X
Dawes' limit: 0.6"
Visual mag. limit: 14.2
Focal length: 2030 mm
Magnification: 226 X
Field of view: 0° 21.813'
Exit pupil: 0.9 mm

Observation Notes Visibility Object Notes Object Annotations (0)

aka ES 19. A triple system near iota and kappa Boötis.
AB - Faint, tight pair. Nearly equal brightness.
AC - To the south of AB. Well away. C is brighter than the first 2 stars.
Viewed with Ian W using his custom 8" Dob.

Figure 4 — The Observations tab. Detailed log notes can be captured including data for the session, site, weather, telescope, eyepieces, accessories used, etc.



Local Date 20/07/2016
Local Time 12:45:08
Local Sidereal 07:22:27
Julian Date 2,457,590.19801
GMT/UTC 16:45:08
GMST 12:40:43
Telescope RA 11h 03m 41s
Telescope Dec +61°45'04"

Telescope: Celestron SP-C8 (hacked
☑ Connected to telescope (V1.00)
Slew to Object
Last: HR4301
Sync to Object

SUN & TWILIGHT Alt: 64.9°
Set: 8:52 PM Rise: 5:57 AM
Civil: 9:29 PM Civil: 5:19 AM
Naut: 10:11 PM Naut: 4:35 AM
Astr: 11:03 PM Astr: 3:44 AM

MOON Waning
Next Rise: 9:15 PM
Next Set: 7:45 AM
Age: 15.5 d
Phase: Full
Illum: 99.4%
Alt: -57.7°

Site: Bradford,Ontario ☐ Fix Date
Seeing: Not specified
Highlight: Observed

ID	Images	Name	Type	RA	Dec	Azimuth	Altitude	Rise	Transit	Set	Vis
NGC 253			Galaxy	00h 47m ...	-25°17.0'	257°	-23°	1:58 AM	6:13 AM	10:27 AM	
NGC 6231		Table of Scorpius	Open C...	16h 54m ...	-41°48.1'	98°	-63°	8:11 PM	10:19 PM	12:27 AM	
NGC 3115		Spindle Gal	Galaxy	10h 05m ...	-07°43.0'	134°	26°	9:57 AM	3:30 PM	9:03 PM	Y
Mel 25		Hyades	Open C...	04h 27m ...	+16°00.0'	247°	44°	2:44 AM	9:52 AM	5:00 PM	Y
NGC 104		47 Tucanae	Globula...	00h 24m ...	-72°04.6'	205°	-46°	Never	5:49 AM	Always	
NGC 3877			Galaxy	11h 46m ...	+47°29.6'	61°	45°	Circum	5:11 PM	Circum	Y
NGC 2841			Galaxy	09h 22m ...	+50°58.3'	61°	69°	Circum	2:47 PM	Circum	Y
HR5062		SAO28751,Alcor	Star	13h 25m ...	+54°59.2'	44°	34°	Circum	6:50 PM	Circum	Y
3C 273			Quasar	12h 29m ...	+02°03.0'	98°	11°	11:43 AM	5:54 PM	12:05 AM	Y
NGC 4526		Lost Galaxy	Galaxy	12h 34m ...	+07°42.0'	93°	14°	11:26 AM	5:59 PM	12:32 AM	Y
NGC 4567		Siamese Twins	Galaxy	12h 36m ...	+11°15.5'	90°	16°	11:14 AM	6:01 PM	12:49 AM	Y
NGC 4568		Siamese Twins	Galaxy	12h 36m ...	+11°14.2'	90°	16°	11:14 AM	6:02 PM	12:49 AM	Y
NGC 5746			Galaxy	14h 44m ...	+01°57.3'	74°	-13°	1:59 PM	8:10 PM	2:21 AM	
Markarian's Chain			Galactic...	12h 25m ...	+12°53.2'	90°	19°	10:55 AM	5:50 PM	12:45 AM	Y
NGC 6885			Open C...	20h 12m ...	+26°29.3'	348°	-18°	5:37 PM	1:37 AM	9:37 AM	
Cr 399		Brocchi's Cluster or T...	Asterism	19h 25m ...	+20°11.2'	359°	-26°	5:23 PM	12:50 AM	8:18 AM	
HR4301		Alp UMa, 50 UMa, SA...	Dbl	11h 03m ...	+61°45.0'	41°	54°	Circum	4:29 PM	Circum	Y
HR1708		Alp Aur, 13 Aur, SAO...	Mult	05h 16m ...	+45°59.8'	286°	68°	Circum	10:42 AM	Circum	Y

Constellation: Ursa Major

Highlighting: ▨ Observed

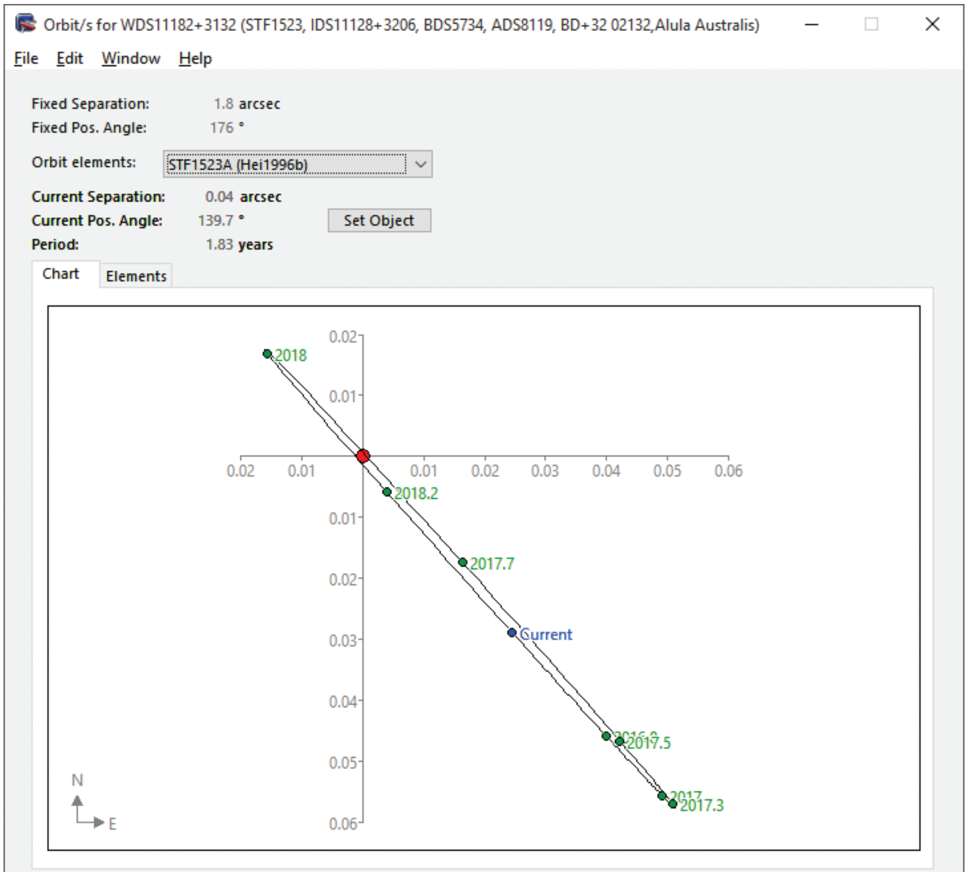
Figure 5 — Driving a Go To telescope from AstroPlanner. *Connected and ready to slew to the next target object.*

Observing plan lists again are easily made. The Plan Creation Wizard can be used to automatically select items from installed catalogues. You can manually add objects, perhaps suggestions from a recent astronomy magazine. Unusual or completely new objects (say a supernova) can be added by specifying the location in the sky. Current comets can be easily appended to a list. Observing plans can be built on one computer and easily copied to another. New plans can be based on others to rapidly copy content. Observing plan files could be shared with fellow users. Lists can be sorted on up to three columns.

The Sky tab (Figure 2) is useful when you want to see a display of the celestial sphere overhead at a particular date and time. Selected objects will appear as fuchsia discs. If you have a custom horizon specified, it will show in green. Various display options can be toggled on or off.

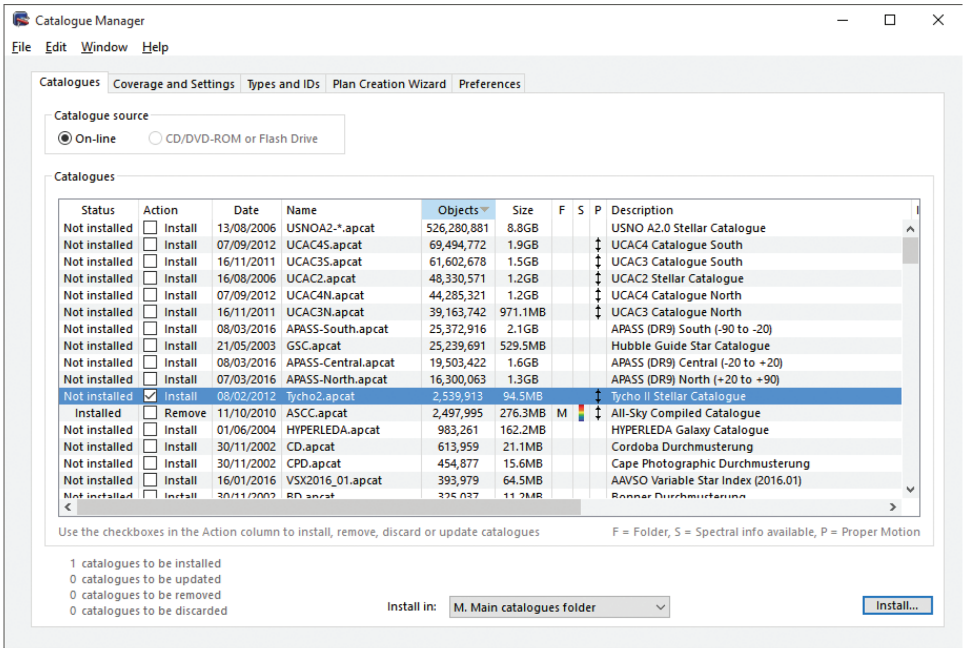
If using *AstroPlanner* at the telescope and you want to verify what you're seeing, or if you're reviewing the previous night's observations, the Field of View mode is extremely useful. On first use, the display shows the selected target in a circular view representing the selected eyepiece, doubler, or reducer, if used, in the designated telescope (Figure 3). Background stars will be displayed from the active catalogues and can be shown in their appropriate spectral colours. Double-star pair data can also be shown. The FOV can be rotated and flipped as needed. You can zoom in and out of this view as well. Proper motion of stars can be shown. The overall display is rudimentary but sufficient.

During an observing session, or perhaps the morning after, viewed objects can be marked or logged. From the bottom of the Objects list, the Quick Obs button can be used to instantly mark the target. For more detailed note-taking, the New Observation button will activate the Observations tab (Figure 4). Data from the session can be recorded along with the conditions and equipment used. Previously captured observations can easily be checked and deleted if necessary. If the Obs column is included in the tabular Objects mode, a number will appear indicating the number of log entries.



Fixed Separation: 1.8 arcsec
Fixed Pos. Angle: 176 °
Orbit elements: STF1523A (Hei1996b)
Current Separation: 0.04 arcsec
Current Pos. Angle: 139.7 °
Period: 1.83 years

Figure 6 — The Show Orbits command for double stars with known orbital element data shows a plot window.



Catalogue source

● On-line ○ CD/DVD-ROM or Flash Drive

Catalogues

Status	Action	Date	Name	Objects	Size	F	S	P	Description
Not installed	☐ Install	13/08/2006	USNOA2-*.apcat	526,280,881	8.8GB				USNO A2.0 Stellar Catalogue
Not installed	☐ Install	07/09/2012	UCAC4S.apcat	69,494,772	1.9GB			↕	UCAC4 Catalogue South
Not installed	☐ Install	16/11/2011	UCAC3S.apcat	61,602,678	1.5GB			↕	UCAC3 Catalogue South
Not installed	☐ Install	16/08/2006	UCAC2.apcat	48,330,571	1.2GB			↕	UCAC2 Stellar Catalogue
Not installed	☐ Install	07/09/2012	UCAC4N.apcat	44,285,321	1.2GB			↕	UCAC4 Catalogue North
Not installed	☐ Install	16/11/2011	UCAC3N.apcat	39,163,742	971.1MB			↕	UCAC3 Catalogue North
Not installed	☐ Install	08/03/2016	APASS-South.apcat	25,372,916	2.1GB				APASS (DR9) South (-90 to -20)
Not installed	☐ Install	21/05/2003	GSC.apcat	25,239,691	529.5MB				Hubble Guide Star Catalogue
Not installed	☐ Install	08/03/2016	APASS-Central.apcat	19,503,422	1.6GB				APASS (DR9) Central (-20 to +20)
Not installed	☐ Install	07/03/2016	APASS-North.apcat	16,300,063	1.3GB				APASS (DR9) North (+20 to +90)
Not installed	☑ Install	08/02/2012	Tycho2.apcat	2,539,913	94.5MB			↕	Tycho II Stellar Catalogue
Installed	☐ Remove	11/10/2010	ASCC.apcat	2,497,995	276.3MB	M	▮	↕	All-Sky Compiled Catalogue
Not installed	☐ Install	01/06/2004	HYPERLEDA.apcat	983,261	162.2MB				HYPERLEDA Galaxy Catalogue
Not installed	☐ Install	30/11/2002	CD.apcat	613,959	21.1MB				Cordoba Durchmusterung
Not installed	☐ Install	30/11/2002	CPD.apcat	454,877	15.6MB				Cape Photographic Durchmusterung
Not installed	☐ Install	16/01/2016	VSX2016_01.apcat	393,979	64.5MB				AAVSO Variable Star Index (2016.01)
Not installed	☐ Install	30/11/2002	BD.apcat	325,037	11.2MB				Bonner Durchmusterung

Use the checkboxes in the Action column to install, remove, discard or update catalogues

F = Folder, S = Spectral info available, P = Proper Motion

1 catalogues to be installed
0 catalogues to be updated
0 catalogues to be removed
0 catalogues to be discarded

Install in: M. Main catalogues folder

Figure 7 — The Catalogue Manager window. Many objects databases can be downloaded from this screen. The Coverage and Settings tab shows a visual mapping of all the elements.

These are the main features of *AstroPlanner* and you can see it is very capable. Still, this is just scratching the surface of this application. It is very rich and powerful and would take a user some time to explore and utilize all of its feature set.

I briefly tested the telescope control capability with my hacked Celestron/Vixen Super Polaris mount (Figure 5). It worked as expected, allowing me to quickly get to the next target object from my observing plan.

It took a little while for me to unlock some of the double-star capabilities in the app, mostly because I was used to a different approach or method. I was pleased to find the orbital diagram chart (Figure 6) to help gauge the split-ability in binary systems. The Lord's Rating feature I thought very interesting.

I briefly explored the catalogues available to *AstroPlanner*. Through the Catalogue Manager, I loaded a number of databases (Figure 7). This seems most impressive with a large number of catalogues available to the user suiting various needs and demands. I like the idea that you can load in what you want and ignore others. Note that the very large catalogues (generally 1 GB and larger) cannot be downloaded through the Internet; you must obtain the data via optical disc or USB drive. If you have a big aperture, perhaps you'll want the US Naval Office A2.0 list. When catalogues are updated (say the Washington Double Star Neglected Doubles), they appear in green to catch your eye.

I quickly tested the export option building an observing list in *AstroPlanner*, which I transferred to my *SkySafari* app on my Android. One or two items aside, it worked fine.

There were many features I did not try. The most intriguing is the ability to interconnect *AstroPlanner* to a full planetarium application, like *Cartes du Ciel*. That should offer better charting features. I did not try to find-objects-within-a-certain-radius. That would be neat when just casually exploring.

So, like other astronomy planning software, *AstroPlanner* proves itself robust for the user looking to plan observing sessions or imaging runs in advance, drive a Go To telescope, split double stars, identify faint galaxies and dim moons, and log what he or she has visited.

AstroPlanner 2.2 can be downloaded for free from www.AstroPlanner.net and operated as an unregistered user. A great way to try before you buy. Some features are restricted or disabled. You can buy a licence for USD $45 to fully unlock the software. If you want some of the large stellar catalogues, you can buy the licence plus hard media for $65 or $70. Additional fees are applicable for the very largest catalogues. Funds may be processed with PayPal to get up and running quickly.

Learning the app can be accomplished via the aforementioned user guides. The abbreviated guide has a very good follow-along section for setting up the software. The website has a Frequently Asked Questions section for tips and tricks. There is a Yahoo!Group where users assist one another and share files. There seems to be a large community of ardent fans. The author Paul Rodman of iLanga was fairly quick to answer my questions.

The software worked well for me in general. That said, being an advanced double-star observer, I struggled with the display of components for multi-star systems. I was mildly irked that I could not hide or filter out items from a list, say, those not currently visible; through the Highlighting feature I was able to draw attention to visible objects. The IDs and Names for objects are very curious in some cases (but I believe it is a challenging situation overall). The screen redrawing on both the Windows and Mac computers was sometimes jumpy and distracting. Red night mode on Windows does not work the way I expected with many of the screen elements still showing in white; it worked nicely on the Mac turning the entire screen (and all other apps) red. I did encounter one or two severe errors and crashes but did not lose any data (there are, importantly, auto-save and backup features that one should use to avoid painful lessons).

Astronomy planning-session software is a different approach perhaps but for me it is the way I like to work. If I don't have a list of targets ahead of me, I end up looking at the same things over and over. Generally, I want to see new stuff. And I want to go deeper, see more challenging objects, push myself, explore off the beaten track. Of late, I've taken to visually observing quasars, particularly ones with high red-shift values. These are extreme objects, very dim, and even with the aid of a Go To mount, still require well-developed star hopping and field identification techniques to tag the target. I love viewing multi-star systems, identifying not just the primary A star and the B companion, but all the other components, which sometimes number a dozen or more. I'm finding planning software increasingly helpful as I undertake more astrophotography projects. Specifically, I want to try to shoot when the target is highest in a dark sky. And then, when I'm all done, I like to note all the confirmed sightings as logged, so to support my next session. If you're looking for a good software solution to better plan your observing or imaging sessions, *AstroPlanner* is a very good option. If you have a Mac, it might be your only choice.

Update Bits

Stellarium, the popular Windows, Mac, Linux planetarium application was updated recently. The latest version is 0.15.0. Changes include new sky cultures (e.g. Ojibwe), initial support for the Washington Double Star data, and updates and improvements to the deep-sky and star catalogues. ✶

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.

Dish on the Cosmos

The Snow Line

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

As you rattle off the planets in order of distance from the Sun, it becomes clear there are two main groups of planets. The terrestrial planets—Mercury, Venus, Earth, and Mars—are small and rocky with high densities, about five times that of water. The Jovian planets—Jupiter, Saturn, Uranus, and Neptune are significantly larger than the terrestrials but with much lower density (comparable to water). These big differences are because of their compositions: the terrestrial planets are rocky, but the Jovian planets are made mostly of gases. Compared to the Universe, the terrestrial planets are chemically strange since they are made of rare elements like silicon, iron, and oxygen. The Jovian planets are much more typical of the Universe's chemistry: hydrogen, helium, and the compounds of hydrogen with the next most common elements (water, methane, and ammonia). This raises the immediate question: why are there two types of planets?

Our best answer lies in our understanding of the origins of our Solar System. The Sun and planets formed from a disk of material. The disk is the physical consequence of needing to channel matter onto the forming proto-Sun, and planets form within that disk as a by-product of star formation. The disk is warm near the star and gets cooler as it fades off into interstellar space. The theory holds that somewhere between the current orbits of Mars and Jupiter, the temperature of the disk reached the conditions where water and other ices could form, dropping below about 100 K, or −173 °C. Note that the freezing point of water is much lower in the low-pressure conditions of the protoplanetary disk. Inside this *snow line*, the water was in a vapour, and mixed through the disk. Outside the snow line, the water freezes onto small grains of rocks and metal, called *dust*. This tiny difference is thought to regulate which planets form where in the Solar System because these dust grains are the seeds of planet formation. Dust grains grow by sticking to each other into progressively larger objects. Grain growth poses some unanswered questions including answering how two pieces of what is basically gravel can stick to each other to make a larger rock. The gravel is too large for surface forces to cause sticking and too small for gravity to matter. Still, there are some good suggestions to work beyond this barrier, but they remain untested.

In the inner Solar System, the seed dust grains just contain the rocks and metals. In the outer Solar System, however, the added ice causes the grains to be about three times more massive and stickier. This makes larger seeds for planet formation. The seeds have enough gravity to capture more than just the rocks and metals that the inner planets form from. They capture the rocks, metals, and ices. The seeds also have enough gravity to pull in matter that is still in a gaseous state, including the hydrogen and helium gas that hold 98% of the nebula's mass. Planet formation is a phenomenon where the rich get richer: more massive planets exert a stronger gravitational pull allowing them to pull in more mass. The Jovian planets beyond the snow line gather up much more material, including a lot of the gases. The build-up runs away until the gas of the disk is depleted and winds from the newly forming Sun clears the remainder of the gas and dust from the disk. This theory explains the size and locations of the terrestrial and Jovian planets as well as their composition. At its heart is the location of the snow line.

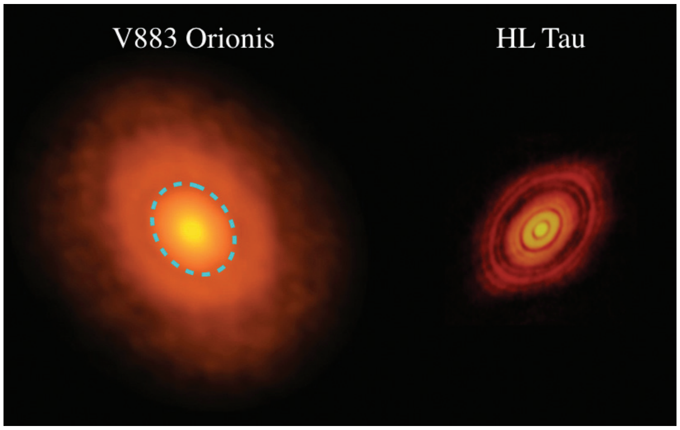


Figure 1 — ALMA image of dust in the V883 Orionis system compared to a similar ALMA image made of the HL Tauri system on a matched physical scale. In contrast with HL Tauri, the V883 Orionis system has a bright central feature and no signs of the lanes of planet formation present. The slightly darker region outside the bright central peak is the signature of the snow line, highlighted with the dashed ellipse. The image for HL Tauri appears sharper because the system is closer and was observed for longer with ALMA. Image Credit: L. Cieza, C Brogan, et al.; ALMA (ESO/NAOJ/NRAO)

We cannot look back in time to see our own Solar System forming, but in looking around the neighbourhood, we can see other planetary systems forming right now to gain clues about our origins. A new tool in our kit is the Atacama Large Millimetre/submillimetre Array (ALMA), which can image these protoplanetary disks at high resolution, looking for the snow line. The key physical process that allows this is the change in the dust-grain properties associated with the snow line. Inside the snow line, the matter is in smaller grains, which absorb and re-emit light more effectively than large grains. To give some intuition, think about how well a clod of dirt on a car's windshield blocks light. It is quite effective at blocking light for a small area but most of the light gets through. If that clod is smeared out it can block a far larger fraction of the light coming through. The dust grains are operating on the same principle: if the mass blocking the light is spread out into smaller grains, it can block more light. Dust absorbs the light and then heats up, re-emitting the light at the long wavelengths for which ALMA is most sensitive. The disks inside the snow line should be much brighter than the disks outside the snow line.

This should be a hard measurement to make. For stars like the Sun, the snow line should be on the scale of Mars's orbit.

Unfortunately, the most active star-forming regions are over 1500 light-years away, meaning that the telescope resolution needed to see this line is 0.01 arcseconds, better than *Hubble* at its best. ALMA is an interferometer, meaning that it can use wider separations between its component dishes to achieve this resolution, but at the cost of sensitivity. This is challenging in ALMA's early days, so astronomers have turned to a peculiar system for more insight. The forming star system V883 Orionis showed a forming disk of material around the central star with an exceptionally bright spot in the centre (Figure 1). The disk had the tell-tale features of a snow line but the size was much larger than expected: roughly the size of Pluto's orbit.

Why would the snow line be 15 times farther out in the disk that our initial prediction? The research team hit upon an important idea: stars form by *accreting* matter. This accretion is not steady and many protostars are observed to undergo flaring, where their brightness spikes up suddenly because of a sudden burst of accretion. The energy from the flare is the energy liberated by the material falling onto the surface of the star. When this energy hits the disk, it could possibly melt the ice off dust grains and push the snow line out much farther from the protostar. The team conjectures that V883 Orionis is undergoing such a flare leading to the bright inner region with small dust grains. In fact, the clue is in the name: the V designation indicates the star is optically variable.

This discovery was important for two main reasons. First, it showed that the water snow line existed in systems and we could see it under particular circumstances. The theory of our Solar System formation was supported by this idea. Second, the flare showed that the snow line can move around, which is a complication that was not considered in the static model that we had previously considered. How does this affect planet formation if the planetary seeds get changed suddenly in the formation process? Will that lead to no planet formation? Or all terrestrials? Or other systems very different from our own? By exploring more systems and understanding how common this phenomenon is, we will be able to place our own Solar System into context. ✶

Read the details: http://arxiv.org/abs/1607.03757

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.

Skyward

Of Friendships and Mentors and Favourite Telescopes

by David Levy, Montréal and Kingston Centres

When I wrote recently about the many advantages to meeting other people who enjoy the sky, it is possible that the people I left out were even more important than those included. One of those people was Rolf Meier, an amateur astronomer from Ottawa, Ontario, who passed away recently after a brief bout with cancer at the young age of 63. It is difficult to overstate the effect that his wisdom had on my own development as an astronomer.

Rolf was born in Germany in 1953 but relocated to Canada when he was about five. He became interested in astronomy after reading *The Search for Planet X* about how Clyde Tombaugh discovered Pluto. Rolf joined the Ottawa Centre of The Royal Astronomical Society of Canada in the early 1970s. In 1972, he travelled to Florida where he witnessed the spectacular launch of a mighty Saturn V rocket that carried geologist Harrison Schmidt, as well as astronauts Eugene Cernan, and Ronald Evans, on the final Moon flight.

I wish I could have joined him to see that launch, but I actually didn't meet Rolf until the RASC's General Assembly, held in London, Ontario, in 1979. At that meeting, Rolf was the 15th recipient of the Society's Chant Medal. Named for Clarence Augustus Chant, this solid silver medal honours an amateur astronomer resident in Canada for a lifetime of achievements: in Rolf's case, it honoured him for the work he did as the long-time editor of the Centre's newsletter *Astro Notes*, for being president of the Centre, for developing an original astronomical device for measuring light called a photometer, and for his designs for unique and original telescopes. But more than any of that, the medal commemorated the hours upon hours of observing he did, culminating in his discovery of a comet the previous spring. Comet Meier—then designated as 1978f and now C/1978 H1—remains one of the largest comets ever found. Two of his telescopes received awards at the Stellafane national convention held annually in Vermont.

Figure 1 — Rolf Meier with wife Linda McRae

Figure 2 — Wendy Levy with Echo

At the time, I was well into my own, and thus far, unsuccessful search for comets, and I despaired of ever meeting the famous cometeer. After the banquet at which he received his award, I saw him walking across the campus grounds toward his dormitory. Carrying his award, surrounded on one side by five gorgeous young women and on the other side by another five equally gorgeous young women, I simply assumed that he was too famous to deal with the likes of me.

Not one to give up after one success, Rolf continued his search, and he discovered a second comet (Meier, C/1979 S1). There was a third comet Meier (C/1980 V1) and a fourth (Meier, C/1984 S1). By this time, Rolf and I were good friends, a friendship that became ever closer after his marriage to Linda McRae in July 1984. Early in 1985, he set up his camera about a mile south of my home, then in Corona de Tucson. While I had a camera set up at my home, we both tried to photograph bright meteors. It turned out that we both captured the same bright meteor travelling through the constellation of Leo, The Lion, and Rolf even used trigonometry to try to calculate the height of the meteor above the Earth as it disintegrated.

Rolf and Linda had just completed their winter home at the Arizona Sky Village, a place where they and their son Matthew and daughter-in-law Melissa could visit and where we had hoped to visit them in the future, when he received his shattering cancer diagnosis. What we have left are many fond memories, and of course we can watch as he finds his new way among his four comets, all of which will bear with pride the name Meier as they sail through the Solar System.

What is your favourite telescope?

What is the best telescope in the world to use while viewing the night sky? For most of us, I believe the answer would be the *Hubble Space Telescope*. Since its launch in 1990, and its successful repair in 1993, *Hubble* has provided the majority of beautiful images of stars, galaxies, clusters of galaxies, and almost everything we find wonderful to gaze at in the night sky. I am not an exception to this general rule: the images that *Hubble* returned to Earth of the impacts of the Comet Shoemaker-Levy 9 during its impact with Jupiter in 1994 were absolutely breathtaking. I cannot deny that. And soon, the Large Synoptic Survey telescope (LSST), with an eight-metre mirror and a field-of-view covering six Moon diameters, will send us pictures of a sky we know almost nothing about. So shouldn't one of these be my favourite telescope? They surely would be, if only I could have looked through them.

Neither the LSST nor *Hubble* are my favourites. If they aren't, then what is? My own favourite is a tiny 3.5-inch diameter telescope with a black tube that I've owned for more than half a century. Echo (this telescope's name) does not have the aperture or the power to spot anything other than the brightest objects in the sky. But because it gave me my very first telescopic view of Jupiter, and inspired me to go into astronomy, it therefore is my favourite telescope.

I have had my eye on the sky since the warm, clear evening of 1956 July 4, when I saw a shooting star appear out of the darkness that summer evening and scoot across a stretch of sky until it disappeared near the star Vega. (I assume that it was Vega since that is the brightest star in the summer sky and this particular shooting star was heading toward that bright star.) By the summer of 1960, as I recovered from a broken arm sustained in a bicycle-riding accident, I really thought that I would like to see the night sky through a telescope—any telescope. *Hubble*, and the LSST, were not even a gleam in anyone's eye at the time. On the afternoon of 1960 September 1, my uncle stopped by our home and brought out a box containing a Bar Mitzvah present from him and my parents. Inside the box lay Echo.

A few hours later, I carefully set the telescope up in our garden. I noticed that, between two trees in the southern part of our lawn, were two rather bright objects, and I decided to set the telescope up on the brighter of the two. Carefully centring the object in the middle of the finder telescope, I then looked through the eyepiece. I saw what looked like a doughnut of light, complete with a hole in the middle. What was wrong with my new telescope? By playing with it a little, I learned a lot about telescopes in the next few minutes. The most important thing was that by sliding the eyepiece up and down the doughnut appeared to get either larger or smaller. As I continued to adjust the eyepiece, the doughnut shrunk in size until the hole in the middle disappeared. Almost miraculously, the light in the telescope became the mighty planet Jupiter. What's more, I saw markings on Jupiter, and three star-like dots nearby that I later learned were Jupiter's moons.

Were I growing up in today's culture, the experience from so long ago might have meant nothing. We now have spacecraft that are studying Jupiter at close range, as if we knocked on the front door and Jupiter invited us in. But as amazing as these spacecraft are, nothing can take away from actually looking through a telescope and seeing something in the sky for yourself. In future years, I expanded my collection of telescopes, and I tried to begin the career of each new telescope with a look at my favourite planet Jupiter.

Both Echo and Jupiter are very special to me. Echo now holds a place of honour inside my home. Although I rarely use this telescope, the views it provides are still thrilling. And in 1993, Gene and Carolyn Shoemaker and I discovered a comet which, a year later, slammed directly into that planet. Now, from our home in Vail, a lovely 14-inch Meade telescope called Voyager shows young people the night sky at the Corona Foothills Middle School. It could be someone's favourite telescope. Despite the amazing telescopes that are available now to all of us, it still seems to me that our favourite telescopes are the ones we first looked through, the ones that inspired us to reach for the stars. ✶

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

John Percy's Universe

The Astronomy of Civilizations Past

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

Astronomy is deeply rooted in almost every civilization. The sky has always been both useful and mysterious. It has been used as a clock, calendar, and compass, and consequently become part of spirituality and ceremony, as it still is today in many cultures. If the civilization in question has left written records, then astronomy is simply part of their recorded history. Otherwise, the study of their astronomy is more difficult, and becomes part of the discipline called *archaeoastronomy* or, sometimes, *cultural astronomy*. According to R.M. Sinclair[1], it is "the study of how people in the past have understood phenomena in the sky, how they used these phenomena, and what role the sky played in their cultures." Archaeoastronomy being in its infancy, Sinclair's definition is not universally accepted. The International Astronomical Union has recently created a Working Group on Archaeoastronomy and Astronomy in Culture, with 35 members (so far), so the field is certainly a legitimate one.

By its nature, archaeoastronomy relies on varied, indirect, and incomplete information. The old tale of "the wise men and the elephant" reminds us that, if scholars with narrow expertise consider only their own fragments of what's known, they may come up with very different interpretations. Progress requires an interdisciplinary approach: archaeology, anthropology, ethnology, history, geography, engineering, surveying, as well as astronomy. Clive Ruggles, a noted archaeoastronomer at the University of Leicester, described his field as one with "academic work of high quality at one end, but uncontrolled speculation bordering on lunacy at the other." For instance: archaeoastronomy was popularized by astronomer Gerald S. Hawkins in his 1965 book *Stonehenge Decoded*, which is now regarded as an over-interpretation, and a bit too New Age. Then there are the breathless books and documentaries by Erich von Daniken, an accused plagiarizer and convicted embezzler and fraud who attributed the wonders of the ancient world to space aliens. One problem is that few scholars—especially scientists—are exposed to non-Western history, culture, or language, so the great civilizations of the past—other than perhaps the Greek and Roman—may seem foreign and mysterious to them.

The Sky as a Cultural Resource

We know that pre-technological cultures observed the sky, kept records in some form, used the sky for practical purposes, and passed on their knowledge to subsequent generations. Girl Guides and Boy Scouts learn how to use the North Star as a compass at night. The Sun is due south (or north) at noon, when highest in the sky. The belt of Orion rises and sets due east-west, and was used as a compass by seafaring Polynesians, along with other clues from their environment. The Sun marks the passing of time by day; we still have sundials today. The progress of the seasons can be measured by the constellations visible at night, by the changing rising and setting points of the Sun on the horizon, or by its height at noon. This information was once essential for agriculture and hunting, or simply for having a "climate forecast" for everyday life. The Moon was important also, both because of its connection with the tides, and because it provided light at night.

This knowledge was so important that it became part of the culture's spirituality. Astronomy was necessary to set the dates and times of religious ceremonies. This was done in various ways, and we still experience this variation today when we compare the calendars and times of celebration of the New Year by Christians, Jews, Muslims, etc. The sky was so important and mysterious that celestial objects became connected with the gods; witness the two meanings of the term "heavens" today. This led to astrology, which is unfortunately still with us. Egyptians, among others, oriented their temples and tombs with the cardinal points of the compass, to connect life and afterlife. The custom of aligning churches and burials east-west persisted for centuries, in many cultures. Earlier this summer, I attended a christening service in which west was associated with Satan, and east with the Saviour.

Sky phenomena are latitude-dependent. In the Arctic, sky motions are nearly parallel to the horizon. MacDonald (1998) explains how these were used and interpreted by the Inuit. In tropical latitudes, the Sun can appear directly overhead, and these "zenith passages" are an important part of tropical archaeoastronomy—in Mexico and Central America, for instance.

Furthermore: the dark night sky—which is now inaccessible to most of us—was a source of wonder and mystery. Almost every culture had a different story about the Milky Way and, for northern cultures, about the aurora. Unexpected events such as comets and eclipses were omens of disaster. Each civilization wrote their stories in the sky, in the form of constellations whose names and nature are culturally determined. The Pleiades—Matariki in the Maori language—figures prominently in Maori season-keeping and navigation. Its rising marks the Maori New Year, which is now a major festival in New Zealand. The Pleiades is likewise prominent in Australian Aboriginal astronomy.

When did astronomy begin? We know that, to guide their migration, some species—some birds, for instance—navigate by the Sun, or by the Earth's magnetic field. Does this count? The "Blanchard bone," from France ca. 25-32,000 BC, has been interpreted as a two-month Moon calendar, because it

Figure 1 — The medicine wheel in Bighorn National Forest in Wyoming is the prototype of dozens of such structures across the western US and Canada. The lines joining the cairns may be aligned with the rising points of the Sun and a few bright stars. Photo: US National Forest Service.

has dozens of Moon-shaped tallies on it. Symbols on the walls of the Lascaux Cave, also in France, ca. 16,500 BC, have been interpreted as stars. But that's *our* interpretation; the artists are not around to confirm it.

In Canada, we think of our astronomical heritage as being rather recent, but Aboriginal peoples have been here for over 12,000 years (Williamson 2008). We strongly suspect, from archaeological and ethnological evidence, that astronomy has been part of their culture for a very long time.

A Few Notable Archaeoastronomical Sites

Chaco Canyon. This dense collection of buildings in New Mexico is the major centre of Pueblo culture, ca. AD 900–1150. Many of the buildings have been claimed to have astronomical alignments. The most famous is the "sun dagger" of Farada Butte, in which a narrow shaft of sunlight illuminates markers on the solstices and equinoxes.

Chichen Itza. This Mayan city on the Yucatan Peninsula, ca. AD 600-1200, contains at least two buildings for which astronomical alignments have been claimed. The Mayans were fixated on time, both Sun time and the 260-day cycle of visibility of Venus (remember the "Mayan non-apocalypse" of 2012 December 21?), and this is apparent from the few codices or documents that survived the Spanish Conquest.

The Great Pyramid and Sphinx of Egypt (ca. 2500 BC), at Giza outside Cairo are part of a complex of tombs and temples, aligned in a NSEW direction. A passageway into the Great Pyramid may be aligned with Thuban, the Pole Star at the time of its construction.

Medicine Wheel National Historical Landmark (previously Bighorn Medicine Wheel) in Wyoming (Figure 1) is the prototype of about a hundred such structures in western US and Canada. The ceremonial significance of this 25-metre circle of stones with radiating lines and cairns, on a 3000-metre mountain top, is consistent with ethnographic information. Alignments with the rising and setting points of the Sun and a few bright stars have been studied, mainly through the work of astronomer John Eddy (1974).

Nazca. On the plains of Nazca, in Peru, there are thousands of gigantic animal figures and long, straight lines, covering 1000 km^2. formed in the desert by sweeping aside the stones and exposing the bare sand. The lines have been interpreted as astronomical alignments, but are more likely ritualistic—but perhaps initially based on the sky. Von Daniken claimed that the lines were airstrips for alien spacecraft—a bizarre interpretation.

Newgrange, ca. 3300–2900 BC, is a large passage tomb in Ireland, covering 4000 m^2 Around winter solstice, sunlight shines into the tomb through an aperture above the door, which appears to have been purpose-built.

Stonehenge, ca. 3000–2000 BC, is perhaps the most famous archaeoastronomical site. It is aligned with the midsummer sunrise (or the midwinter sunset). Many other alignments with Sun or moonrise or set have been claimed, but not widely accepted. Stonehenge is part of a much larger complex of structures, which appear to have been constructed for ceremonies honouring the dead.

Chinese, Indian, and Islamic Astronomy

These astronomies do not count as archaeoastronomy, because these civilizations have left us a rich written record, but they are often under appreciated. Much of their astronomy was motivated by their astrology, but this was also the case with "Western" astronomy. It is useful and sobering to remember their astronomical achievements when the Western world was in the "Dark Ages," and before. The Chinese developed science and technology 5000 years ago. They were especially interested in observing and recording both expected and unexpected sky events, and their records are still valuable to astronomers today. Indian astronomers have been active for over 2000 years, contributing to mathematics, acting as links between other great civilizations, and building the magnificent observatories that tourists still wonder at today. Islamic astronomers preserved knowledge from Classical times, contributed to the development of mathematics, and built and used astronomical instruments, culminating in the observatory of Ulugh Beg (1394–1449) in Samarkand—the greatest observatory before Tycho Brahe's time.

In summary: sky watching has pervaded almost every culture Many of them devoted great effort and expense to the observational and/or ritualistic aspects of the sky. Unfortunately, much of the knowledge about them is incomplete, or misinterpreted, or lost forever. Further progress requires an interdisciplinary approach. In the meantime, archaeoastronomy remains a fascinating but challenging topic.

This article only skims the surface. For further information: beware search engines that take you to pseudoscience like Von Daniken. Clive Ruggles (www.cliveruggles.net) is one of the most respected people in the field. Recent books by physicist and archaeoastronomer Giulio Magli (2009, 2015) have been well reviewed. You can start with *wikipedia*. ✶

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

Notes

1. As quoted in *wikipedia*

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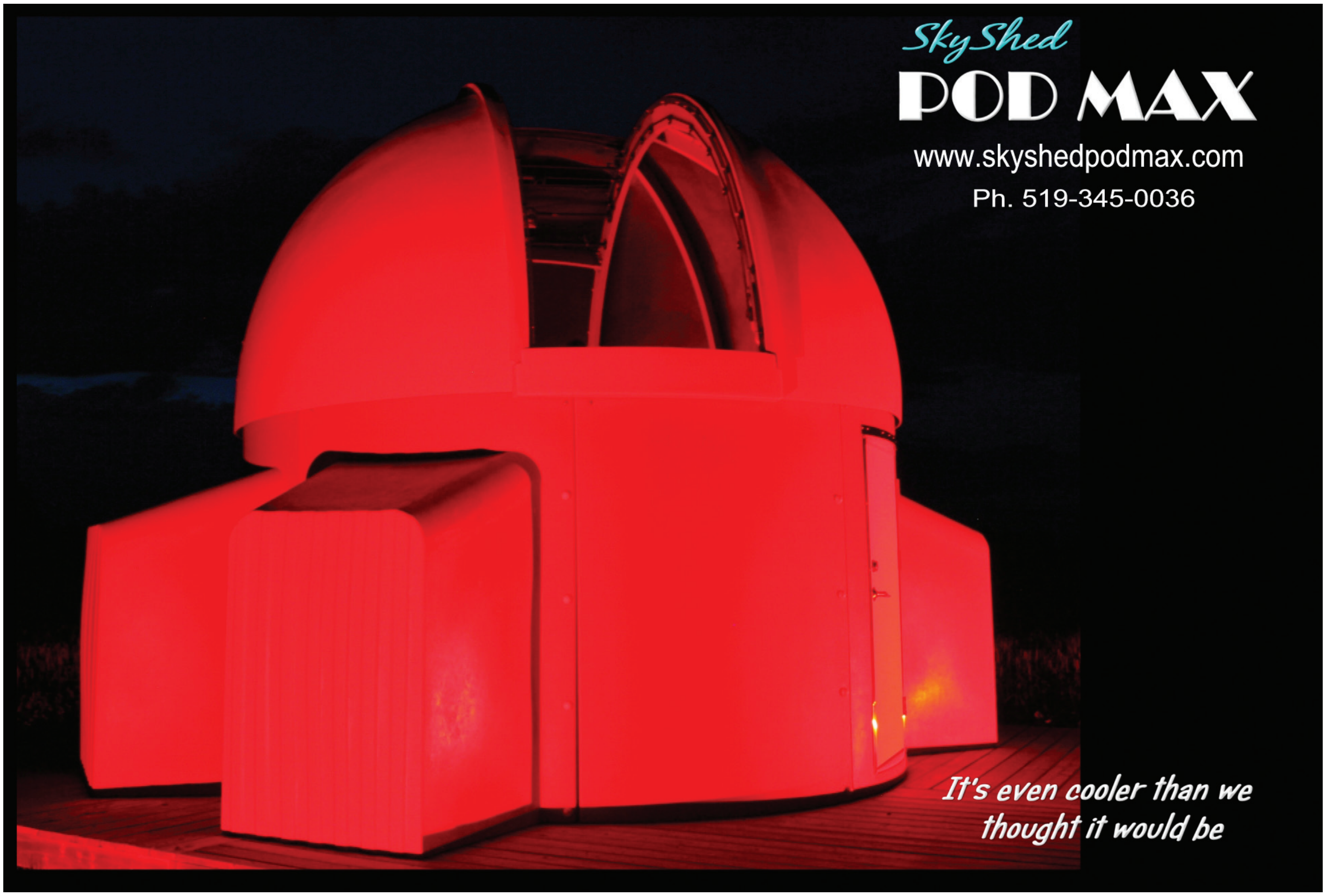


Second Light

A Heat Pump on Jupiter

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

You might not have heard about it, but there is an "energy crisis" on the giant planets. Their upper atmospheres—where we can directly measure the temperatures—are warmer than can be explained by solar heating. In Jupiter's case, in low to mid latitudes, the imbalance amounts to about 600 kelvin (K). Observations show the temperature to be about 800 K, when the equilibrium temperature with only solar heating should be 200 K. Previous explanations for the imbalance have all failed. Now James O'Donoghue of Boston University and his collaborators have found a new source of energy (see the 2016 August 18 issue of *Nature*). The north side of Jupiter's great red spot is at a temperature of 1600 K—hotter than anywhere else on the planet. It seems that energy is being pumped from the lower atmosphere to the upper, which may help to resolve the energy crisis.

The problem of Jupiter's warm upper atmosphere has been with us since 1973. For a while it was believed that auroral heating could explain the high temperature, but it turns out that auroral heating is confined to the polar regions, and there is no way to distribute the energy to lower latitudes. Gravity waves carrying energy from the lower atmosphere do not work. Acoustic waves above thunderstorms have been observed to heat Earth's thermosphere, but such waves have not been seen at Jupiter, though in theory they could provide some heat.

O'Donoghue and his collaborators observed the infrared emission lines of the ion H_3^+, using NASA's Infrared Telescope Facility on Mauna Kea. The ion is abundant in Jupiter's ionosphere. There are six H_3^+ emission lines within the wavelength range of the instrument, and the temperature can be calculated based upon the intensities of the lines and knowledge of the rotational-vibrational properties of the molecule. The so-called branching ratios are sensitive to temperature.

O'Donoghue observed Jupiter for 9 hours, which means that he got spectra covering most longitudes, as Jupiter's day is 9 hours and 56 minutes. He found that the temperature was ~1000 K over all latitudes, with some variation, except on the northeast side of the Great Red Spot, where it was about 1650 K. The south side of the spot is at the average temperature, as is the northwest side. So heat is welling up through the spot and pouring into Jupiter's atmosphere through the northwest side. O'Donoghue concludes that storm-enhanced turbulence, arising from the different velocities of the atmosphere inside the storm (which are roughly circular), and outside (which are mostly east-west). The largest difference in velocity is on the north side of the spot.

The spot is in the troposphere, with the cloud tops reaching an altitude of about 50 km. The H_3^+ layer is at an altitude of about 850 km. So the heat has to travel vertically. O'Donoghue concludes that some of the waves arising from the turbulence travel upwards, heating the atmosphere on the way.

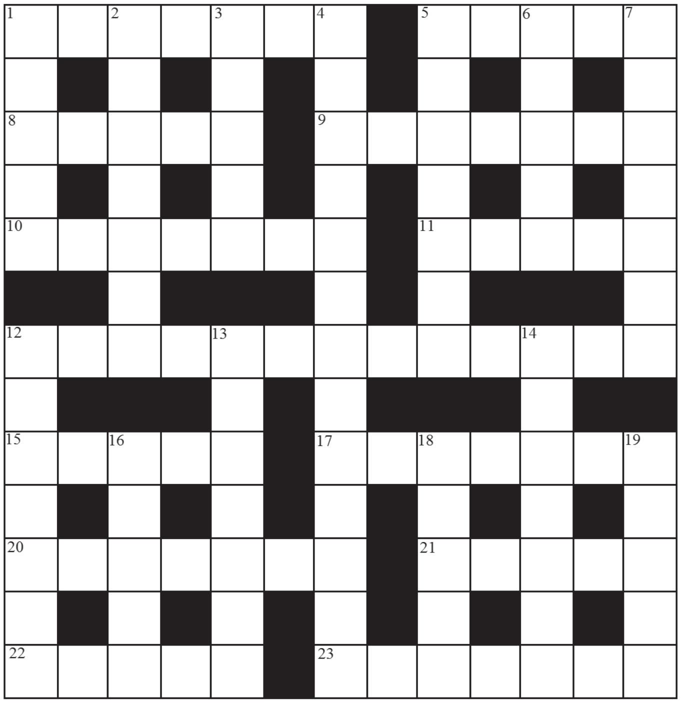
Why has this not been seen before? The bottom line appears to be that no one actually looked. Only one previous map of H_3^+ temperatures including the Great Red Spot had previously been made, and in that study no particular mention was made of the spot. O'Donoghue looked at the old map and concludes that the temperature was elevated, but not by anywhere near as much as in his work. But the earlier study had significantly poorer spatial resolution, and as the heat source seems to be quite localized, it seems reasonable to conclude that the signal was simply washed out.

On Earth, hurricanes pump energy from the warm ocean into the cold atmosphere. So perhaps the Great Red Spot is more like a hurricane than a giant thunderstorm. Something to think about the next time you point your telescope at Jupiter. ✶

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

Astrocryptic

by Curt Nason



ACROSS

1. Barely resolved galaxy where you can camp out in a cot (7)
5. Basin impacted from age-old rhythm in astronomy (5)
8. Old constellation satisfies a silly question for the audience (5)
9. His cluster is popular with closet astronomers (7)
10. The greatest father to the east simply measured altitudes (7)
11. Get the answer by splitting Antares again (5)
12. Sun, Moon, and a tiger reformed his Latin version of Almagest (13)
15. Traffic jam reminiscent of Boötes (3-2)
17. Solar effect reflects off Eurasian mountains and pre-1950's satellites (7)
20. Racy spin around the origin of Venus (7)
21. NIGHTScapes and TIMELapses, e.g. gave Kobo a turn after Easter (5)
22. Many are spent at ESA facilities (5)
23. Rival star of mass extinction theory (7)

DOWN

1. Dog star leaves church at the altar (5)
2. Mass problem for the space station with expensive vase around (7)
3. It's in a triangle. Yes it is. (5)
4. Lacaille's peak is set in the sky (5,8)
5. Not some strange time for deep-sky observing (7)
6. Coin flip before lunch determines who keeps the old prism (5)
7. Mirror supports often seen on the Web? (7)
12. Endless electric malfunction in the crosshairs (7)
13. With back support he leads us to Lyra's strummer (7)
14. Star atlas shows the right time in midday's schedule (7)
16. Interstellar molecule type located in western sky (5)
18. Mother cracks up, loses oxygen and gets heat (5)
19. Whirling leaks of ethane on Titan (5)

Answers to August's puzzle

ACROSS

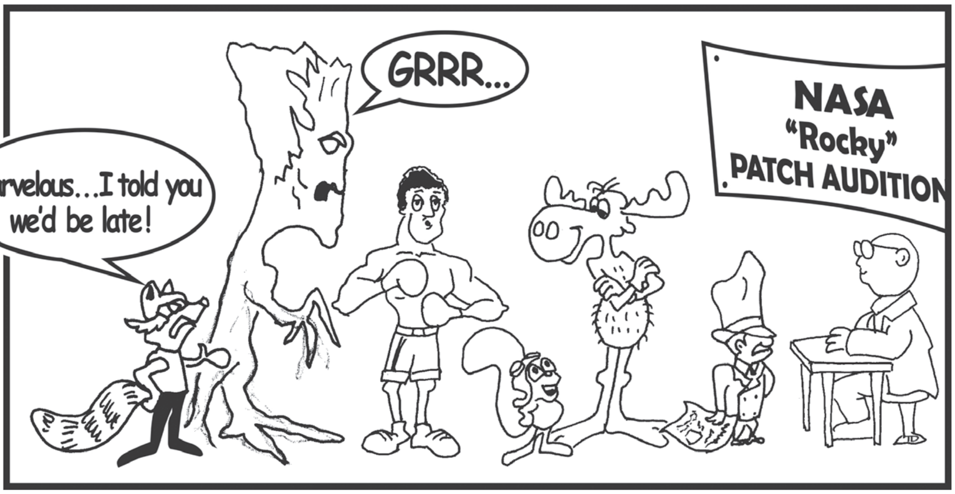
1 STROMLO (rev+lo); **5** HOMAM (anag+AM); **8** FABER (2 def); **9** ST. CROIX (St+cr+o+ix); **10** ALISTER (A-lister); **11** STERE (anag); **12** YUKON (yuk+on); **13** HAMAL (h+lama(rev)); **15** CIGAR (2 def); **18** OH MASER (anag); **20** TAU CETI (anag); **21** LAIRD (L(air)D); **22** NODES (on(rev)+des); **25** STAGGER (sta(gge)r)

DOWN

1 SOFIA (2 def); **2** ROB DICK (ro(bid)ck); **3** MORETON (mo(ret)on); **4** OBSERVATORIES (anag); **5** HACKS (2 def); **6** MOORE (moo+re); **7** MAXWELL (2def); **12** YUCATAN (yu(cat)an); **13** HIMALIA (Hi ma+ail(rev)); **14** MISSING (2 def); **16** GOURD (2 def); **17** RHEAS (2 def); **19** RADAR (h=r)

It's Not All Sirius

by Ted Dunphy

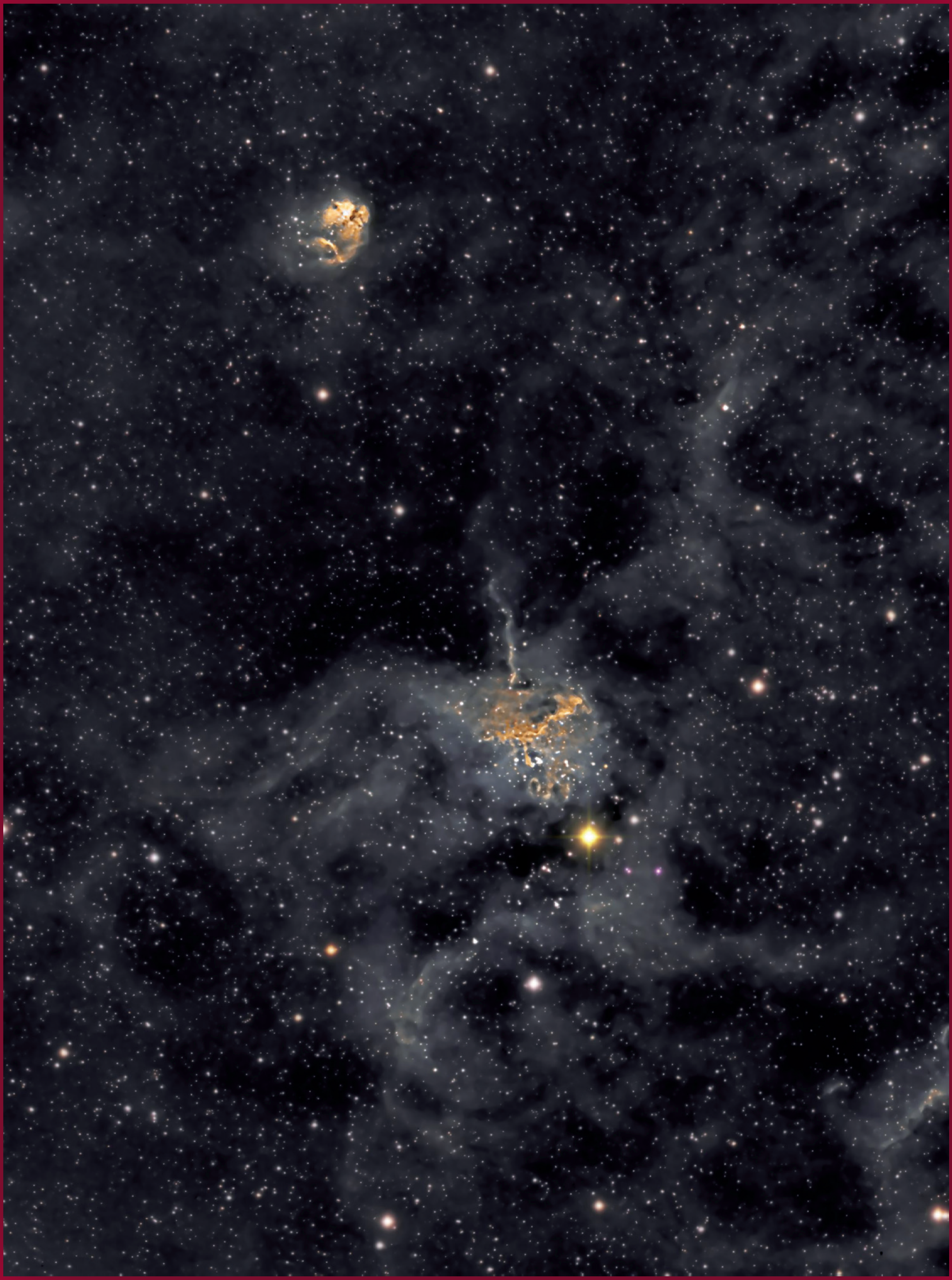


THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

Great Images

by Ron Brecher

Accomplished astrophotographer Ron Brecher imaged Sh2-84 from Guelph, Ontario, using an ASA astrograph 10″ ƒ/6.8 on a Paramount MX and an SBIG STL-11000M camera. The image was captured using Baader Hα, R, G, and B filters, guided with a QHY5 guide camera and 80-mm ƒ/6 Stellar-Vue refractor for a total of 12 hours.



Journal

Great Images

Dan Meek imaged this 5.5-hour narrowband image of the Spider Nebula (IC 417) and the Fly Nebula (NGC1931) with a Tele Vue NP127 and a QSI 583wsg camera from Calgary, Alberta. Meek was able to bring out "Integrated Flux Nebulosity," a term coined by Steve Mandel to describe high-galactic-latitude nebulae that aren't illuminated by a single star but instead by all the stars in the Milky Way.