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Journal

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PROMOTING ASTRONOMY IN CANADA

April/avril 2015
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Inside this issue:

Birding in Cygnus

The Best of Monochrome.

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

The Soul Nebula (SH2-199) is a glowing cloud of hydrogen gas lying in Cassiopeia at a distance of 7500 light-years. The nebula is populated with numerous gaseous protrusions rimmed with bright hydrogen haloes caused by compression of the gas and fierce ultraviolet heating from nearby hot stars. This image was provided by Calgary's Barry Schellenberg, who used a Borg 101ED at f/4.1 and a QSI683WSG camera to capture the hydrogen emission through a 3-nm filter. Exposure was a total of 540 minutes in October and November last year.

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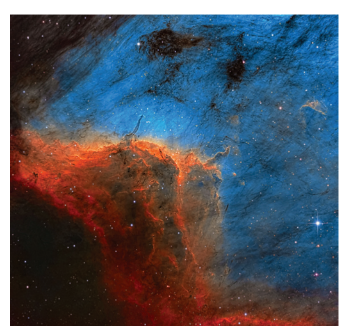

Front Cover — Howard Trottier's eye for colour and his processing skills combine to give Journal *readers this stunning image of a section of the Pelican Nebula in Cygnus. Howard collected the photons from his "Cabin in the Sky" observatory using a PlaneWave CDK17 with an Apogee U16M camera. Exposure was a total of 17 hours in Hα (orange), SII (red), and OIII (cyan). And where does the name come from? In Howard's words:*

I framed this image with the "pelican" structure right of centre, and have given emphasis instead to another part of the nebular complex, which I placed near the top-left "third" of the frame; this structure, with its long neck and angled head (which is the object Herbig-Haro 555), looks to me like a Little Blue Heron catching a fish. So I call this image "Birding in Cygnus," with a heron and a pelican lying inside the great swan.

Journal

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

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President's Corner

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

"Oh, the weather outside is frightful…" (Lyrics from *Let it Snow!* by Sammy Cahn, written during a California heatwave.) I haven't had my telescope out for weeks, because it's no fun having my eyeball stuck to the glass of an eyepiece, or having the eyepiece just freeze over. And I can't touch the telescope tube because my fingers freeze. But, enough of that. I sometimes do my observing vicariously by admiring the wonderful images captured by others, like Alan Dyer's recent daily postings from New Mexico, or the ones obtained by Franklin Loehde using the Slooh telescopes (there are 15 of them worldwide). We live in a marvellous time when we can instantly connect with like minds around the world and share distant images.

After a three-month probationary period, Executive Director Randy Attwood (FRASC) has received a glowing positive report. We on the Board are most pleased with his performance, and we look forward to great things to come. He is a welcome part of our Society Office team, steering us into the future.

Good news on the Discover the Universe program front—Julie Bolduc-Duval successfully applied for a continuing grant and received enough money to expand the program in 2015. DtU offers free astronomy workshops and Webinars for teachers and informal educators all across Canada.

If you haven't already done so, get your Centre to order a packet of (or even order for yourself) the new *Getting Started in Astronomy* brochures that we printed in conjunction with *SkyNews*. They're great for handing out during outreach events.

A surprise for me is how few members took up the offer to obtain the electronic *Observer's Handbook*. Over the years, we have had numerous letters and comments that it would be the "very best thing" if we could only provide a Handbook that people could use while out observing with their tablet or laptop computer alongside. We have such a thing now, but have had relatively few takers. Give it a try—it's only $10, and easily managed. See www.rasc.ca/rasc-member-benefit-programs

Astronomy Day is coming up soon on April 25, so get together with some friends, set up your telescopes or binoculars, and show the public what they're missing! That's what I plan to do.

Clear skies! ✶

News Notes / En manchettes

Two Cepheid variables on the far side of the galaxy

Figure 1 — Upper image: A new image from the VISTA *telescope showing the Trifid Nebula (M20) in a ghostly infrared light. The long-wavelength infrared view allows astronomers to see through M20 and spot previously unknown stars and other objects in the background. In the newly revealed background, two distant Cepheid variable stars are visible, lying almost directly behind the Trifid. A more familiar visible-light image of M20 is shown below. Upper image: ESO/VVV consortium/D. Minniti. Lower image: Jay Anderson.*

The VISTA (Visible and Infrared Survey Telescope for Astronomy) is a 4.1-m telescope operated by the European Space Agency and situated at the Paranal Observatory site in Chile. Since its inception in 2009, the telescope has been engaged in a major survey of the central regions of the Milky Way, one part of which is a search for variable stars (known as VVV or VISTA Variables in the Via Lactea).

In the course of the survey, VISTA observed the well-known Trifid Nebula (Messier 20), but the familiar three-laned object has a completely different appearance (Figure 1) in infrared light. The nebula is almost completely transparent; the dust clouds are far less prominent; the bright glow from the hydrogen clouds is barely visible; and the three dust lanes are almost invisible. However, the infrared view through the now-transparent nebula reveals a rich assembly of stars and other objects on the far side of the Milky Way galaxy. Among the objects are two Cepheid variable stars, a type of star that brightens and fades with a period that is related to their intrinsic brightness.

Cepheid variables are a cornerstone of distance measurement in the Universe, giving astronomers a reliable distance scale for nearby objects that extends to the closer galaxies in our neighbourhood—in fact, currently as far as Messier 101 at a distance of 56 million light-years. The two new Cepheids lie on the far side of our galaxy and near the central plane, the first such variables discovered in this region of our home galaxy.

Visual evidence of a galactic merger in NGC 7714

The *Hubble Space Telescope* has captured a striking view of spiral galaxy NGC 7714—a galaxy that has drifted too close to a companion and has had its spiral arms twisted out of shape, streams of material dragged out into space, and triggered bright bursts of star formation. The culprit is a smaller companion, NGC 7715, which lies just out of the frame in Figure 2, but is visible in the wider-field images. The two galaxies came too close together between 100 and 200 million years ago, and began to drag at and disrupt one another's structure and shape. Tell-tale signs of this gravitational wrestling can be seen in NGC 7714's strangely shaped arms and in the smoky golden haze that stretches out from the galactic centre.

Figure 2 — A Hubble Space Telescope *view of NGC 7714, showing a hazy extension of stars extending to the right toward a galactic companion, and bright blue stars in distorted spiral arms that signal an intense burst of new star formation. Image: Credit: ESA, NASA / A. Gal-Yam (Weizmann Institute of Science).*

A ring and two long tails of stars have sprouted from NGC 7714, creating a bridge between the two galaxies. This bridge funnels material from NGC 7715 towards its larger companion and feeds bursts of star formation. Most of the star-forming activity is concentrated in 7714's bright galactic centre, although the whole galaxy is sparking with new stars, especially the right-side arms. NGC 7714 is a typical Wolf-Rayet starburst galaxy, as a large number of the new stars are of the Wolf-Rayet type—extremely hot and bright stars that begin their lives with dozens of times the mass of the Sun but lose most of it very quickly via powerful winds.

New *Planck* satellite images extend our view of the Milky Way

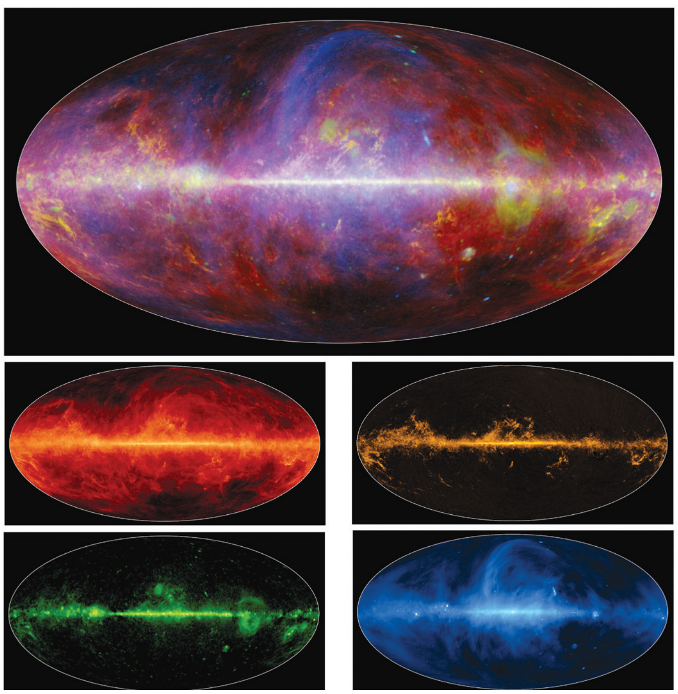

Figure 3 — The Milky Way as observed by the Planck *satellite. The upper image is a composite constructed from the four lower images. The characteristics of each image are explained in the text. Image: ESA/NASA/JPL-Caltech*

The European Space Agency released dramatic new images of the Milky Way by the *Planck* satellite. The images show a swirling mixture of hot gas and dust embedded in arcing magnetic fields, all combined in a colourful map of our home galaxy. Though *Planck* spent more than four years since its launch in 2009 observing the cosmic microwave background, the new images show features much closer to home. Light generated from within our galaxy—light originally subtracted from the ancient signals from the surrounding Universe—now brings the Milky Way to life in the glorious new images.

In Figure 3, different colours represent various materials and types of radiation. Red shows the long-wavelength thermal glow from interstellar dust. This sooty dust fills the spaces between stars—filaments and clumps throughout the disk of our galaxy. While most of this dust is extremely cold, around 20 degrees above absolute zero, it is still warm enough to emit a faint glow in the infrared and microwave parts of the light spectrum. The brightest part of this glow fills a narrow band along the galactic plane. The fainter structures that fill the rest of the scene are clouds that are relatively close to our Sun.

Yellow-orange shows gas molecules—primarily carbon monoxide—that are also concentrated tightly along the mid-plane of the Milky Way. Carbon monoxide is found in the densest clumps of gas and dust that fuel the formation of new stars.

This new portrait of the Milky Way shows the glow from fast-moving electrons trapped by the magnetic fields running through our galaxy. This kind of electromagnetic glow is known as synchrotron radiation and is generated by the oscillations of fast-moving electrons, spit out of supernovae and other energetic phenomena, and captured in the galaxy's magnetic field, spiralling along them near the speed of light.

The green image traces hot regions of star formation found throughout the galaxy, revealed by a kind of radiation known as free-free (or bremsstrahlung) that occurs when isolated electrons and protons careen past one another in a series of near collisions. The particles are formed in the environment around large, newly formed stars that radiate strongly in the ultraviolet. Surrounding hydrogen gas clouds are heated by the UV light, causing them to shed fast-moving electrons electrons and creating a plasma of positive and negative particles. When the resulting charged particles interact with each other, changing direction or slowing down, conservation of energy requires that they emit electromagnetic radiation. The process is known as free-free because the particles are not bound to each other before or after the interaction.

The top image is composed of the combined signals from each of the separate processes outlined above.

Rosetta continues to delight comet enthusiasts

The latest images from *Rosetta*, in orbit around Comet 67P/Churyumov–Gerasimenko, continue to delight aficionados of Solar System bodies. The old "dirty snowball" attribution, while still valid in some respects, is now changing in favour of a model of comet structure that is much more complex. In some of the latest images (Figure 4), one almost expects to see a wagon train coming down the side of 67P's diminutive mountains. All that is missing is the cacti.

Seriously, though, Figure 4 transforms the comet into another world rather than a gassy ice lump. At the left of Figure 4, jagged peaks evoke memories of 1960-vintage illustrations in science-fiction magazines, before the lunar landings revealed the smooth profiles of the lunar landscape. This scene shows the smooth, boulder-strewn, Hapi region in the comet's neck,

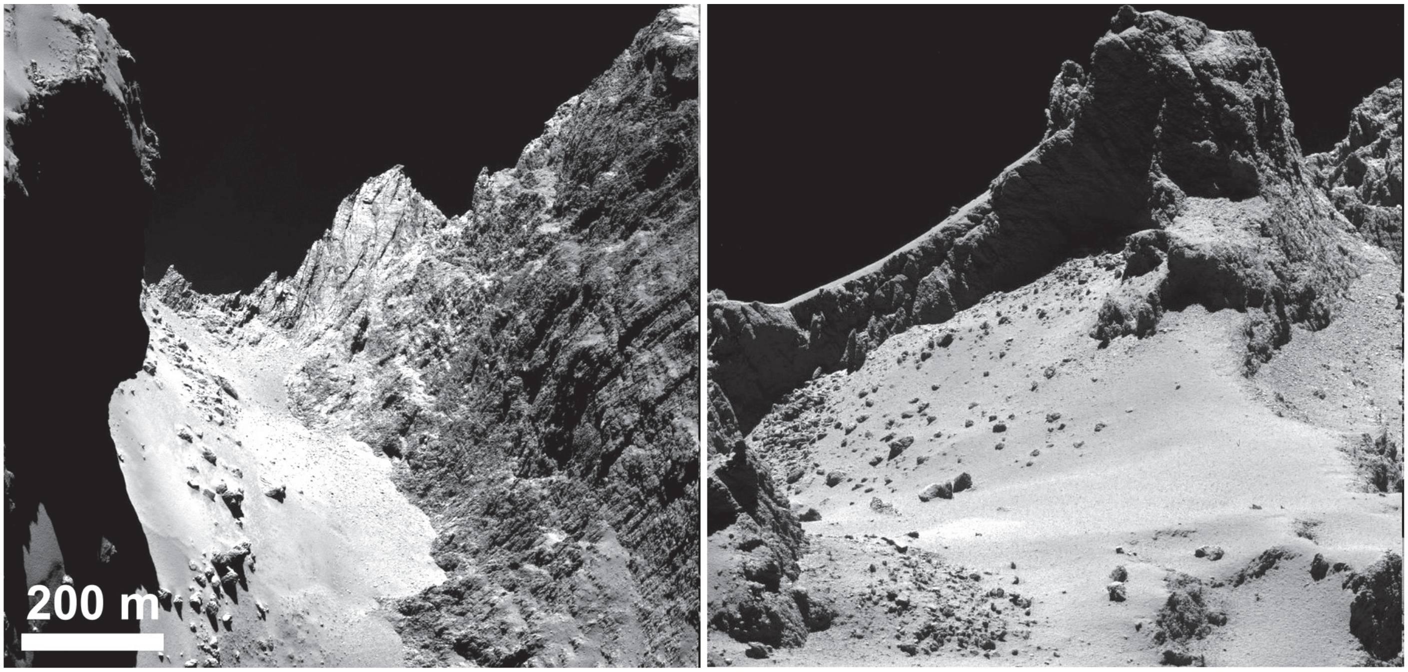

Figure 4 — Two views of the surface of Comet 67P/Churyumov–Gerasimenko from the Rosetta *spacecraft showing the regions Hapi and Hathor on the left and the smaller lobe of the comet from 8 km distance on the right. See the text for additional details. Image: Credits: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA*

with the Hathor cliff face to the right. On the right of Figure 4, we are treated to a view of the smaller of the comet's two lobes from a distance of about 8 km. Resolution is a sharp 15 cm/pixel, and while it may look sandy, the European Space Agency (ESA) prefers to describe the smooth surface as dust. The large boulders look perilous, lying at the bottom of steep cliffs, but in Churyumov–Gerasimenko's gravity, humans would not be in any great danger.

Recent press releases have emphasized the growing outgassing of the comet as it approaches the Sun. Most of the gas is coming from the neck region, which has an interesting 500-m crack that bodes ill for some future passage (or perhaps this one), but smaller geysers have also been spotted in anonymous 40-m wide pits on the comet's surface. When the plumes were examined, the proportions of hydrogen and deuterium turned out to be something other than expected—or at least, wished for—and now the theoreticians are having to redraft ideas about where the Earth's water might have come from.

One of the more interesting aspects of the study of Comet 67P is the absence of water ice (or any ice) on its surface, in spite of the large amounts of water ice emitted in the plumes. Some close-up images have revealed small white patches that may be exposed ice, but it seems unsurprising that the ice is hidden away below the surface. The many past visits to perihelion by the comet have likely evaporated any ices that lay near the surface and now the remainder are tucked away behind a dusty exterior and only gradually sublimated as surface temperatures climb. Still, a nice big crack would do wonders for the science of comet tails.

The news that organic chemicals had been detected on the comet attracted a great deal of media attention, but the unfortunate bounce experienced by the Philae lander and the short duration of the sampling period have left the experiment's owners with a bigger task than expected to identify the species. Only one of seven samples by the Ptolemy instrument over a one-hour period showed a rich sample of organics, but that one was at the first touchdown point while the others were at the eventual resting place. A final sample, using the CASE oven, has not been completely analyzed and results are pending.

Whatever the present state, the next nine months of *Rosetta*'s adventure should be the most interesting of all. Perihelion is in August, with activity steadily increasing as the date approaches. Philae may wake up if the sunlight returns to its hidey-hole, perhaps by the time you are reading this.

Funding approved for 3.2 gigapixel camera for Large Synoptic Survey Telescope

Canon and Nikon have their brand-new 50-megapixel cameras about to hit the store shelves, but they've been outpixelled by the Department of Energy's SLAC National Accelerator Laboratory. SLAC has had funding approved for the 3200-megapixel centrepiece camera of the Large Synoptic Survey Telescope (LSST). LSST science operations are scheduled to begin in 2022, taking digital images of the entire visible southern sky every few nights from atop Cerro Pachón in Chile. It will produce the widest, deepest, and fastest views of the night sky ever observed. Over a 10-year time frame, the

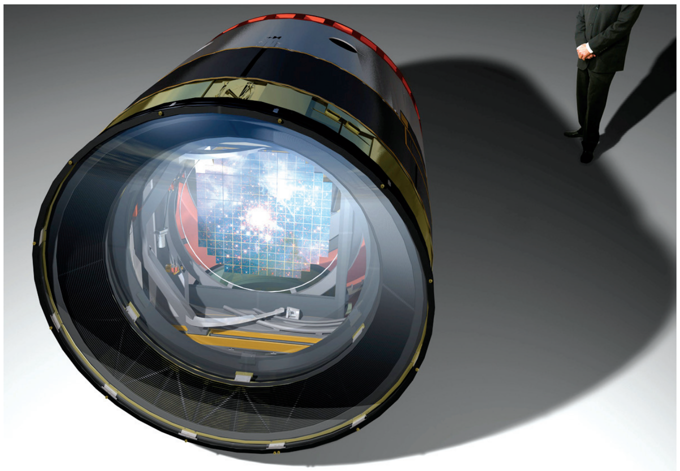

Figure 5 — An artistic rendering of the LSST gigapixel camera with a figure standing beside for a perspective of the camera's size. Image courtesy LSST Project.

observatory will detect tens of billions of objects and will create movies of the sky with details that have never been seen before.

The "camera" consists of a total of 189 sensors and over 2.7 tonnes of components packed tightly into a cylindrical body, all attached to the LSST's 8.4-metre primary mirror.

LSST will generate a vast public archive of data—approximately 6 million gigabytes per year—that will help researchers study the formation of galaxies, track potentially hazardous asteroids, observe exploding stars, and better understand dark matter and dark energy.

"The telescope is a key part of the long-term strategy to study dark energy and other scientific topics in the United States and elsewhere," said David MacFarlane, SLAC's director of particle physics and astrophysics. "SLAC places high priority on the successful development and construction of the LSST camera, and is very pleased that the project has achieved this major approval milestone."

The LSST team can now move forward with the development of the camera and prepare for the "Critical Decision 3" review process next summer, the last requirement before actual fabrication of the camera can begin. Components of the camera, which will be the size of a small car and weigh more than 3 tonnes, will be built by an international collaboration of labs and universities, including DOE's Brookhaven National Laboratory, Lawrence Livermore National Laboratory, and SLAC, where the camera will be assembled and tested. ✶

Research Paper / Articles de recherche

The Discovery, Orbit, and Upcoming Close Earth Encounter of Asteroid 887 Alinda

by Martin Connors
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Abstract

Asteroid 887 Alinda was discovered by Max Wolf at Heidelberg in 1918. Alinda, the second-known, near-Earth asteroid, aroused considerable interest and some confusion at the time. The discovery circumstances are examined with an aim to clarification, including the possible detection of a satellite in follow-up observations. Alinda is also the namesake of a small group of asteroids that orbit the Sun three times per Jupiter orbit, and thus are in 3:1 mean-motion resonance with the planet, in a Kirkwood gap of the asteroid belt. These asteroids are also approximately resonant with Earth, and can make close approaches that are potentially hazardous. Their sidereal period is about four years, but close approaches to Earth usually take place less frequently than that. Alinda had one set of approaches near the time of discovery, one set in the 1970s, and will have another set in the 2020s, including one very favourable approach for its investigation by telescopes, radar, and possibly spacecraft in 2025. An asteroid on a similar orbit, 4179 Toutatis, has recently been investigated in detail.

Résumé

L'astéroïde 887 Alinda a été découvert par Max Wolf à Heidelberg en 1918. Il est le deuxième reconnu parmi ceux qui se rapprochent de la Terre et il a suscité beaucoup d'intérêt lors de sa découverte, en plus de la confusion. Les circonstances de cette découverte sont examinées dans le but de la clarifier, en prenant compte d'une détection soupçonnée d'un satellite durant des observations plus récentes. Un groupe d'astéroïdes qui orbitent le soleil trois fois pendant une période orbitale de Jupiter porte aussi le nom d'Alinda et, dans une lacune de Kirkwood, est en résonance de mouvement en moyenne de 3:1 avec cette planète. Ces astéroïdes sont aussi en résonance approximative avec la Terre et certains d'entre eux peuvent présenter des approches hasardeuses. Leur période sidérale est près de 4 ans, mais normalement ils s'y rapprochent moins fréquemment. Une période d'approche d'Alinda a eu lieu lors de sa découverte, ainsi que durant les années 1970, et aura de nouveau lieu durant les années 2020. L'investigation de son approche très favorable en 2025 sera alors alors entreprise par télescope, par radar et peut-être même par sondes spaciales, tout comme s'est récemment produite pour celle de l'astéroïde 4179 Toutatis, en orbite semblable.

1. Introduction

The first asteroid, 1 Ceres (now designated a dwarf planet), was discovered on 1801 January 1 (Cunningham *et al.* 2011; Foderà Serio 2002), between Mars and Jupiter, in a region of the Solar System that was, in that era, expected to contain a planet. Subsequent discoveries in the 19th century made it clear that a large group of small bodies existed in that zone, which was called the "asteroid belt." According to the tabulation of Tholen (2006), 463 asteroids were discovered in that century (including the year 1900). The Königstuhl Observatory (Landessternwarte), on the small mountain of the same name overlooking Heidelberg, was among the foremost in the world in asteroid discovery in the late 19th and early 20th centuries due largely to advanced photographic and search techniques (Freiesleben, 1962) developed by its eventual director, Max Wolf (1863-1932). The equipment included large refractors and the Waltz 28-inch (72-cm) reflector, a capable instrument in an era of rapidly growing apertures. By the end of 1917, 919 asteroids had been discovered, of which 367, or an astonishing 40 percent, had been netted at Heidelberg. In turn, nearly 54 percent of these had been discovered by Wolf, a very active observer. By early 1918, however, almost all known asteroids were in the asteroid belt.

One exceptional group of asteroids had already been discovered by Wolf. These were the Trojan asteroids, which follow the orbit of Jupiter. In 1906 and 1907, three such asteroids were found (Connors *et al.* 2014). Their exceptional nature was noted on the night of discovery (Wolf 1906) of the prototype, 588 Achilles, since, according to Kepler's third law, the large semi-major axis *a* results in slow motion through the sky and, in turn, a trail produced on a survey photographic plate that is shorter than those of asteroid-belt objects. The simultaneous assignment of the names Achilles, Hektor (now Hector), and Patroclus, heroes of the Trojan War (Wolf & Kopff 1907), was *de facto* recognition that these objects were different from most asteroids. This grouping appeared to be confirmed by the discovery on 1908 March 23 of 659 Nestor (Wolf 1908), soon suspected (Ebell 1908) to be associated with Jupiter. Nearly ten years were to elapse before the discovery of the next Trojan asteroid. 1917 CQ was found on 1917 September 22 and measured to have slow motion on subsequent nights (Wolf 1917). It was later named 884 Priamus, after the king of Troy. Wolf photographed it on 1918 January 3 (Wolf, 1918) with the 28-inch Waltz reflector and then proceeded to use the smaller Bruce telescope for the latter part of the night, in a survey that discovered a new class of asteroid, as described below.

Only one other asteroid besides the Trojans had been found outside the main belt as of 1918. 433 Eros was discovered on 1898 August 13 by Witt (1898) in Berlin. Some aspects of the discovery are confused (Scholl & Schmadel 2002), but an editor's annotation attached to Witt's notice makes it clear that the object's large motion in right ascension (29′ daily, as opposed to more typical values of 1-2′) made following it desirable. The first known asteroid to come inside the orbit of Mars, Eros was quickly realized to be very valuable in solving the long-standing problem of converting the relative scale of the Solar System into accurate absolute units (Payne 1900), that is to say, determining accurately the value of the astronomical unit (au) in km. The discovery elicited a large amount of interest, and although Eros does not come particularly close to Earth by modern standards, a new class of object, the near-Earth asteroids, was introduced. From an observational point of view, Wolf had found the distant Trojans through careful attention to short trails on survey photographic plates, and Eros made observers alert that there could be long trails also, indicating very nearby objects. Wolf in particular was alert in examining Bruce telescope survey plates, and this paid off on 1918 January 3.

Figure 1 — One of the two original 40-cm aperture f/5 Petzval objective lenses of the Bruce double astrograph. The design consists of four lenses in groups of two. These lenses operated between 1900 and 1950, and allowed the discovery of nearly 500 asteroids (photo by author).

2. Discovery of Alinda

The success of the Landessternwarte was in part based on cutting-edge equipment. Wolf had obtained funding from American heiress Catherine Bruce to develop a specialized double astrograph. This consisted of twin 40-cm aperture (Figure 1), 200-cm-focal-length telescopes imaging onto photographic plates with a field of view 6° by 8°. A separate visual guiding telescope had a 25-cm aperture and 400-cm focal length (Figure 2). Normally, both cameras were active, sometimes with a time offset so that asteroid motions could be determined quickly. The Bruce astrograph came into use in 1900, supplanting an earlier astrograph that had been Wolf's personal instrument. It was used, for example, for the discovery of Trojan asteroid 588 Achilles (1906 TG). Shortly after this discovery in early 1906, the Waltz 72-cm reflector (Figure 3) came into operation. It was financed by Frau K. Bohm (maiden name Waltz) and was a fast f/4 optical system made by the Carl Zeiss Corp. in Jena, with a 20-cm guide telescope of roughly the same focal length, on a massive fork mount. Both telescopes are still present in their domes on top of the Königstuhl, and their plates and logbooks are available on the Internet (see Acknowledgements). Perhaps not surprisingly, the first attempt at asteroid imaging with the Waltz reflector was of 1906 TG (by then numbered 588, but still without a name), with note "TG gefunden" (TG found), on 1907 January 22, eleven months after its discovery.

Figure 2 — The Bruce double astrograph in its original dome at the Landessternwarte Königstuhl. The guide telescope is to the left, with one astrograph clearly visible on the right, and the second slightly visible in the gap (photo by author).

By 1918, the operations of the Landessternwarte were highly optimized for asteroid research, with the Bruce double astrograph used primarily in a search role and the Waltz reflector, with its larger aperture and smaller field of view, being used for followup and precise position determination. Both were used in photographic mode. Reduction of data was done with methods developed by Wolf, including stereoscopic techniques with an instrument he helped to develop. Theoretical work on asteroid orbits was being developed simultaneously, largely at other institutions. Orbit determination was very important so that objects could be located again in the future, and this relied not only on obtaining sequences of follow-up observations, but also on good fits to the data, taking into account planetary perturbations.

Alinda first appears as a footnote in a list of observations of asteroids on 1918 January 3 in the *Astronomische Nachrichten*, Number 4922 (Kobold 1918a). It states that "the nature of this object on the edge of the plate cannot be determined with certainty. The motion is only approximately given; it is perhaps larger than given. The position angle of the motion is 204°. The direction of motion may be reversed." The motion referred to was mainly in declination, inferred as −66′ per day, and the magnitude was estimated as 11. This fast-moving, bright object clearly elicited immediate interest; however, the unfortunate

Figure 3 — The Waltz reflector of the Landessternwarte Königstuhl, with 72-cm mirror by Carl Zeiss, Jena. The telescope has an ƒ/3.9 primary mirror. Its light-gathering power, although with a smaller field of view than the Bruce astrographs, made it ideal for asteroid followup after its construction in 1906. The telescope has been converted to a Nasmyth-Cassegrain with a secondary mirror near the entrance (top) and a tertiary mirror directing light to instruments along the declination axis (lower right). Photo by author.

location near, and going off, the edge of plate B4031a (which is damaged and was scanned in support of this article) made further searching difficult, as may be imagined by examining Figure 4. Even worse, the twin plate B4032b, which would normally have allowed verification of the reality of a faint asteroid trace, did not completely overlap with the discovery plate, and did not show the long trace. Wolf's subsequent recovery strategy can be deduced from observing logs available online. Despite the long trace, Wolf's first attempt at finding the object again was to take an exposure adjacent to where it had initially been seen. Presumably due to bad weather, this plate was not taken until January 8.

Kobold had noted in *AN* 4922 that there had been a report the previous month (Kobold 1917) of an unconfirmed possible comet relatively distant in the sky from the discovery location. This seems to have motivated a search along the extension of that path, on January 14, with exposures over three hours long (plates B4035, B4036). This path would have corresponded to a negative declination motion. A second pair of plates (B4037, B4038) was taken the same night in a location that would have reflected positive declination motion from the discovery location, along the direction of the long trace. These plates were exposed for roughly two hours. One must also bear in mind that, unlike modern CCDs, plates had to be developed. Wolf would not know until the next day that neither pair of plates had succeeded in finding the object. Some plates taken January 28-29 were for unrelated projects, since the full Moon interfered with asteroid searching.

On January 30, an early evening plate pair looked in a region not clearly related to the new object. The Moon then rose, presumably precluding further searching. On 1918 February 2, the search resumed close to the area indicated by the discovery plate if the declination motion had been northward but slow (plates B4045, B4046). Finally, on February 3, the object was found at a yet more northerly location. A repeat exposure was made on February 4. These four plates, each with a three-hour exposure time, were B4047 through B4050. On February 5,

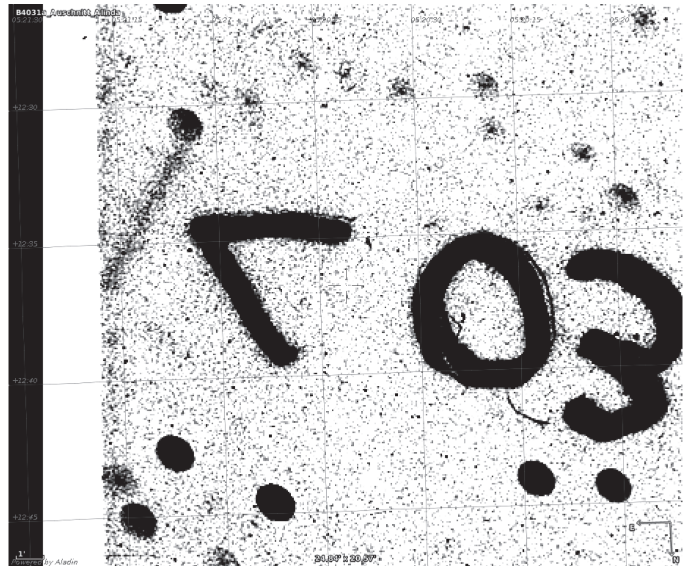

Figure 4 — Alinda's trace on the discovery plate taken on 1918 January 3. A leftward pointing arrow written in ink points toward the trace, which begins at a star and moves northward (downward). The star directly below this mark is on the edge of the twin plate. J2000 coordinates are overlain and the contrast has been enhanced. The exposure time was 2.5 hours.

the Bruce astrograph returned to its normal search for new asteroids, while the Waltz reflector took over following the object, which the recovery by the Bruce astrograph allowed to be found within its smaller field of view. The object was denoted Planet-Comet 4031.03 in the observing log, this designation from the number of the discovery plate. The exposures tracked its motion, resulting in a point-like asteroid in a field of trailed stars (Figure 5). A notation was made of the need to turn the guiding rod every minute because of the object's rapid motion. The larger Waltz reflector aperture allowed the exposures to last only 30 minutes each and motion to be seen between them.

The recovery by Wolf was announced by the *AN* editor (Kobold 1918b) as the first of several short articles filling three pages of the journal. Several days of observations, up to February 14, were provided from several observatories, and preliminary orbit determinations and ephemerides given. The "remarkable celestial body" was provisionally named 1918 DB and referred to as the "*Wolf*sches Gestirn" (italics those of *AN*). As imaged on 1918 February 5, it showed no gas shell, and so was not a comet. Incredibly, Wolf announced that it appeared to be accompanied by a satellite. This may be seen on the superposed plates shown in Figure 5, with motion between the time of the plates. In hindsight, we may realize that if a satellite had been slowly moving around Alinda, its traces would have been lengthened and not pointlike. The marks may have originated in defects that were unfortunately positioned on the two subsequent plates. None of the many other images of Alinda showed any evidence of a satellite. Many asteroids are now known to have satellites, although

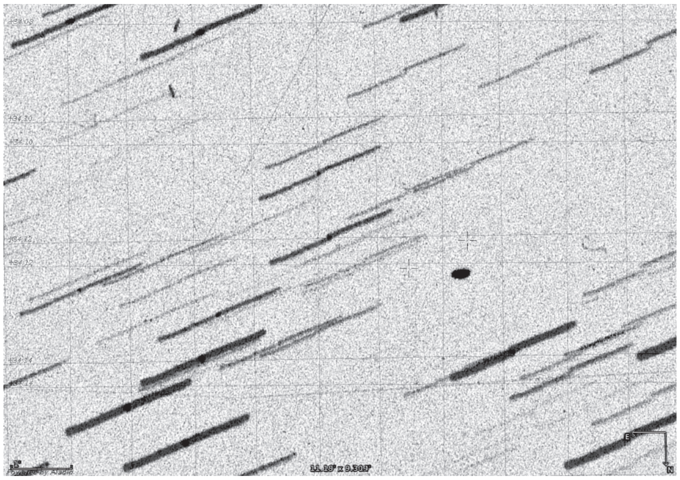

Figure 5 — Alinda on the first plates showing it with the Waltz reflector, which have been digitally superposed. Alinda is at middle lower right as a spot. The two marks from the suspected satellite are in the upper left. All other features are trailed due to tracking at the rate of the asteroid. Double grids in J2000 coordinates are shown.

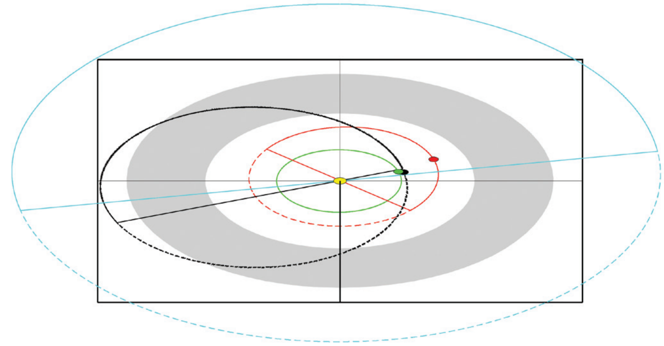

Figure 6 — Orbits and positions relevant to Alinda's close encounter with Earth on 2025 January 8. Orbits are shown with dashes when below the ecliptic, and solid when above. The vernal equinox is toward the bottom and a grid with spacing 3.885 au is shown. The orbits of Mercury and Venus have been omitted for clarity. Those of Alinda (black), Earth (green), Mars (red), and Jupiter (cyan) are shown, with the positions of the first three shown on the date of encounter. Most main-belt asteroids remain within the grayed region.

this was contentious until the discovery of one in 1993 by the *Galileo* spacecraft; one had even been claimed for Eros in 1901 (Merline *et al.* 2002). In retrospect, Wolf was displeased by his rapid but erroneous conclusion, by now published. Freiesleben (1962) quotes from his diary entry of 1918 February 15, referring to the satellite finding as "The greatest embarrassment of my life???" and Alinda as "a completely ordinary asteroid with large eccentricity," concluding "I am condemned!"

In any case, the recovery observations were now consistent with the observations on 1918 January 3, which thus were now referred to as the "discovery exposures." It was possible to conclude that the large-eccentricity object (in fact a parabolic approximation was used for the orbit) had been at its node and also at perihelion very close to the discovery date, and been only 0.2 au from Earth at the time. This explained the rapid motion of the object when detected. With these observations, the presence of a second near-Earth asteroid was affirmed.

3. Alinda's Orbit

Thanks to Wolf's rapid work in following up Alinda, basic details of its unusually eccentric near-Earth orbit were already clear in 1918. Its physical nature was not determined until much later observations (Veeder *et al.* 1989) gave a diameter of 4.2 km, visual albedo 0.23, and a common inner-Solar System type of S, meaning a stony asteroid. These values are based on 10μ infrared observations from Mauna Kea. This relatively large asteroid (among near-Earth types) does not cross Earth's orbit, but its orbit is changing in such a way that it will.

The orbital configuration at the upcoming close encounter of Alinda with Earth on 2025 January 8 is shown in Figure 6, and its recent orbital elements are given in Table 1. Alinda has an inclination of $i = 9.36°$, and thus spends most of its time out of the plane of the ecliptic. For example, the orbit passes above and below that of Mars, and it also traverses the asteroid belt non-centrally. Its inner node is very close to its position at perihelion, and this in turn is only about 0.1 au outside Earth's orbit, and when it does line up with Earth in the manner shown, this is roughly how far away it is. At the present time, close encounters with Earth do not greatly affect its orbit, and orbital change is mostly caused by Jupiter.

The eccentricity of the orbit (e) is 0.5675, which means that the object goes out past most of the main belt, but not far enough out to have close encounters with Jupiter. Its semi-major axis (a) is 2.4784 au, resulting in a period of 3.90 years. A rough idea of the geometry relative to Earth can be had by reasoning that the position of Earth would be the same as in

Element	**Value**	**Uncertainty (1-sigma)**	**Units**
e	.5674585315701524	5.4245e-08	
a	2.478434474102797	1.8393e-08	au
q	1.072025686835581	1.3747e-07	au
i	9.359372430222889	7.6642e-06	deg
Ω	110.5521543922645	3.6085e-05	deg
ϖ	350.3383965724346	4.0788e-05	deg
M	149.3667119772119	3.8028e-05	deg

Table 1 — Standard orbital elements of asteroid 887 Alinda for epoch Julian Day 2457000.5 (2014 December 09.0) in heliocentric ecliptic J2000 coordinates. Elements not identified in the text are Ω, the longitude of the node, ϖ, the argument of perihelion, and M, the mean anomaly at the epoch. From http://ssd.jpl.nasa.gov/sbdb.cgi?sstr=alinda&orb=1, cited 2015 January 29.

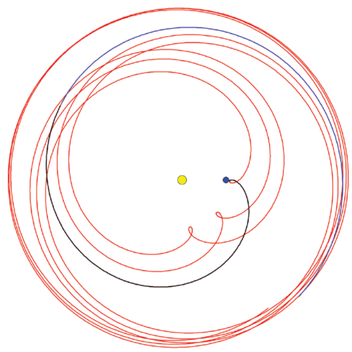

Figure 7 — Clockwise motion of Alinda in a frame co-rotating with Earth from 2014 August 8 to 2026 August 8. Relative motion in the year 2025 is shown in black, and in 2026 in blue. Earth (blue dot) is 1 au from the Sun (yellow dot).

Figure 6 if a time one year later was plotted. The asteroid would move more than one-quarter way around its orbit by that time, since Kepler's second law has it moving faster when near perihelion. One year more, and Earth would again be in the same place, but Alinda near aphelion. One year more, and Alinda would be less than three-quarters of the way through an orbit, having moved slowly when near aphelion. And on the fourth anniversary, Alinda would again be near perihelion; however, since its period is slightly less than exactly four years, it would be a bit past perihelion. Gaining on Earth by 0.10 year's motion each four years, but with motion near apogee slow, it takes roughly 50 to 60 years for Alinda to come back to the same position relative to Earth and have a close passage. At the other end of this cycle, approaches of Alinda steadily become more favourable before its next close encounter. Its position relative to Earth from 2014 to 2026 is shown in Figure 7. The cycloidal pattern arises from the asteroid moving in and out on its elliptical orbit, and around the Sun relative to Earth by the process described above. The close approach in 2025 is clear, and this and the previous perihelion passages can be seen as loops in the inner portion of the orbit. In such a diagram, opposition takes place directly to the right of Earth (*i.e.* when the asteroid is on the opposite side from the Sun as seen from Earth). It can be seen that the asteroid is usually far away at opposition, and only at close approach would it be bright. Further, at most perihelion passages, it is not well placed for observation, although in this epoch it is better placed than usual, being closer and thus brighter.

If the orbit of Alinda is plotted with respect to Jupiter, the threefold symmetric path shown in Figure 8 arises. The outer points in this figure arise when the asteroid is near aphelion. The figure is not closed, and slowly reorients itself with respect to Jupiter with a period of about 370 years. This slow motion is referred to as libration. Space does not permit discussing the details here, but Alinda was used as an example by Greenberg (1977). The pattern in the rotating frame, and the libration, are characteristic of 3:1 resonance, but this was not quickly realized.

4. Recognition of 3:1 Resonance with Jupiter

The modern view of our Solar System places a great deal of emphasis on the phenomenon of resonance. Indeed, in the introductory chapter to *Solar System Dynamics* (Murray & Dermott 1999) it is stated that "the subtle gravitational effect that determines the dynamical structure of our Solar System is the phenomenon of *resonance*" (italics those of the authors). We now have access to information about many more planetary systems, and this statement applies to many of them as well (Zhang *et al.* 2014). The importance of resonant phenomena was already pointed out by Brown (1911a), attempting to give a theoretical basis to the gaps in the asteroid belt's distribution of semi-major axes noted by Kirkwood in 1866 (Kirkwood 1888). The theory of resonance was, however, not well developed, as evidenced by Brown's own (Brown 1911b) advancement of the three-body problem for 1:1 resonance (relevant to the then recently discovered Trojan asteroids) through an essentially geometric argument based on 18th-century work of Laplace. Despite Kirkwood (1888) having specifically mentioned the gap at 2.5012 au (significant figures given by Kirkwood) as being related to the fact that "an asteroid's period would be one-third that of Jupiter," the presence of Alinda in a Kirkwood gap, and the fact that it was a Jupiter-resonant asteroid, seems to have gone unnoticed until 1969. E.W. Brown wrote numerous papers after 1911 on Trojans as a resonant system, and discussed the Kirkwood gaps extensively in terms of resonance and high eccentricity. Examination of the papers leading up to his review (Brown 1932) seems to indicate that he did not know of the existence of Alinda, and in fact had last looked at the observational data in 1911 (Brown 1911a)! Schweitzer (1969) referred to the 3:1 gap as the "Hestia" gap, and identified Alinda as being in it. Sinclair (1969) also found this result. Both authors used computers to calculate various orbital parameters through time, and demonstrated libration, an essential characteristic of resonance mentioned in the previous section.

The seeming lack of attention to basic properties of asteroid orbits, such as resonance, seems puzzling to us. In recent years, we have easy access online to tens of thousands of very well-determined asteroid orbits and hundreds of thousands of good ones. We can easily look for interesting orbits to study, and we can do meaningful statistical studies. It was not always so! It was noted above that a driving force behind major observational and data reduction efforts was determination of asteroid orbits with high precision, so that the growing number of them could be followed and so that they could be found again after passing close to the Sun in the sky. The

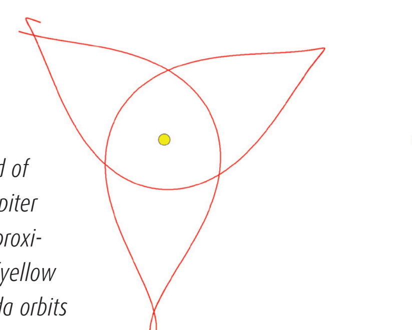

Figure 8 — Counterclockwise motion of Alinda in a frame co-rotating with Jupiter from 2014 August 8 to 2026 August 8, which is approximately Jupiter's period of revolution around the Sun. Jupiter is indicated by a blue dot approximately 5.2 au from the Sun (yellow dot). During this period, Alinda orbits the Sun three times, making the pattern relative to Jupiter shown.

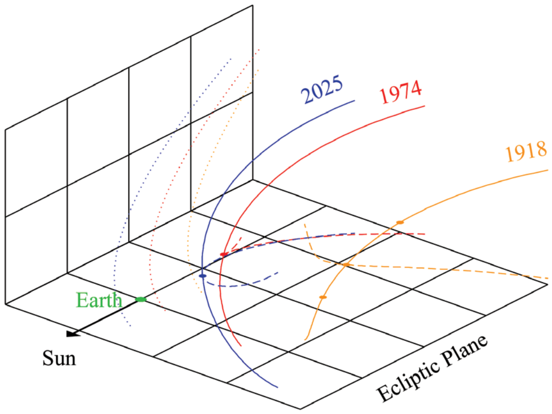

Figure 9 — Motion of Alinda in its 1918, 1974, and 2025 passes, relative to Earth (green dot). Each square is 0.1 au on a side and the arrow points to the Sun. At this scale, the orbit of the Moon is smaller than the dot indicating Earth. On all traces the motion of Alinda is toward the year marker. Dots indicate where Alinda crosses the ecliptic. In 1918, the dot below the ecliptic plane is for the 1918 January 3 discovery date, and the dot above the plane is for the 1918 February 3 recovery date. Dashed lines show the projection of the path into the ecliptic plane. Alinda was discovered below the plane but near closest approach to Earth in 1918. Dotted lines are projected onto the perpendicular plane to the ecliptic, and the relative motion rises quickly above it.

importance of the ability to "recover" an asteroid was made clear already in 1801 and 1802 when the first of them was lost in solar glare almost immediately and only recovered through the application of the prodigious theoretical skills of Gauss (Cunningham *et al.* 2011). The need to represent orbits accurately led to orbit determination becoming a highly specialized branch of mathematics. A good illustration of that in the present context is a series of papers by Stracke (1933, 1936) and Steinmetz (1941). In the first of these, Stracke emphasizes that "among the minor planets discovered by Wolf, Alinda is, next to the Trojans, the most unusual find." He noted that several large-eccentricity asteroids (among them 719 Albert, discovered before 887 Alinda) could only be observed near perihelion due to being faint, and that this made approximate methods of orbit determination unsatisfactory to ensure their recovery from year to year. Further, Albert had been lost despite having been named and numbered (requirements for this are now much stricter). It was clearly known to be an interesting object, and of high eccentricity, but Alinda was of greater interest, in part because its orbit had been well determined through the efforts of Wolf. Stracke noted that Albert might be found in the future, but only by chance; in fact this happened in the year 2000 (Tsiganis & Varvoglis 2000). To ensure that Alinda did not eventually suffer a similar fate, he proceeded to produce the best ephemeris possible, asking observers to be sure to recover it in 1933–1934, in the face of the fact that each opposition saw it farther from perihelion and fading in brightness (see discussion of the orbit above). The effort was successful, and he was able to conclude his 1936 article by stating that "the result of the orbit determination of 887 Alinda came out so well, that we can presently say that it can be counted among the asteroids whose orbits are the most reliably determined." Noting the deteriorating observational situation, and asking southern observatories in particular to help, Steinmetz (1941) gave details about the mathematical precision required and the high order of terms added to series representing perturbations from planets. These heroic efforts did pay off in that the unusual minor planet Alinda was never lost.

On the other hand, our developing modern view of celestial mechanics allows some insight into the basic nature of the problem of orbit determination for certain asteroids, and in particular resonant ones. In the lecture given in appreciation of the American Astronomical Society's Urey Prize, Wisdom (1987) pointed to developments in chaos theory during the 20th century that showed that averaging (an essential element in development of series solutions such as those used in the classic approach to the orbit of Alinda) could not be guaranteed to give convergent results in all circumstances. In the case of small perturbations, they usually would. In the case of eccentric orbits and with resonance playing a role, convergence was not even likely, or could happen at some times, and seemingly inexplicably not at others. He specifically gave examples from his work on the 3:1 mean motion resonance, in which Alinda is found. Chaotic effects in these strong resonances can give rise to an increase in asteroid eccentricity, which is what has brought Alinda from the asteroid belt to our vicinity.

5. Close Encounter in 2025

Alinda was discovered at about 11th magnitude when making a near-Earth opposition at a distance of 0.216 au in 1918 (it had been slightly closer in 1914). Only one other favourable opposition took place in the 20th century; Steinmetz (1941), for example, referred to the deteriorating observational situation in its first half. In 1970, it passed 0.229 au away and in 1974, 0.137 au away, with a maximum brightness of about V=10.6 in 1974 that permitted photometry to be done (Dunlap & Taylor 1979). This photometry revealed the longest then-known period of rotation among asteroids, 74.0 hours, with an amplitude of about 0.3 magnitudes.

On 2025 January 8, Alinda will make its closest approach to Earth in the 20th or 21st centuries, at 0.0822 AU. The circumstances for this and previous encounters are shown in three dimensions in Figure 9. The projection of the 2025 encounter into the ecliptic plane corresponds to the small loop near Earth shown in Figure 7, but this view makes the rapid motion upward out of the ecliptic plane clearer. A few days after closest approach, its magnitude should be 9.0, much brighter than it has been since its discovery, and it will be at favourable northerly declinations. This should present good opportunities for observation, including by amateurs. An even more intriguing possibility is that a space mission could be developed to take advantage of this unique opportunity.

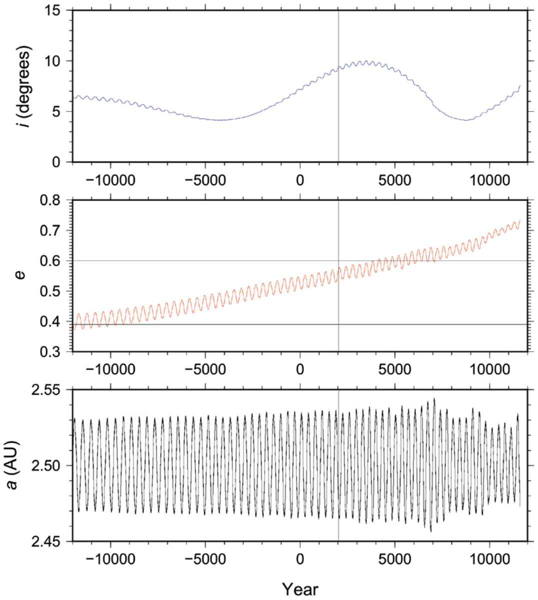

Figure 10 — Orbital elements of Alinda over 22,000 years. The semi-major axis (a) (bottom panel) does not change appreciably over the long-term, but varies with about a 370-year cycle due to libration. The inclination (i) (top panel) remains moderate during this period. The eccentricity (e) (middle panel) rises steadily, causing planetary crossing, with the bottom horizontal line indicating average Mars crossing, and the top (e = 0.6) line Earth crossing. Once Earth crossing begins, a variations become more irregular due to close encounters. Vertical bars in each panel indicate the year 2014.

The asteroid 4179 Toutatis shares some orbital characteristics with Alinda, including being in the 3:1 resonance at high eccentricity. Its perihelion distance (q) brings it slightly inside Earth's orbit, and its period of 4.03 years has led to a series of close-Earth passages in recent years, allowing its study by radar and optical means, and culminating in the Chinese *Chang'e-2* spacecraft flyby (Huang *et al*. 2013). Toutatis has, in the past, been described as "potato-shaped" and now is described as "ginger-shaped"; in either case, it is an intriguing highly elongated body, with a rotation period of 5.4 days (longer than the ≈3 days for Alinda). Much information about the elongation of Toutatis was initially derived from light curves (Spencer *et al.* 1995) with an amplitude of 1.2 magnitudes. Further, the spin state is one of "tumbling." In preparation for a possible Alinda mission, verification of its spin parameters would be a desirable objective. Unfortunately, its typical magnitude in the next few years is fainter than 18, making this a task for a large telescope. If the spin period is in fact long, a further problem is that a large time allocation would be needed. Nevertheless, the much lower amplitude of the light curve as compared to that of Toutatis suggests a less elongated body and likely a simpler rotation state.

A flyby mission similar to that for Toutatis described by Huang *et al*. (2013), with more detail provided by Liu *et al.* (2014), is likely within the scope of a nation with space capabilities at the level of Canada's. Launch services would need to be obtained from another country. Since Alinda would be near Earth, considerably lower telecommunication power would be needed than for a deep-space mission such as *Dawn* (Russell *et al.* 2007), especially as such a mission would be operating in the asteroid belt and more solar power would be available. The change in velocity needed to have a slow rendezvous with Alinda would be comparable to what *Dawn* had to achieve in getting to Vesta. A mission with similar ion propulsion could conceivably lead to a view very close to the asteroid lasting several weeks, or possibly a landing. Extrapolating from Figure 7, it is clear that rendezvous with Alinda is a once-in-a-lifetime opportunity for study of an object whose characteristics remain poorly known. Other stony asteroids visited by spacecraft, like Toutatis, have been elongated and heavily cratered. We may be able to find out whether the low-amplitude light curve of Alinda means that it has had a different collisional history, if we can observe the degree of cratering or other deformation.

6. Discussion

The systematic search program at Heidelberg, using the world's most suitable optical equipment, led Wolf not only to dominate the discovery of main-belt asteroids in the early part of the 20th century, but also to discover at least two new classes of asteroidal motion, the Trojans and Alindas. The latter was due to vigilance in looking for unexpected objects and a follow-up program that also served to determine orbits more precisely to allow recovery of newly discovered objects in the following year. Perhaps the rigours of this task, and the attention paid to enhancing predictive models, led to the resonant properties of the new classes taking a long time to find, with Alinda's relationship to Jupiter not recognized for about 50 years after its discovery.

The 3:1 resonance, for which Alinda is the prototype, is now recognized as an important source of near-Earth asteroids, many of which have collided with planets, plunged into the Sun, or been expelled from the Solar System. Calculations based on the Mercury integrator (Chambers 1999) show that Alinda itself will cross Earth's orbit starting in about 3000 years (Figure 10). Resonance chaos effects (Wisdom 1987) impose the steady increase in eccentricity that will bring this about, superposed on the short-term (370-year period) variation mainly due to libration (Greenberg 1977). Our ability to predict orbits in detail is limited by the chaotic effects, so that we cannot say what the long-term fate of Alinda will be, and a future collision with Earth cannot be ruled out, although it is not possible now. A recent development, arising from the ability to compute close encounters accurately, is that 3:1 asteroids can be "flipped" into a retrograde orbit (Greenstreet *et al.* 2012). Some likely candidates for this have been observed among the near-Earth asteroid population.

Alinda serves as a prototype for resonant asteroids in general, with the understanding of resonant behaviour now enhanced through the application of the tools of chaos theory. By 2018, the centennial of its discovery, it would be fitting and useful to be preparing once again to apply the world's most sophisticated techniques of asteroid research by preparing a space mission to visit it. ✶

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On Special Epochs, the Copernican Principle and Future Astronomy

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Abstract

The history of astronomy teaches us that many special epochs have occurred in the past. Indeed, it is at these exceptional moments that rapid changes in technological advancement and/or theoretical understanding take place. These transitory epochs are literally the "anchor points" of human intellectual development. Building upon the idea of expeditious, yet transitory, developments in astronomy, this essay explores the timeline that has resulted in humanity's ability to measure the size of the observable Universe. Remarkably, we have within the last 50 years attained knowledge of the very limits of observability—a special achievement and epoch, indeed. While the future for astronomical research and new discovery appears as exciting and as large as ever, it is argued that the strict adherence to the Copernican Principle, a philosophical methodology apparently sacred of present, should be abandoned as astronomers contemplate their future research. Additionally, it is argued that the same opportunities that have enabled the most recent opening up of new "windows" through which we can view the Universe do not necessarily exist as we move forward in time, and this begs an analysis of the question apropos the future outlook for observational astronomy.

Résumé

L'histoire de l'astronomie nous enseigne que par le passé il y a eu de nombreuses époques spéciales. En effet, c'est à ces moments exceptionnels que des changes rapides ont lieu en technologie et/ou en notre compréhension de la théorie. Ces époques transitoires sont littéralement les points de repère dans le développement intellectuel de l'homme. Se fondant sur le concepte des développements expéditifs mais transitoires de l'astronomie, cette dissertation explore la période dans laquelle l'homme a pu mesurer l'étendu de l'univers observé. Ce qui est remarquable est que durant les dernières cinquante années, nous avons atteint des connaissances des limites ultimes de l'observabilité—vraiment une réussite et une époque très spéciales. Pour l'avenir la recherche astronomique et les nouvelles découvertes paraissent aussi passionnantes et importantes que jamais. Toutefois nous soutenons qu'une stricte adhésion aux principes de Copernicus, aujourd'hui une méthodologie philosophique d'aspect sacrée, devra être abandonnée lorsque les astronomes considèrent leurs recherches futures. Nous soutenons aussi que les opportunités qui ont permises l'ouverture récente de nouvelles 'fenêtres' à travers lesquelles nous pouvons contempler l'univers ne seront pas nécessairement disponibles à l'avenir. Ceci exige une analyse de la question concernant l'avenir de l'astronomie observationnelle.

1. Introduction

One of the great benefits of teaching a course related to the history of astronomy is that it provides an opportunity to look anew at the subject; to probe the story lines and to re-assess what has been said and done before. I am in the fortunate position to teach such a course every few years, and during the progress of the last offering, the topic of special events and unique epochs gave me specific cause for reflection. While all history is partly about unravelling firsts, who did what and when, the development of astronomy itself, since the mid-16th century, is generally portrayed under the guise of expanding horizons along with the developing concept that humanity, along with the Sun and the Solar System, is not centrally located within the Universe or, indeed, located within any special place at all. This latter idea is usually expressed under the guise of the Copernican Principle, or the Principle of Mediocrity. While Copernicus himself would neither recognize nor appreciate the principle named in his honour, it is the case that the principle has been greatly misused in recent decades. Indeed, it can lead us to wrongheaded ways of thinking about the Universe and humanity's standing within it. As described in an earlier article (Beech 2011), for example, the blind acceptance of the Copernican Principle has resulted in the entirely wrong concept being propagated within popular astronomy texts that the Sun and Solar System are in every way average, even bland and/or typical. They patently are not average in many demonstrable ways, and our seemingly modern fear of allowing for special circumstances and the existence of unique structures, events, epochs and

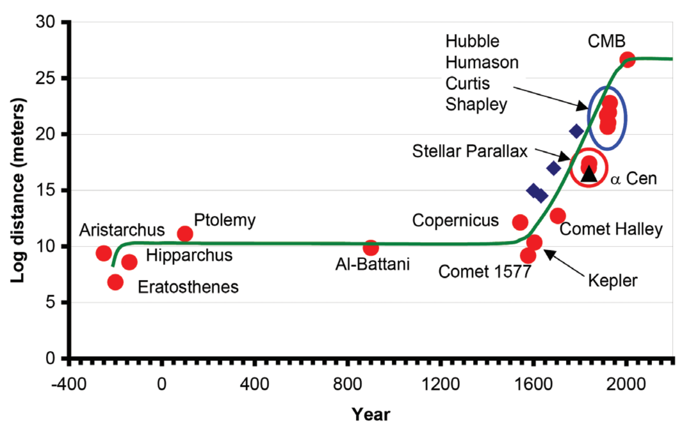

Figure 1 — Estimates to the minimum size of the Universe over recorded history. The vertical scale is expressed as the logarithm of distance measured, in metres. While it may appear that recent history indicates an ever-increasing measure, the cosmic microwave background (CMB) point marks, in fact, the absolute limit of increase at the present time. The "trajectory of knowledge" (solid line) has increased like a logistic curve and we are currently at the special location of the upper turnover point.

Authority	Year	log d(m)	Method
Aristarchus	-250	9.38	Moon = 20 × Earth radius Sun = 19 × Earth-Moon distance
Eratosthenes	-200	6.80	Earth circumference = 252.000 stadia
Hipparchus	-140	8.60	Moon = 62 × Earth radius
Ptolemy	100	11.11	Stars = 20,000 × Earth radius
Al-Battani	900	9.86	Sun = 1146 × Earth radius
Copernicus	1543	12.13	Saturn = 9 × Earth-Sun distance
Tycho Brahe	1577	9.17	Parallax distance to comet C/1577 V1
Tycho Brahe	1600	14.97	Stars = 700 × distance to Saturn
Johannes Kepler	1604	10.34	Solar parallax = 1 astronomical unit
Galileo Galilee	1632	14.51	Distance to 6th magnitude star (1)
Isaac Newton	1687	16.96	Distance to Sirius (2)
Edmund Halley	1705	12.72	Comet 1P/Halley at aphelion
William Herschel	1785	20.27	M31 = 2000 × distance to Sirius (3)
Friedrich Bessel	1838	16.99	Stellar parallax (61 Cygni)
John Henderson	1839	20.27	Stellar parallax (a Centauri)
Otto Struve	1840	17.39	Stellar parallax (Vega)
Harlow Shapley	1918	20.79	Distance to galactic centre0 = 20 kpc (4)
Heber Curtis	1920	21.67	M31 = 500,000 light-years (5)
Harlow Shapley	1922	21.03	Distance to LMC = 35 Kpc (6)
Edwin Hubble	1925	21.94	M31 / M 33 = 285 Kpc (7)
Edwin Hubble	1929	22.79	Most distant galaxy at 2 Mpc (8)
Richard Gott III	2005	26.64	Observable Universe 14,300 Mpc (9)

Table 1 — Summary of selected distance measures throughout recorded history (see Figure 1). Column 1 indicates the authority concerned; column 2 provides the approximate year of the work; column 3 indicates the logarithm of the distance measure converted to units of metres; column 4 is a short description of the distance determining methodology—bracketed numbers refer to additional notes (given below).

us, has, in effect, led our collective understanding astray. Not only, in fact, is the Solar System located at a very specific and special place within our galaxy, we also live in a very special epoch within the history of the Universe. Indeed, we live in the epoch in which humanity is able to determine and at least partially comprehend the full scale of the observable Universe. This is a remarkable and special achievement, and a step in the evolution of human civilization that has been realized in an incredibly short interval of time. It was this idea that grew out of my recent class discussions, and the next step was to assemble a set of diagrams and notes to illustrate the timeline.

Underscoring the historical measure of the Universe is the determination of the greatest known distance—for example, if we know the size of the Earth, then we additionally know that this must also be a lower bound to the size of the observable Universe, since the latter contains the former. So, while the theoreticians and philosophers are certainly free to speculate upon the possible size of the Universe, be it finite or infinite, only measure tells us how far our knowledge potentially stretches. Throughout the vast majority of recorded history, the greatest measured size or most distant known object has greatly under-estimated the actual size of the observable Universe (compared, of course, in a look-back sense to our current knowledge). Figure 1 is an attempt to trace the evolution of actual measure through history, with the various numbers and methodologies being described in Table 1. The data shown in Figure 1 is selective in the sense that we have tended to highlight the works of the historically more famous authorities, and those works that introduced new methodologies.

1 Argument provided in *Dialogue Concerning the Two Chief World Systems*. Hughes (2001) describes in detail Galileo's method for estimating the distance to the faintest stars (*i.e.*

naked-eye visible at 6th magnitude) based upon a measurement of the angular diameter for the bright (1st-magnitude) star Vega. Galileo finds a distance equivalent to 2160 Earth-Sun distances.

2 Argument given in *Principia Mathematica*. Newton's approach is particularly imaginative and worth seeing in more detail. His method uses a relative flux argument with the planet Saturn to draw out a distance estimate to the brightest stars. First, Newton notes that the body of Saturn (excluding its rings) has a diameter of some 17 to 18 arcseconds, and this dictates that its Sun-facing hemisphere will intercept "about $\frac{1}{2100000000}$ of the Sun's light." This result follows from the relationship that there are A_{sky} = 41,253 square degrees around the entire sky. The amount of sunlight intercepted by Saturn, therefore, will be $A_{int} = \pi\,(0.00236)^2/41253 = .25\times10^{-10}$ (taking Saturn to have a diameter of 17 arcseconds—at opposition, Saturn actually has an angular diameter of 20.790 arcseconds). Next, Newton comments that supposing ¼ of the sunlight incident upon Saturn is reflected back to the Earth, and that this reflected light is diminished by the inverse square law upon its journey then, "the whole light reflected from its illuminated hemisphere will be about $\frac{1}{4200000000}$ of the whole light emitted from the Sun's hemisphere." At this point Newton switches from the light intercepted by the cross-section area of Saturn to that re-radiated over an entire hemisphere and accordingly, the reflected light fraction will be reduced by a fraction of one-half. The final step in Newton's argument goes on to note that, "since light is rarefied as the square of the distance from the luminous body, if the Sun were √42 [this is the square root of 4200000000] times more distant than Saturn, it would yet appear as lucid." This is a wonderful result and given Saturn is located some 9.5 AU from the Sun, so the distance to the brightest stars (assuming that they have the same luminosity as the Sun) will be of order 615,670 AU which is about 3 parsecs (or some 10 light-years) away. While Newton's calculation is highly perceptive it makes a number of assumptions. The most questionable assumption, however, corresponds to the unstated fact that he assumes all stars have the same luminosity as the Sun. In general the distance estimate will increase according to the square root of the stars luminosity, giving, $d_{star} \approx \sqrt{L}(d\,/\,a^2{}_{Saturn}$ where L is the luminosity of the star in solar units, and d and a are the distance and angular diameter of Saturn respectively.

3. Herschel made this deduction based upon relative brightness estimates, and we have here assumed Newton's distance to Sirius. See Herschel (1785) *On the Construction of the Heavens*.

4 This measure was based upon the distances to some 69 globular clusters. See Shapley (1918) and Shapley (1919) for a summary of the distance estimates as they were then known.

5 This estimate was based upon the detection of various novae within the Andromeda nebula. I have suggested a date of 1917 for this result, as it built upon the detection, announced by Harlow Shapley, of faint novae in Andromeda in that year. The actual distance value adopted is taken from Curtis (1920).

6 Shapley based his result on the observed angular diameters to five globular clusters located within the LMC. The data and distance estimate were first published in the Harvard College Observatory, Bulletin No. 775 (1922).

7 Hubble (1925) estimates the distances to M31 and M33 through Cepheid variable calibration. His results were first announced at the 33rd Meeting of the American Astronomical Society held in Washington, D.C., in 1924.

8 In collaboration with Milton Humason, Hubble publishes his classic paper leading to Hubble's Law (Hubble 1929). Both galaxies are estimated to be 2 Mpc away on the basis of the standard-ruler method in which the sizes of elliptical galaxies are assumed constant.

9 From Gott *et al*. (2005). A Map of the Universe, *ApJ 624*, 463. The authors of this latter paper develop a shape-preserving map projection that displays, "the entire range of astronomical scales from the Earth's neighborhood to the cosmic microwave background." The distance given in the table corresponds to the most distant particles that we might potentially observe at the present epoch given that the Big Bang initiating the origin of the Universe took place 13.7 billion years ago.

Moore's Law and more

In many ways, the profile revealed in Figure 1 corresponds to expectation; throughout most of recorded history, the extent of measurements were confined to estimates for the size of the Earth, and the distance to the Moon, the Sun, and the planets out to Saturn. A clear change in the historically flat profile shown in Figure 1 occurs around the mid-16th century onwards—this change is only partly a consequence of Copernicus introducing his heliocentric cosmology. Indeed, with the freedom of intellectual thought and exploration that flourished with the onset of the Renaissance era, the measure of the deduced scale of the observable Universe increased steadily. Thomas Digges, for example, suggesting (with no observational evidence, of course) as early as 1576, that perhaps the stellar realm is infinite in extent—extending very much farther from the Earth, therefore, than the confines of a thin spherical shell just beyond the orbit of Saturn. The steady increase in technological ability along with the continued development and acceptance of purely abstract (that is, theoretical) investigations is at the heart of the observed scale increase as we move into the modern era. Indeed, the scale increase post *circa* 1550 follows that of a power or Moore's-like law. Without applying any refined techniques, we find that from the mid-16th century onward, the deduced scale for the size of the Universe increases by a factor of 100 every 60 years.

No Moore's-like law can increase forever[1], and given that the distance deduced for the size of the observable Universe as presented by Gott *et al*. (2005) is the physical limit to which any measurement can in principle be made, the profile of increase must once again become flat as we move through the rest of the 21st century and immediately beyond. The profile in Figure 1 demonstrates, in fact, a segment of a logistic-like curve rather than that of a continually increasing power law. We do indeed live in a special epoch—the time of the logistic curve switchover. Technically, of course, universal expansion will continue to operate and the size of the observable Universe will increase over time, with the increase being dictated by the presently unknown evolutionary characteristics of the dark-energy contribution. Remarkably, however, in the here-and-now, we have reached the limit of observability, and while many, many details about the Universe and its contents have yet to be resolved, we will only see significantly farther by allowing vast swaths of time to pass by.

The number of new discoveries that future generations of astronomers might potentially make as time moves forward is entirely unclear (although, see Harwit and Hildebrand 1986), and while we do not pursue the question here, the future of astronomical innovation has been ably discussed in recent times by Bondi (1970), Harwit (1981), Fabian (2009), Rees (2012), and Loeb (2014). Perhaps ironically, however, as deep time washes over us, the measurable size of the Universe will actually decrease, as all but the locally bound group of galaxies move beyond the cosmic horizon. Additionally, the cosmic background radiation will become increasingly redshifted to longer and longer wavelengths, ultimately becoming entirely un-measurable (Krauss and Scherrer 2007). The Universe is slowly, but assuredly, erasing its early history as time marches resolutely onwards (Adams and Laughlin 1999). Fortunately for us, however, we live at a time, indeed at an insanely short moment in the possible history of time[2], when the origin of the Universe is still knowable.

To reiterate the point of our argument, in terms of the history of astronomy, we live at a special time—the epoch at which we can measure and comprehend the actual size of the observable Universe. Such knowledge requires, beyond the theoretical underpinnings, the development of technologies appropriate to making meaningful measurements. The latter developments refer both to the ability to construct larger and larger telescopes to see fainter and more distant objects, the design of more and more sensitive detectors that operate across the entire electromagnetic spectrum, as well as the development of new cognitive ways of looking at and thinking about the Universe. Figure 2 shows the evolution and development of largest telescope diameters over time since the early 1600s,

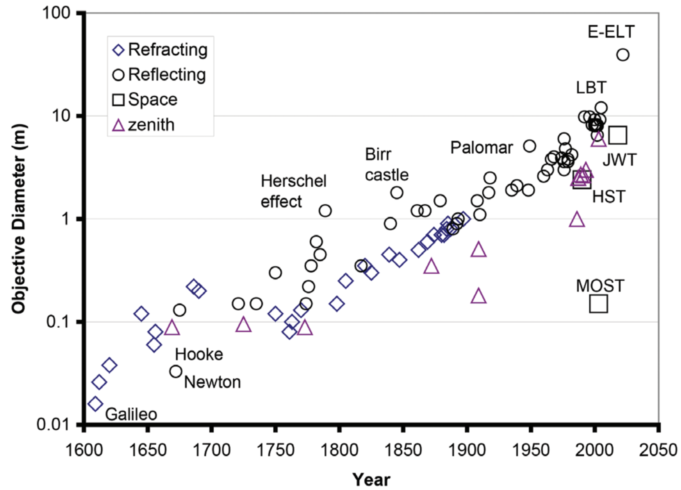

Figure 2 — The increase of telescope aperture size from 1609 to the present day (and a little beyond). Diamonds, circles, triangles, and squares correspond to refracting, reflecting, zenith, and space-based telescopes respectively. A number of data points are labelled and indicate Isaac Newton's first refracting telescope of 1668, Robert Hooke's first zenith telescope for 1669, the Birr Castle (Leviathan) telescope of Lord Rosse constructed in 1845, and the Palomar 200-inch telescope of 1949. The "Herschel effect" indicates the series of increasingly bigger telescopes constructed by William Herschel, culminating in his gargantuan 40-foot reflector, constructed between 1785-9. Other telescopes indicated are the Large Binary Telescope (LBT—first light in 2005), the Hubble Space Telescope *(HST—first light in 1990), the* Micro-variability and Oscillation Space Telescope *(MOST—operational since 2003). Future telescopes include the* James Webb Space Telescope *(JWST—hopefully being launched in 2018) and the European-Extremely* Large Telescope *(E-ELT—potentially seeing first light in 2024).*

while Figure 3 illustrates how the electromagnetic spectrum has been opened-up to astronomers over the past century (with a short extension into the near future). Indeed, Figure 3 reveals the incredible advancement in technological abilities and the development, beyond that of the historical optical, of new observational windows by which the Universe can be viewed (Hughes, 2012). Not illustrated as such in Figure 3, but equally as important, is the development of computational ability—as poignantly noted by Hughes and de Grijs (2007), "in 1900, astronomical calculations were carried out using logarithm tables and slide rules, but by 2000 we had the laptop and supercomputers." Remarkably, as well, the fast electronic computer is now the primary tool of theoretical research and numerical simulation.

Clearly, while many technological factors must be at play, Figure 2 shows, as one might expect, that the development of the largest telescope diameter has steadily increased since the early 1600s (Racine, 2004). The primary period of increase, however, occurred after *circa* 1750. From this time onward, the diameter of the largest refracting telescope increases as a near-perfect Moore's law, with the objective diameter increasing by an order of magnitude over a 15-year

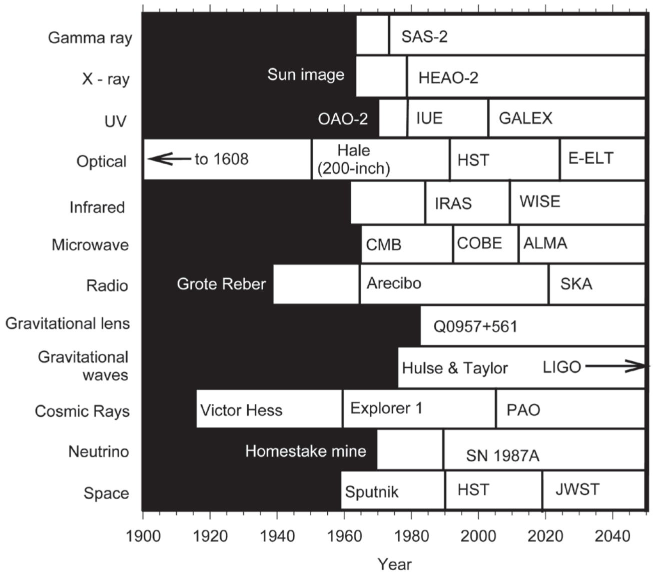

Figure 3 — Fiat Lux: revealing the observable Universe: 1900–2050. The upper seven panels indicate the key moments when new wavelength regions of the electromagnetic spectrum were opened-up for astronomical study. The additional panels indicate when observational techniques, beyond the electromagnetic spectrum, became available to astronomers. Gravitational lensing and gravitation-wave astronomy effectively began in the 1980s, although in the latter research area, astronomers are waiting for the Light Interferometry Gravitational Observatory (LIGO) to come on-line (hopefully in the 2020s). Elementary-particle-detection astronomy effectively began with the observation of cosmic rays, through balloon-borne experiments conducted by Victor Hess from 1911 to 1913; neutrino astronomy, and the direct probing of the Sun's deep interior, effectively began in the 1970s with the opening of the Homestake Mine neutrino observatory. Much of the electromagnetic spectrum is not available to the ground-based astronomer, and the opening up of those wavelength regions heavily (or totally) absorbed by Earth's atmosphere required the development of space-based platforms; it was the launch of Sputnik-1 in 1957 that heralded the beginning of the Space Age.

interval. With the completed construction of the 40-inch Yerkes telescope in 1895, however, the era of building large refracting telescopes came to a rather abrupt end. The development in the evolution of reflecting telescopes appears to have been much more complicated than that relating to refracting telescopes. Between *circa* 1750 and 1800, for example, the sizes of reflecting telescopes increased by an order of magnitude, although it was entirely the dedicated efforts of William Herschel that drove the increase. Following the construction of Herschel's 40-foot telescope, there was a period of approximate stasis that lasted all the way through to the beginning of the 20th century. From *circa* 1900 onward, the rate of telescope development once again increases with objective sizes growing by an order of magnitude before the close of the 20th century. To the far right in Figure 2, the new era of space-based astronomy is highlighted by the 1992 launch of the *Hubble Space Telescope*; also shown in the diagram is a marker for the *James Webb Space Telescope* (JWST)—presently scheduled for launch in 2018.

Are there limits to the growth in optical telescope size? The historical trend revealed in Figure 2 suggests that no, there are no specific limits to the sizes that future telescopes might attain—the real limiting factor, of course, being engineering complexity and the fantastically high costs associated with such structures. Ultimately there must be a limit to the size of the largest ground-based optical telescope, but it would appear that that limit has not as yet been reached. The next benchmark in optical telescope size will be set with the first-light opening of the 39-m European Extremely Large Telescope in 2024. In the more distant future, it may also transpire that the drive for making larger and larger telescopes will disappear, not necessarily because of escalating costs, but because of new innovations (Bondi 1970; Fabian 2009). One such innovation may build upon the recent ideas discussed by Kellener (2014) who argues that the classical diffraction limit of a telescope can be significantly improved upon through the quantum cloning of incoming, starlight, photons. In this case, by utilizing quantum physics, there is no specific need to increase the size of a telescope's objective in order to substantially improve upon its performance capabilities.

While the *Hubble Space Telescope* was the first, large, primarily optical telescope to be placed in Earth orbit, the opening-up of the electromagnetic spectrum for astronomical research had been in play for the previous 40 years (Figure 3). In terms of an historical timeline plot, the opening-up of the electromagnetic spectrum, beyond that of the optical region, spreads out like a veritable step-function. Indeed, this special epoch of rapid technological development spanned the decade following the launch of the first spacecraft, *Sputnik 1*, on 1957 October 4. In more recent times, additional techniques enabling the detection of elementary particles from space, as well as the study of gravitational waves and gravitational lensing, have been developed. In terms of understanding the Universe, the mantra is quite simple: the more we *see*, the more we shall know and comprehend. Additionally, as recently emphasized by Loeb (2014), we should not allow our collective imaginations to be stifled by expectation (as, for example, by an unquestioned acceptance of the Copernican Principle)—that is, we should never assume, as has often been the case throughout recorded history, that we know all the answers prior to the acquisition of empirical feedback and data. As Loeb (2014) writes, we should adopt an "honest and open-minded approach to scientific exploration."

Although cosmic rays were first identified by Victor Hess, during balloon-borne flights in the early 1900s, it was the development of radio telescopes, initiated through the pioneering work of Grote Reber in the 1940s, that jump-started a new era of astronomical research. Furthermore, with the introduction of space-based platforms, the short-wavelength region of the electromagnetic spectrum (γ-rays, X-rays, and the UV) was opened up to study. Likewise, innovation in detector design during the 1960s enabled the initiation of ground-based infrared and microwave astronomy—the first great triumph of the latter field being the discovery of the cosmic microwave background by Arno Penzias and Robert Wilson in 1965. In the mid- to late-1970s, gravitational-lensing techniques were developed following the discovery of the first lensed quasar Q0957+561—this technique now allows for the mapping of galactic dark-matter halos as well as the detection of exoplanets. The discovery of the binary pulsar PSR 1913+16 by Russell Hulse and Joseph Taylor in 1974 expanded the domain of tests on general relativity and can be reasonably taken as the onset of gravitational-wave astronomy. Presumably, as we move into the future, the field of gravitational-wave astronomy will move toward the direct detection of space-time ripples. In the elementary particle domain, neutrino astronomy essentially began in the late 1960s with the development of the Homestake Mine experiment directed by Ray Davies, with the first extraterrestrial neutrino source, supernova 1987A, being detected nearly 25 years after the first solar neutrinos were recorded. The recent establishment of the IceCube Neutrino Observatory in Antarctica has taken the field of neutrino astronomy to its next level of development, and, as of 2014, it has been recording about one high-energy astrophysical (non-solar) neutrino per month (Aartsen *et al.* 2014). Indeed, we are now beginning to see the slow trickle of ghostly particles that promise, eventually, to reveal deep stellar secrets.

While instrument sensitivity and design will no doubt continue to improve, there are very few entirely new areas into which observational astronomy might potentially shift as time moves on. Indeed, with the electromagnetic spectrum now fully accessible, it is only within the particle (both elementary and physical sample return) realm that further developments are likely to take place in the near future. Of critical importance to observational cosmology will be the development of dark-matter detectors. The development of such detectors is currently in its ascendancy and many experimental results have already been published—but the true picture of what is actually going on still remains unclear. Remarkably, however, the large-scale distribution of dark matter has already been mapped out in some situations via gravitational-lensing techniques (such as in the study of the COSMOS survey data by Massey *et al.* 2007). Dark matter, of course, is illusive by its very nature, and its present invocation may be just the first hint of a much broader and much more complex zoo of elementary particles that underlie universal structure.

Historically, astronomers have been concerned with the remote observation of their chosen cosmic prey; increasingly, however, as we move into the future, and especially so with respect to Solar System studies, it might be expected that the subject will be brought into the laboratory. Meteorites have been collected on Earth's surface for centuries, and they have long been recognized as fragments of main-belt asteroids. Likewise, after the *Apollo* lunar sample return missions of the 1970s, when rocks from the Moon were first collected *in situ*, it was realized that lunar meteorites, as well as meteorites from Mars, existed within terrestrial collections. Meteorites derived from the asteroid 4 Vesta are also now identified, and it is quite possible that meteorites from Mercury additionally exist within present-day collections, although none have been physically recognized to date. Direct sampling of Solar System bodies will no doubt continue as we move into the future. Already, small samples of refractory material from comet 81P/Wild 2 have been returned to Earth, along with a few grains from the surface of asteroid 25143 Itokawa. Future lander missions, it is to be anticipated, will eventually return material from the surfaces and interiors of all the terrestrial planets, the dwarf planets, as well as the Jovian planetary moon systems, for direct laboratory study. The doors to indoor, laboratory-based astronomy have barely begun to open to date, but it is anticipated that this is one area of observational astronomy that will see dramatic growth in the future.

Is there a final frontier for observational astronomy? One is inclined to say yes—yes, there must be. But, to repeat the sage words of Niels Bohr, "prediction is difficult, especially if it is about the future." New domains of observation beyond those of the electromagnetic spectrum, direct sampling, particle physics detectors, and spacetime geometry warping may yet be found—although what they might look like is currently unclear (Loeb 2014; Fabian 2009). Perhaps the ultimate observational tool, although the statement at first seems like an oxymoron, is computer simulation. The point here being that computers just generate numbers that are based upon a set of specified equations—in no direct manner can any computer simulation be called reality. Computer simulations are at best an abstract representation of what we think we know is going on, and they are a guide to what might conceivably be possible.

Much has been written of late about the idea that the Universe is *just* a mathematical structure (see *e.g.* the wonderful book by Max Tegmark, 2013), but to say that the Universe is describable through mathematics is a very different statement to that which says the Universe *is* a mathematical structure, and that our Universe is just one expression of an infinite number of possible Universes (White 2013). Indeed, as a theory of everything, the Universe as a mathematical structure is rather a cop-out, since it attempts to explain everything, allows all things that can possibly (even impossibly)[3] happen to happen in an infinity of infinitely dividing Universes, and yet provides no apparent answers to anything connected to human reality. Such theories not only lose contact with physics and astronomy as empirical scientific disciplines, they additionally seem to completely ignore consciousness itself. Perhaps the deeper anthropic question is, do we study the Universe to understand it from a *human* perspective, or do we study the Universe in a way that makes *us* a totally irrelevant and meaningless add-on (dare one say a mere "app"). Such philosophical quibbling aside, it is the case that much of present science, astronomy very much in the forefront, is already highly dependent and even predicated upon the *observations* derived from computational simulations. Indeed, there appears every reason to suppose that massive computer-based simulations will constitute the ultimate frontier of all sciences—observations of the actual Universe and laboratory-based experimental physics providing but a limited subset of boundary conditions[4]. Philosopher Clement Vidal has speculated on this particular theme in his recently published book *The Beginning and the End* (2014), and indeed, he develops the idea of *cosmology in silico*, in which computer simulation experiments play the same role as empirical experiments in present-day science. An early example of this latter process is presently being played-out through the Illustris Project (2014), in which galaxy formation is being investigated via large-scale cosmological simulations.

Once again, is there a final frontier for observational astronomy? At best, and in a seemingly contradictory fashion, it seems the answer is both yes and no. Certainly, there seems to be every reason to expect observational astronomy to expand both its scope and domain as we move into the future. Ultimately, however, it would seem that, from what one can read of current trends, in the not-so-distant future, observations will turn ever inward, moving away from empiricism and eventually becoming the judged output from ever-more-complicated experimental computer simulations. This is the exact opposite to the situation recently called for by Loeb (2014), who suggests that what we should really be doing is to give "priority to evidence over imagination," and let "nature itself guide us to the correct answer… [recognizing] that nature is much richer than our imagination is able to anticipate." As always, the future path for astronomy, no doubt, lies somewhere between the two extremes set by the enforcement of strict empiricism and the limitless (?) possibilities of *scientia in silico*.

Expanding thoughts

In terms of our knowledge of the scale of the Universe, and the ability of astronomers to study it over all wavelengths of the electromagnetic spectrum and via elementary particle detectors and the measurements of gravitational space-time warping, we live in an extraordinary special epoch. Counter to the bland thinking that results from the dogmatic and rigid imposition of the Copernican Principle, there are special epochs in which we, that is humanity, are the central players and there are also times when special developments and extraordinary advancements take place. On a grander philosophical scale than we have hitherto discussed, Deutsch (2011) has recently criticized the rigid application of the Copernican Principle (under the guise of the Principle of Mediocrity) as leading to parochial thinking—that is, views that unnecessarily narrow our expectations and outlook. Ironically, Deutsch notes, the strict adherence to the Copernican Principle ultimately leads us to an anthropocentric world view—the very opposite of what the principle claims to avoid. By such arguments,

Deutsch rejects the famous lines of J.B.S. Haldane that, "the Universe is not only queerer that we suppose, but queerer than we can suppose." Yes, the Universe is most certainly queerer than we suppose, but that does not mean it is inexplicable, and that we can never comprehend its make-up and content. Deutsch places humanity front and centre in the Universe by defining *us* as being "entities that can create explanatory knowledge," and this special ability applies whether other extraterrestrial intelligences exist within the Universe (or not, as the case may be). Indeed, Clement Vidal (2014) picks-up on this very same theme in his book *The Beginning and the End*, where it is posited that, "we are not merely spectators, we are actors in the great show of cosmic evolution." Vidal is searching to understand the role of intelligent life within the cosmos, ultimately moving toward an all-encompassing worldview, in which he sees intelligence as a guiding mechanism for universal heredity, "thus playing an essential role in the Darwinian evolution of universes." Such concepts echo Thomas Nagel's guiding principle that mind is, "not just an afterthought or an accident or an add-on, but a basic aspect of nature" (Nagel 2012).

Continues on page 72

Pen & Pixel

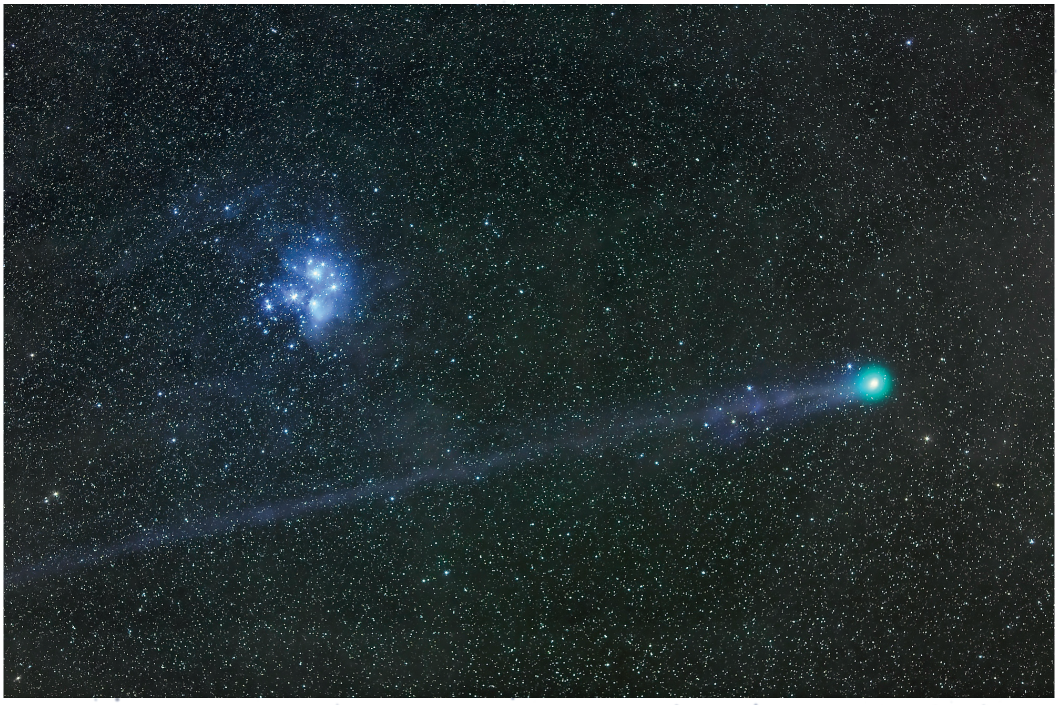

Figure 1 — Steve Altstadt and Sheila Wiwchar of the Winnipeg Centre combined efforts to capture Comet Lovejoy as it passed the Pleiades in late January. Steve used a Canon 5D MkIII at ISO 1600 and a 135-mm f/2 lens at f/2.8 and an exposure of 2.5 minutes for each sub frame. Sheila combined 20 frames to produce this delightful meeting of comet and cluster.

Figure 2 — Warren Finlay of the Edmonton Centre provides us with this digital painting and a description of Comet C/2014 Q2 (Lovejoy). In Warren's words: "I was fortunate to observe this comet from Banff recently, with the splendour of the Rockies surrounding me, and which inspired the attached painting. The comet was only a few degrees above the mountainous horizon when I observed it, so atmospheric extinction was large and its tail was not evident. Thus, I painted it without a tail (although if you look closely, and from the right angle you might convince yourself that there is a ghost of a tail). While the location I was at has lent itself to many en plein air *paintings of Mt. Rundle, it was −21 °C on my car's dashboard thermometer when I arrived to observe this comet."*

Figure 3 — The Victoria Centre's Dan Posey used a Tele Vue 127 and a total of 2½ hours of exposure in both visible light and Hα wavelengths to collect enough photons to produce this colourful representation of the Orion Nebula. Dan used a QSI 583c camera from the Victoria Centre Observatory. Exposure was 6 × 20 m in Hα and 13 × 10m in colour.

Figure 4 — Dan Meek has caught the astrophotography bug and sends along this image of Messier 81 in Ursa Major to the Journal. *The image was taken from Calgary in January and is an Hα RGB composite with a total exposure of 330 minutes using an NP127 telescope and a QSI583wsg camera. The Hα component of the exposure enhances the bright-red hydrogen nebulae in the galaxy, which lies at a distance of 12 million light-years.*

Continued from page 69

I have now moved far beyond the intended topic of this article, but the preceding thoughts highlight the necessity of breaking free from a blind acceptance of our supposed cosmic mediocrity and the non-specialty in both time and space of human intelligence and ability. The Copernican Principle, as an all-encompassing philosophical framework, has largely outlived its usefulness in the practice of modern science[5]). Pointedly, there are epochs of special and extraordinary achievements in the history of the Universe, and likewise humanity (situated as it is on a truly remarkable planet, located within a highly special zone within the confines of the Solar System, which is in turn located at a quite specific and special location within the galaxy—see *e.g.* Lineweaver *et al*. (2004), which is assuredly assuredly not irrelevant to the recent past, the present, and the future of the Universe. ✶

Endnotes

1 Moore's law was originally applied to measure the doubling time for the number density of transistors that could be placed upon an integrated chip. The longevity of Moore's law over time, however, is partially due to the fact that once having seen the rule established, then manufacturers then used it as a guide to future development.

2 The lifetime of ordinary matter is set by the proton decay time, currently thought to be of order 10^{33} years, and accordingly we live at a time when the Universe has barely achieved one 10^{-24} of its potential ordinary, atomic matter, building phase.

3 By impossible, I include such wonderfully ludicrous structures as Boltzmann brains (for a discussion, see Cirkovic 2012).

4 The idea that we might be living in a computer simulation, developed and overseen by some external intelligence is not considered here—but see, for example, Bostrom (2003) and Vidal (2014).

5 Perhaps the only remaining domain where it is of passing importance is in cosmology, where the assumption that our view of the Universe is not special carries specific interpretive meaning—see *e.g.* Valkenburg, Marra and Clarkson (2014). Even from a cosmological perspective, however, we live in a special epoch, when dark energy dominates Universal expansion.

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Featured Articles / Articles de fond

The Launch of *Orion*: The Return of Human Spaceflight

by Nicole Mortillaro, Associate Editor-in-Chief

There was a time when America's space program meant something. It was inspiring. Children wanted to become astronauts; the country dreamed about building bases on the Moon, of colonizing Mars, of heading out into the stars.

And then it all came to a grinding halt.

The Apollo program was the last great foray into space by the United States. After six successful missions to the Moon, the program ended in 1972.

That's not to say that NASA hasn't had an impressive legacy of unmanned missions. Early missions included *Voyager* and *Galileo*. Most recently there's been the Mars Exploration Program, with Opportunity, Spirit, and Curiosity roaming the surface of Mars and the impressive *Cassini* mission that has given us so much valuable information about Saturn and its system. There has also been *Venus Express,* and *MESSENGER* that has sent back amazing data on Mercury (which will come to an end early this year). But manned missions are still relegated to science fiction.

Then in 2004, President George W. Bush announced a focus on returning Americans to the Moon. Out of that was born the Constellation program.

"We will build new ships to carry man forward into the Universe, to gain a new foothold on the Moon, and to prepare for new journeys to worlds beyond our own," President Bush told a crowd at NASA headquarters in 2004.

But then, once again, America abandoned the Moon.

In 2010, President Barack Obama announced the cancellation of the Constellation program. However, manned exploration wasn't abandoned altogether. Instead of the Moon, Obama announced a new vision: Mars.

The *Orion* capsule, a relic of the Constellation program, would be part of the new vision.

NASA's *Orion* capsule will be the re-entry vehicle that returns humans safely from a mission to Mars (the European Space Agency is building the service module). However, it will also be used to go to the Moon and back or to a near-Earth asteroid for a retrieval mission.

Figure 1 — Orion, in anticipation.

Orion will eventually launch aboard NASA's new *Space Launch System* (SLS), the most powerful rocket since *Apollo*'s *Saturn V*. SLS is more powerful than Saturn by 10 percent.

Lockheed Martin (the contractor building the *Orion* capsule) and NASA, conducted several tests on the *Orion* capsule here on Earth, but a true test of the new capsule's capabilities needed to be undertaken.

NASA scheduled the first test launch of *Orion* for 2014 December 4 aboard a United Launch Alliance *Delta IV Heavy* rocket (the SLS is still under development).

Some of the critical systems that had to be tested during the flight—called Exploration Flight Test 1 (EFT-1)—were the launch abort system, heat shield and the computer systems, and several other aspects including control.

I was fortunate enough to cover the EFT-1 for Global News, and the experience was truly amazing, particularly as it was my first launch.

The mood at the News Center at the Kennedy Space Center was palpable. Many of the old-timers—those writers and photographers and even NASA public affairs employees—said that they hadn't seen this much interest since the Shuttle program, which ended in 2011.

The launch was scheduled for 7:05 a.m. December 4. On the night of December 3, media was taken out to launch pad 37 for the rollback of the tower around the *Delta IV Heavy*. It

Figure 2 — Launch!

was truly an amazing sight. The orange and white rocket was ablaze in lights as the tower crawled back, almost imperceptibly. Remote cameras, set up by seasoned rocket photographers, dotted the grounds. When we were told to leave, most lingered, snapping selfies with *Orion* poised atop the rocket in the background.

We arrived back at the News Center around 1 a.m. and settled in for the night. The large room would serve as a bedroom for many of us who couldn't be bothered heading back to our hotels only to get an hour or two of sleep. But among the snores of the weary, was the excited chatter of many, myself included.

The next morning we boarded our buses at 5:00. I was fortunate enough to sit beside a former NASA employee and older gentleman who was anxious to share his many stories of past launches. Admittedly, however, I dozed off for a few minutes as our bus trundled the long route to the NASA Causeway, a popular location to watch past Shuttle launches.

I awoke to a sight that surprised me: thousands of people—a reported 30,000—had lined the Causeway, with food stands, excited laughter, and music. It was a veritable festival. These weren't media, but the public, set to watch the first step to returning America to space.

But the launch experience was a rollercoaster.

First, the countdown was stopped when it was believed that a boat was on the range, meaning that it was in a restricted area just off the coast where it could be hit if there was a total failure of the rocket (it wasn't). The countdown resumed, and once again, the excitement built.

But then, another hold. High winds exceeded the acceptable limit. Once that issue was resolved, the countdown once again resumed.

I must admit that at this point, I was more than a little jaded. I'd sat on the brink, listening to the go/no-go call for launch, my excitement building, only to be crushed—twice. But the countdown resumed, and once again, my hopes soared.

And then there was another hold. This time a valve failed to close. And that was the final call. The countdown was terminated, and another launch attempt was scheduled the next day.

The scrub allowed me to get some rest after almost 36 hours of no sleep—a definite plus.

The next day, the countdown resumed. Once again, we headed out to the launch pad at 5 a.m. Instead of the sky dotted with holes of blue, it was mainly overcast. I was skeptical that *Orion* would launch, particularly because there was just a 40 percent chance of a go.

But at 7:05 a.m., a ball of fire ignited around the *Delta IV Heavy*, and it lifted slowly into the sky. Cheers erupted along the Causeway (which had fewer people than the day before) and shutters clicked, marking the historic occasion.

The mission was an overall success. The heat shield performed well; the launch abort system was flawless; and engineers learned about how radiation affects various computer systems aboard the capsule.

The next launch, called *EM-1*—which will take the *Orion* capsule around the moon—is scheduled for 2017. However, with a changing of the guard at the White House in two years, it will be interesting to see if Mars is still in the running, or if the Moon will be the focus of future manned exploration.

Whatever the destination, I'll be there. ✶

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My "Finest NGC" Quest!

by Rick Stankiewicz, Unattached Member
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The RASC has a great observing program to help stimulate and organize members to learn the night sky and to experience some amazing sights along the way. My quest for the RASC's "Finest NGC" certificate started in July 2009 and ended in September 2013. The New General Catalogue (NGC) includes 7840 numbered objects in the night sky. This certificate is comprised of 110 objects from this catalogue that are not also Messier objects. The idea is that you build on your observing experience.

I had completed the Messier Certificate in 2007, joining 307 other people since 1981 to do so. What a great opportunity to educate yourself about the night sky. You do have to be a RASC member to participate in most of these programs, but it is worth the price of admission. I thought it would be neat to try for another level by kicking it up a notch. What a challenge it turned out to be (at least for me)!

I picked away at the easier objects initially. Then I got serious and purchased a new telescope, so I have made most of my observations for this certificate with a 12-inch (305-mm) SkyWatcher Dobsonian reflector. My eyepiece of choice was a Meade 5000-series 24-mm SWA (62.5×). Maybe this was not totally necessary, but it sure made it fun; I am getting use out of my equipment, and it is getting me out under the stars. To me, this is what it is all about and it does not hurt that you end up with a record of your observing efforts.

Sounds easy enough with equipment like this, but you need a few more things to complete the challenge: an accurate finder, a star atlas, nebula filters, good weather, clear skies, and patience. I found that usually one of these elements was missing on any given night. Often the "spirit was willing, but the body was not," or the weather would not cooperate. It does take time, and it was not simply a matter of finding the object listed, ticking it off your list, and then go on to the next one. Instead, each "find" had to be sketched and logged on a separate sheet with your exact observing details before moving on to the next object. It should go without saying that no GOTO scopes are allowed, unless used manually. Yes, you need a good star atlas and ability to "star hop" your way around the constellations, but it can be done with some practice and it is fun.

I can honestly say that if I know where I am going, I can usually beat most GOTO scopes at getting an object in the eyepiece. More than once, I had my finder on the spot I wanted and then looked in the eyepiece to see that the object was dead centre. Going through the effort of a certificate does give a sense of accomplishment, plus, as an added bonus, you get to know your gear and you learn the night sky. It is worth a try. Once you have started by getting your "Messier Certificate," the "Finest NGC Certificate" is a logical and challenging next step. I highly recommend it, if observing and learning the night sky is your goal. I guarantee your journey through the heavens will be full of surprises and rewarding in the end, and you will have the logbook and certificate to prove it! I have become the 110th person to be awarded this certificate since it was first offered in 1995.

Where to from here? Maybe I will try to shoot for the Moon with the "Isabel Williamson Lunar Observing Certificate," or I may consider the "Deep-Sky Challenge." Whatever I do, I will be having fun under the stars for years to come. Why not join me? ✶

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- Discovery through the scientific method

Binary Universe

SkyTools 3 Professional

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

Never has one piece of software so affected my astronomy.

SkyTools by SkyHound has transformed what I do. Now my observing regime includes pre-planning before a session, verifying targets in the eyepiece or camera chip, crossing off completed observations, and then following up after a session with further verification, life list updates, and logging.

After joining the RASC, I (happily) started a lot more visual observing. And, after many visits to dark-sky sites, I experienced a number of difficulties.

I was seeing ***beyond*** my paper charts. As much as I love my *Tirion SkyAtlas 2000*, I could easily see stars fainter than those shown in its beautiful pages. The *Pocket Sky Atlas*, while helpful in the city, proved to be limited in the country. My abilities improved, and by 2008, in my trusty 8-inch SCT, I was seeing magnitude 13.8 stars. I had heard that imaging would show objects two magnitudes dimmer, and so I wanted an app that could go deeper.

My dissatisfaction continued as I tried various software applications. Faint stars did not show on the computer at all or were clearly in the wrong locations. I needed an accurate tool. A big issue was that I always seemed to be looking at the same objects. I need targets, goals, new challenges. When I sit behind the eyepiece, I need a list. Time and time again, I came away unfulfilled from my evening under the stars if I didn't see something new. I was using various paper-based lists: the Messier catalogue; the seasonal suggestions from *Turn Left at Orion*; and monthly selections from the astro-magazines, but I was frustrated.

I wanted everything in one tool: accurate, current, celestial-object data; stellar databases with stars beyond magnitude 15 or 16; suggested targets on a given evening. Oh, and a rotatable field of view! After research and hearing some very favourable recommendations, I settled on an astronomical planner. Specifically, I procured *SkyTools 3 Professional* with the extended databases (and this article refers to said edition).

When *SkyTools* launches, it presents a screen with a list, from the last-used group. The software comes with a few lists built in, but more can be added. One can make a custom list from scratch, download or import a list that another person has shared, or have the app make a list automatically based on the date, location, and other criteria. I often use a hybrid approach, adding some items I've heard about, perhaps from a magazine or friend, some past targets that I missed or that need review, and accepting suggestions from the auto-generated lists. The searching tools are very powerful.

Lists can include the Moon, the Sun, major and minor planets, current asteroids and comets, single stars, binary and multi-star systems, variable stars, current novae and supernovae, open clusters, nebulae, globular clusters, cometary globules, galaxies, galaxy groups, even quasars. Once the preferred list is selected, it can be sorted and filtered. One might sort by the name of an object or its type, or maybe by its viewed or logged status. During a session, perhaps the best way is by the "Optimum" column, which arranges the objects in the best sequence for viewing or imaging. Targets setting in the west are shown first

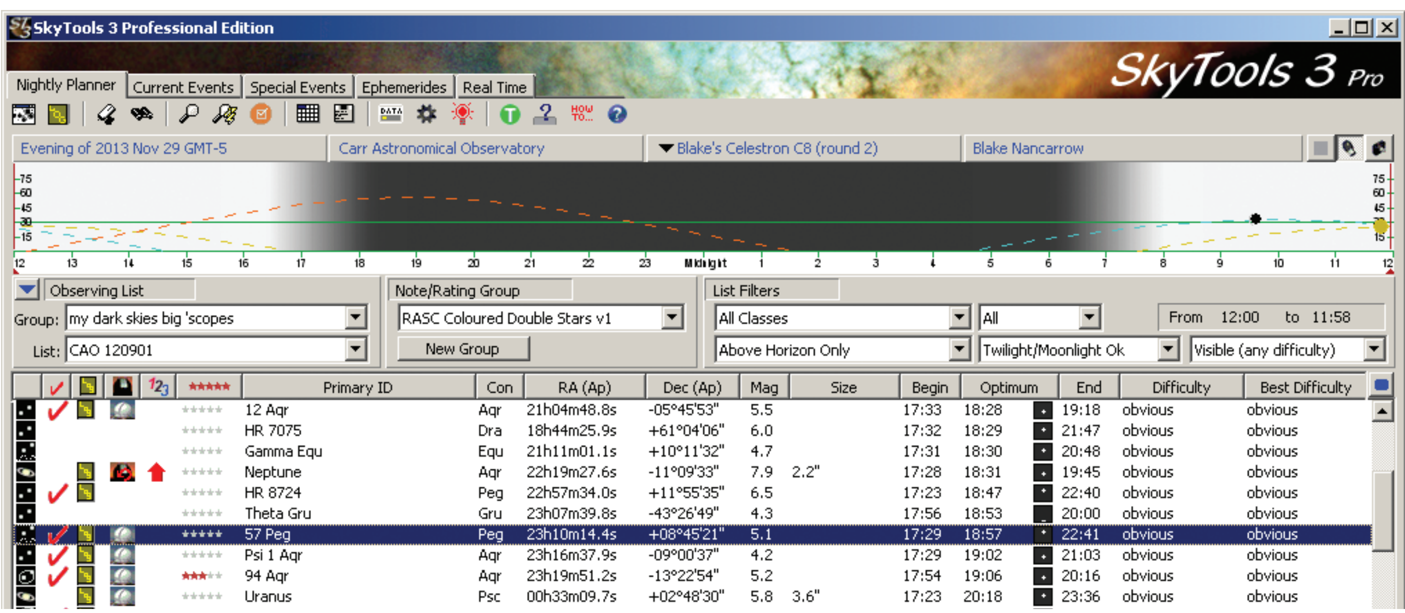


Figure 1 — SkyTool's opening page showing the visible objects list (57 Peg highlighted), the darkness and visibility graph for 57 Peg, and the background information and tabs.

to help you get them done before it's too late; quarry rising later in the evening, you can worry about as the night advances.

An observing list can be filtered in a variety of ways, making very large, intimidating catalogues more palatable, doable, and yet still challenging. During a star party for the public, for example, I use only targets that are "Obvious" and above the "two air mass" limit.

I find the "Night Bar" a useful tool to help me assess the best viewing time for an object. In this display, the selected object is plotted with a red, dashed, curving line that represents its altitude through the night (Figure 1). The highest part of the arc shows when it culminates. A yellow dashed line shows the Sun; a cyan line, Luna. These arcs are superimposed on a bar, centred on midnight, that gradually darkens as the Sun sets, lightening a few hours later. Even the degree of darkness is simulated in the Night Bar. This is just one of the many places where the tool takes into consideration the local light pollution, Moon phase, humidity, observer's age, and other complications.

SkyTools's lists show a good amount of data on an object, but more lies beneath. Double-clicking on an object (or using the "i" keyboard shortcut) brings up the "Object Information" panel. For a planet: phase, distance, and physical characteristics are noted along with its moons. Variable-star maxima and minima are shown. Detailed information on double stars is noted, including the certainty and period of the orbit.

The list management, filtering, and sorting, speak loudly of the *SkyTools* engine: it is, ultimately, a powerful database. The extensive and cross-referenced data suits the many needs of the serious astronomer. How much would you pay for this amazing tool? Wait! Don't answer! There's more! *SkyTools* does charts!

Various star charts can be shown for a selected object (or objects). This includes the "Overhead" chart which renders a circular display not unlike that of a planisphere. The "Naked Eye" chart shows a view, somewhat zoomed, in a less-distorted display. The most powerful chart is the "Interactive Atlas," where you can freely move, pan, centre, and zoom. This view can be made to show all possible objects from the vast databases regardless of conditions or location in the celestial sphere. Keyboard shortcuts again: "o," "n," and "a" can be used to rapidly open these charts.

While awkwardly named, the "Eyepiece/Imager Context Viewer" shows what one can expect to see—and I use it regularly. When I'm observing visually, the software shows me a circular field of view that matches my telescope-ocular combination. It even takes into account magnification and reduction accessories. And, once again, *SkyTools* simulates the view, configured, as best as possible, for stray light, pupil size, elevation, and so on. When setting up an imaging run, the Context Viewer shows a rectangular field that matches the chip and optical-train particulars. This view can be rotated, which is very helpful when using a mirror diagonal or turning the camera.

One final view, which I must admit I'm still adjusting to, is the "telescope view" or "Visual Sky Simulation." It includes three panels: views for the naked eye, the view in the finder scope, and finally the view in a selected eyepiece (Figure 4). With this little treat, one can perform a modified star hop in seconds! When you can see the naked-eye guide stars, it is most impressive how well it works.

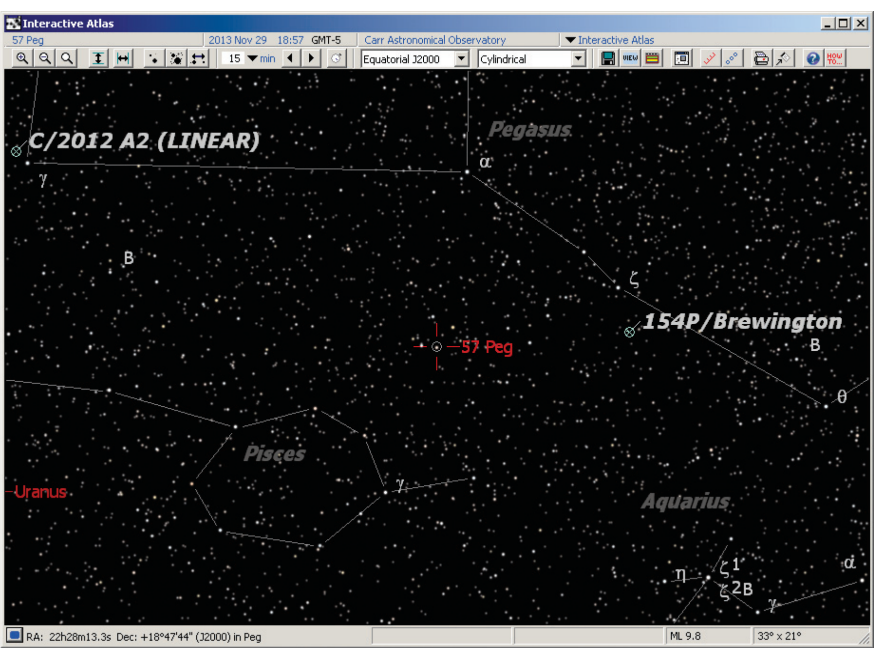


Figure 2 — A view of SkyTool's "Interactive Atlas" display, centred on 57 Peg.

SkyTools includes two similar sections for anticipating Solar System events such as appulses and conjunctions, eclipses and occultations, satellite and shadow transits, and the peaks of meteor showers. The "Current Events" tab is useful for predicting notable astronomical happenings in the upcoming future; "Special Events" is best for reviewing historical or far-future events. Often, I generate a monthly calendar display from these data.

There is an "Ephemerides" tab that can generate tables for an object's position. I typically use this when considering a comet's visibility. It can also be used to plot binary-star positions over time.

The final tab (in the Pro version) is called "Real Time," for telescope control. The application directly supports push-to telescopes using the Argo Navis or Sky Commander systems and

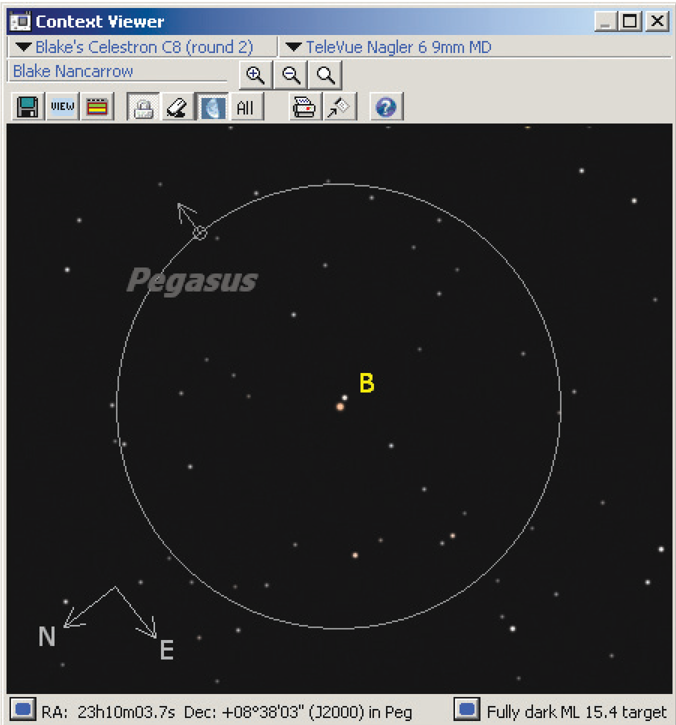


Figure 3 — The Eyepiece/Imager Context Viewer with 57 Peg.

it also supports ASCOM, which, of course, means essentially everything else. I have successfully driven a number of mounts with my little netbook computer, including a Paramount ME, NexStar 11 GPS (in alt-az), and my hacked Vixen Super Polaris/Gotostar (iOptron). I feel a tiny bit guilty using this feature, as it is so darned easy! I can add an interesting object to an observing list then slew directly to it. Boom! There it is. Being able to slew easily and rapidly is fantastic and means, for me, more time to collect photons.

Over the course of an evening, target status can be continuously updated. Items can be tagged as "Observed." I use the "Re-observe" status to indicate that I should try later, perhaps when the object is higher, or when the seeing might be better, or maybe earlier the following night. The status property is session-based and can be different for each observing list.

The next day (after sleeping in), there's still much to do with the tool. I often use the Interactive Atlas and Context Viewer charts to manually plate-solve images and to verify which companions of a multi-star system I was able to coax out of the darkness. In general, I find the charts remarkably accurate.

I also update my logged status. The "Observation Log," unlike the session status, is a permanent setting, and I use it to quickly tag items seen with certainty. In fact, many details can be recorded in each log entry such as the location, instrument, seeing and transparency conditions, and detailed notes. Setting the logged status allows me to generate new observing lists quickly for objects never seen—and that means I'm in good stead for the next session.

SkyHound provides different flavours of this amazing *Windows* application. The Pro edition is US$180. The Standard variant at $100 USD does not include the extended databases, the photographic tools, or real-time mount control. The Starter edition ($40 USD) is smaller still, aimed at novice astronomers with small instruments, and lacks the ability to create custom lists. There is a free trial mode in the Starter edition so you can stick your toes in the astronomy-planner waters. See the website (http://skyhound.com/index.html) for more information. It is relatively expensive software, but deep, club discounts are available!

SkyTools can do much more—I have only highlighted a part of its feature-set. It took me a while to fully understand it, but I really enjoying using it. I don't leave home without it. ✶

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.

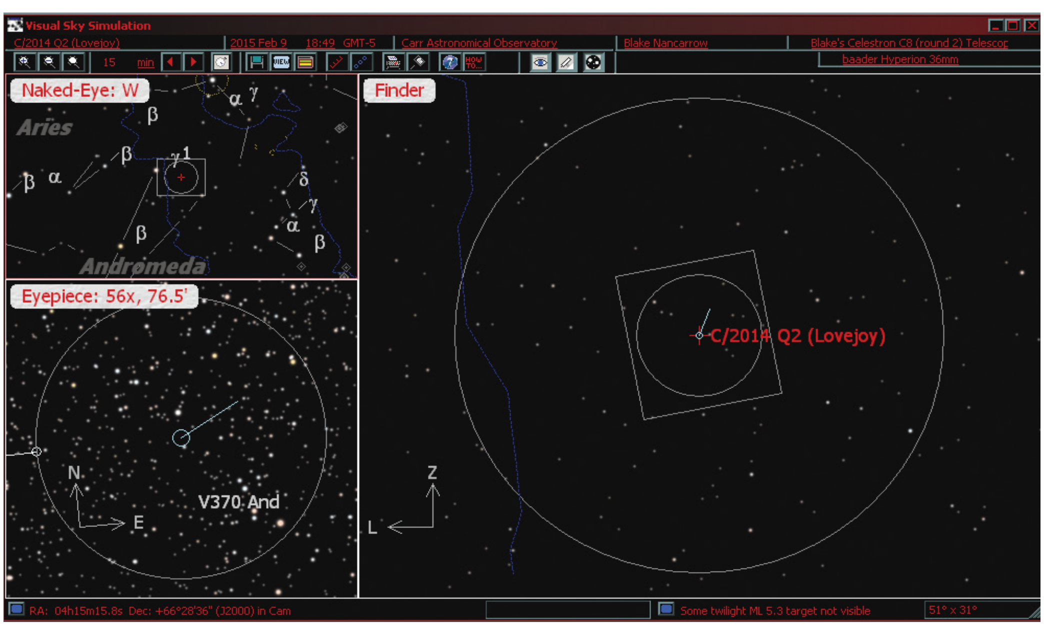


Figure 4 — The Visual Sky Simulation or "telescope view" display showing the location of Comet Lovejoy in naked eye, eyepiece, and finder fields.

Taking a Project to the Next Level—ASCOM

by Rick Saunders, London Centre
(ozzzy@bell.net)

Now that we've worked with some hardware and software in building Arduino projects, it's time to move on to where other folk's software can seamlessly control the gear that we've built. In the *Windows* world, this means ASCOM. What is ASCOM you ask? From Wikipedia:

> *ASCOM (an abbreviation for AStronomy Common Object Model) is an open initiative to provide a standard interface to a range of astronomy equipment including mounts, focusers and imaging devices in a Microsoft Windows environment.*

ASCOM provides a complete framework of methods and properties that allow hardware to be completely abstracted from the controlling software. This means that software can be written to a standard set of commands and protocols without knowing anything about the hardware at the other end at all. This is done through a "driver," a Component Object Model (COM) object that user software communicates with using the specified methods and properties for that class of device (telescope, focuser, *etc.*). The driver then speaks to the hardware to get things done (Figure 1). Linux provides the INDI framework that attempts to do the same but is outside the scope of this article.

The biggest advantages of using ASCOM are that other people's applications can control your hardware **and** that, using an ASCOM hub, multiple applications can connect to a single piece of hardware. I won't go into writing hubs in this article, but ASCOM provides one called the Plain Old Telescope Hub (POTH) that is quite simple to use.

Figure 1

To explain how ASCOM does its work, I'll use a focuser project that I just completed. The hardware is a normal Arduino-style build that accepts commands and then turns various pins on/off to do the work. This project is for an "absolute" focuser—a focuser that is told to move to a specific point. A "relative" focuser has no idea where it is and is only told to move "x steps" in or out. The focuser uses a standard 5-wire, unipolar, stepper motor to move the drawtube.

ASCOM, from its inception, has been built using Microsoft's *VisualBASIC*, which is still the preferred platform. Tools and templates are provided for either *VB* or *C#* using Microsoft's *VisualStudio* (VS) development environment. I use *VisualStudio Express 2013*, which is available free from Microsoft at www.visualstudio.com/en-us/products/visual-studio-express-vs.aspx.

ASCOM is available, also for no charge, from http://ascom-standards.org/. Download the main package and the developer tools.

Once VS and the ASCOM developer tools have been installed, it's simple to start programming. In VS, one just creates a new project and, from the list, selects "ASCOM driver." VS then asks what kind of driver is to be built. For this project, "focuser" was selected. And presto! A template for a focuser driver appears with several TODO comment lines to tell us where we have to add code.

ASCOM uses "properties" and "methods." Properties are things such as the position of the focuser or whether the focuser is moving, while methods are commands. The position property looks like:

```
Public ReadOnly Property Position() As
Integer Implements IFocuserV2.Position
 Get
  Try
   objSerial.Transmit("Fp;")
   Dim inp As String = objSerial.
   ReceiveTerminated(";")
     inp.Replace(";", "" );
   focuserPosition = Convert
   ToInt32(inp)
  Catch ex As Exception
  End Try
  Return focuserPosition ' Return the
  focuser position
 End Get
End Property
```

From the above, note that you can't tell the focuser what position it is at as the Position property is read-only. Here, my code sends the command "Fp;" to the Arduino, which then responds with a string containing the position. This may be "6257;". The code then strips out the semi-colon and returns the actual position as an integer.

I mentioned above that there is no way in ASCOM to tell the focuser where it is, but you can tell it where it should go. This is the "Move" method and in my code looks like this:

```
Public Sub Move(Position As Integer)
  Implements IFocuserV2.Move
  TL.LogMessage("Move", Position.
  ToString())
     If TempComp Then
        Throw New ASCOM
        InvalidOperationException
        ("Temperature_compensation
        enabled during MOVE command")
 End If
 If Position > focuserSteps Then
    Throw New ASCOM.
       InvalidOperationException("MOVE
       larger _ than maximum focuser
       position")
 End If
 focuserPosition = Position ' Set the
 focuser position objSerial.
 Transmit("Fg" & Convert.
 ToString(Position) &";")
End Sub
```

From above you can see that Move() takes an integer (the Position to go to) and then sends a command to the hardware that would be, if the desired position is 6923, "Fg6923;" and the motor turns.

There are several properties such as "isMoving," which tells the driver (and therefore the software) whether the motor is actually turning; and "MaxStep" that tells the driver, *etc*. how far it is allowed to go. A bit of playing will bring them all into focus when you give it a try.

In a perfect situation, there will be nothing that the user wants to do that won't be covered by the built-in properties and methods, but the world is never perfect. ASCOM provides three subs or functions that allow you to speak through the driver to the hardware. These are:

```
CommandBlind, which sends a command and
  returns immediately,

CommandBool, which sends a command and
  decodes the return string to return a
     boolean, and

CommandString, which sends a command and
  decodes the return string.
```

These functions are very powerful, but another person's software would need to know all about your hardware's command protocol in order to use them.

Using the ASCOM driver

For application software to use a driver, a "Chooser" is required that allows the user to select which driver is going to be used. The chooser is standard across all ASCOM client applications and looks like that in the Figure 2. The driver is selected in the drop-down box, in this case, my TOGA Focuser driver.

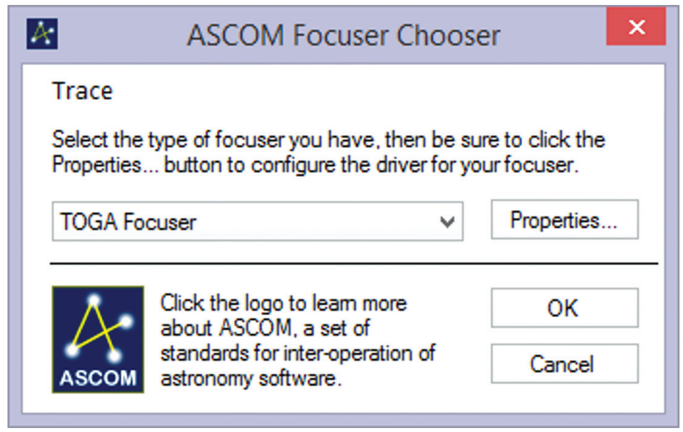


Figure 2

The rule in ASCOM is that configuration should all be done within the driver. Having something like MaxStep implemented outside the driver would mean that a third party may not be able to properly get things working. ASCOM provides a SetupDialog class to do this. The Setup Dialog is opened by clicking the "Properties" button in the Chooser. By default, the SetupDialogue is pre-coded for us to provide the Com Port (Figure 3). The rest is added by the developer.

Once the driver is built, it has to be installed. And ASCOM provides a framework to build and install the driver properly using Inno tools (download from www.jrsoftware.org/isinfo.php). Read up on it in the ASCOM developer documents.

Careful thought has to be given to using the SetupDialog. In my case, I had to modify and trim down the Arduino commands, in places merging two into one to get the thing to work. My project does temperature compensation on the Arduino. Other focuser projects do the whole thing in the ASCOM driver. The latter would make the command structure simpler, but I found that hiding as much as I could in hardware was the way to go.

An example of doing temperature compensation in software can be seen in the source code of the Arduino Jolo Focuser VS project (Google it, if you're interested). I found his code to be quite enlightening, though I chose a different path.

ASCOM Client Application

A driver is not much good without software that accesses it. Client software can be written in any language one wishes, but by using C# or VB, one takes advantage of the resources that are provided for *VisualStudio*.

The application that I wrote to access the driver (remember, any ASCOM-aware software can work my hardware through

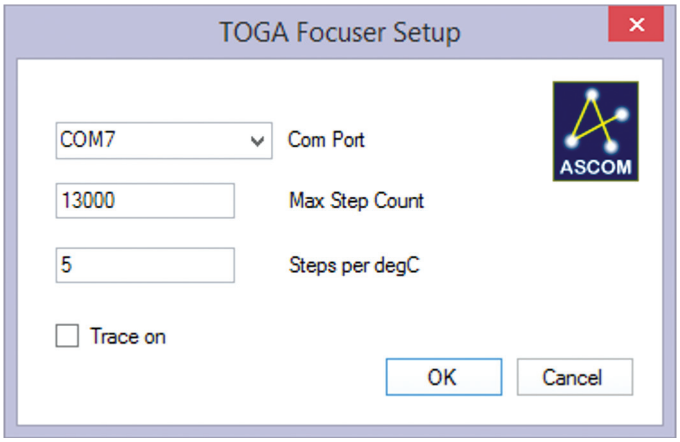


Figure 3

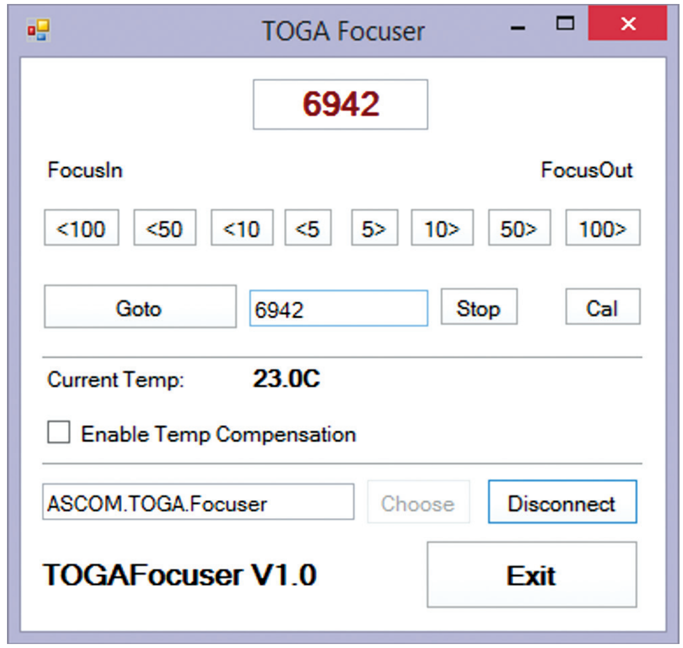


Figure 4

the driver) is shown in Figure 4. It does everything it needs to do and works fine. *MaximDL* also works fine with the focuser.

The software is fairly simple. The first time that it is run, one has to click the "Choose" button to invoke the ASCOM chooser. There, as seen in Figure 3, where the Com Port is selected (only actually available ports are shown), the MaxStep value and Steps Per degC value are entered (or the defaults chosen) and "OK" is clicked. This loads the name of the driver in the text box (Figure 4), in this case ASCOM.TOGA. Focuser. When the "Connect" button is clicked, the software connects to the driver (changing the button to "Disconnect") and the position of the focuser is shown in the box at the top of the window.

The temperature is constantly displayed and if the "Enable Temp Compensation" checkbox is checked (Figure 4), then the movement buttons are disabled and the focuser goes onto auto-pilot. Every three-degree change will cause a movement in or out by the number of steps specified by the "Steps Per C" item in the driver SetupDialog. Ain't technology amazing?

For great videos on how to write an ASCOM driver and client application, go to www.youtube.com/watch?v=XVlrDyIBd5I

For a video by the same person on writing an ASCOM client application, go to www.youtube.com/watch?v=SfFg5xoVKhg

Enjoy coding! ✶

Rick Saunders became interested in astronomy after his father brought home a 50-mm refractor and showed him Saturn's rings. Previously a member of both Toronto and Edmonton Centres, he now belongs to the London Centre and is mostly interested in DSLR astrophotography.

Dish on the Cosmos

Interferometry

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

One of the most scientifically exciting astronomical images from the past year was the image of the disk around the newly forming star, HL Tauri, which was made using the new Atacama Large Millimetre/submillimetre Array (ALMA). This image, reproduced in Figure 1, shows radio waves originating from cool dust surrounding HL Tauri, the relic of the disk that fed the formation of this new star. While the disk is beautiful, what captivated both the public and the scientific audiences were the small gaps visible in the dust, which pointed to the presence of proto-planets orbiting around the star and clearing the gaps. This striking image was enabled by the ongoing improvements to the ALMA telescope, which is slowly coming online after the end of its construction phase (see Second Light; June 2013, JRASC). ALMA combines unparalleled sensitivity to the radio waves emitted by the dust with an improving ability to achieve high *resolution*. But how can a telescope improve its resolution?

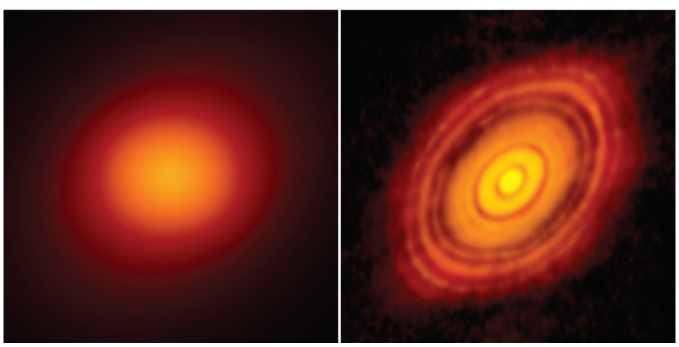


Figure 1 — Two views of dust emission from protoplanetary disks around forming stars from ALMA. The left image shows the HD163296 system and was taken by ALMA during its early test phases. The right image shows the system around HL Tau with gaps in the dusty disk attributed to clearing by planets. The clarity of the new image comes from moving some of ALMA's antennae to wide separations. Image credit: (left) ALMA (NRAO/ESO/NAOJ); E. Rosolowsky (right) ALMA (NRAO/ESO/NAOJ); C. Brogan, B. Saxton (NRAO/AUI/NSF)

Most readers will likely be familiar with the concept of astronomical seeing, where the apparent size of a star, typically measured in units of arcseconds, can be blurred by atmospheric turbulence here on Earth. Seeing also limits the ability of optical telescopes to resolve the separation between close binary stars. The resolution of an image is the apparent angular size of objects within the image, which for optical telescopes is usually limited by atmospheric seeing to about 1 arcsecond. For telescopes above the atmosphere, the resolution is no longer limited by seeing but by the wave properties of light. The study of optics tells us that the resolution of a telescope is about $\theta \approx 200{,}000\ (\lambda/D)$ arcseconds, where θ is the resolution of the telescope, λ is the wavelength of the light being studied, and D is the diameter of the aperture measured in the same units as the wavelength. Larger-diameter telescopes should have better resolution, and the primary reason why Hubble produces such amazing images is that, for yellow light with a wavelength of 500 nanometres and a mirror of 2.4 metres, the space telescope has a theoretical resolution of 0.04 arcseconds—far better than is achievable underneath the atmosphere through normal means, though astronomers and spy agencies both work on technology that can correct for the blurring of the atmosphere. The Earth-bound ALMA image has a similar resolution (0.035 arcseconds) to what Hubble can achieve, with a promise to improve further (*i.e.* get smaller) over the coming years. To understand this feat, we need to examine the origins of the angular-resolution formula.

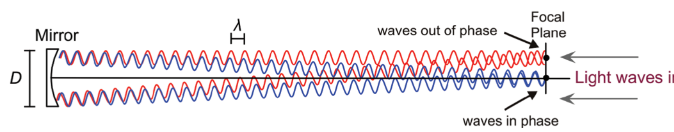


Figure 2 — A simplified telescope showing how wave interference connects the limiting resolution to the size of the telescope (D) and the wavelength of the light (λ). Incoming light (grey arrows) is reflected by the mirror. Waves that travel an equal distance add together (blue), but waves that travel distances different by half a wavelength cancel out (red).

The limitations on telescope resolution stem from the wave nature of electromagnetic radiation. Figure 2 shows a snapshot of two light waves in an abstract telescope. After these two light waves (grey arrows) enter the telescope, they travel down the length of the instrument, reflect off a converging mirror, and return toward the focal plane. The waves (now shown as red and blue waves for clarity, not representing the colour of the light) will converge onto the focal plane. What you should note is that waves that meet on the axis of the telescope, whose peaks and troughs arrive together (blue), will give a signal that is the sum of the wave amplitudes. These waves are said to arrive *in phase* and produce a bright spot. In contrast, reflected waves that reach the focal plane somewhere off the optical axis (red) may have the peak of one wave superimposed on the valley of another, so that their sum cancels out, leading to a dark point on the focal plane. Such waves are said to arrive *out of phase*. Go a little farther out from the optical axis and the waves will come back into phase again to form another bright spot.

A careful examination of the setup shows that this pattern is set by the distance that the waves travel in the telescope in relation to their wavelength. Waves converging at the centre

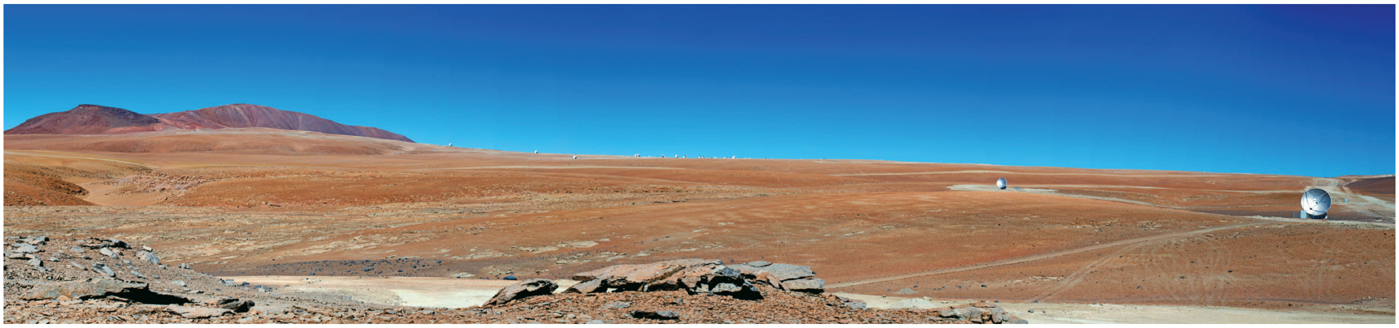


Figure 3 — ALMA antennae at remote stations. The central array can be seen several kilometres away in the background. These antennae will send the light waves they capture back to a central facility for combination with signals from all the other antennae. The large separations between antennae allows for high resolution images to be captured. Image credit: ALMA (ESO/NAOJ/NRAO)/S. Otarola URL: www.eso.org/public/images/ann14069a/

travel equal distances and arrive in phase. The two waves converging to the dark spot must travel different distances, with the lower wave travelling one-half of a wavelength further than the upper wave. For a single star, this geometry will lead to a natural (angular) size of the image, namely the distance between the central bright point and the the dark point formed by the first out-of-phase waves. This size is, in turn, set by the size of the telescope, since a larger diameter mirror will mean that waves hitting the edges of the mirror are farther apart. When these "edge waves" converge, a smaller difference in the angles will produce the same half-wavelength difference in distance, so the size of the image will be smaller. Similarly, shorter wavelengths will also have a smaller angle difference between the bright and dark regions. This is the physics behind the angular resolution formula.

ALMA achieves wonderful resolution by being an *interferometer*, using the interference properties of radio waves to make astronomical images. Interference describes how waves combine: they add when they are in phase and cancel when they are out of phase. While this sounds daunting, it is exactly the phenomenon that is described in the abstract telescope of Figure 2—all telescopes are interferometers! But when scientists discuss interferometers, we usually mean that the reflections are from two different mirrors rather than two parts of the same mirror. Radio-wave and millimetre-wave interferometers, like ALMA, are composed of different dishes that can be located far apart.

Radio astronomers have added two more innovations. First, instead of using reflectors to send the light to a common focal plane, the antenna signals are instead captured and routed over fibre-optic cables to a central location, where they are combined with each other to produce the interference. Figure 3 shows two of ALMA's dishes at remote stations, with the main array visible kilometres away in the background. These two dishes, and the 48 others like them that are scattered across the Atacama Plateau, will capture a wave, transform it to a digital signal, and send it back to the central station. The 50 dishes, acting in concert, thus provide the angular resolution of a telescope with a diameter equal to the separation between the dishes (kilometres), rather than just a single dish (12 metres). Unfortunately, when viewed from space, most of this telescope is just rocky ground with only a few "mirrors" scattered across its vast aperture. The interference patterns then corrupt the image quality, for the same reason that the spider of a secondary mirror produces *diffraction spikes* in optical telescopes, though with interferometers, the image corruption can be much worse.

This image corruption prompted a second radio telescope innovation, which came from Sir Martin Ryle and co-workers at Cambridge. They realized that the rotation of the Earth would spin the radio antennae relative to the sky, so that over time a given antenna would sweep out an arc across the aperture of an imaginary giant telescope, a process called *aperture synthesis*. In doing so, the moving antennae would "fill in" the gaps between the individual antennae and become more like a single, large reflector. This realization made high-quality, high-resolution imaging possible using interferometers, and garnered Ryle and his co-worker Tony Hewish the Nobel Prize in 1974. Interferometry, while genius, is still hard! To allow the signals to be combined correctly, the differences in paths between the individual antennae must be calibrated to a fraction of a wavelength or 0.02 millimetres for the images above. This engineering challenge has recently been overcome. By moving the antennae to large separations and successfully combining their signals, ALMA's vision suddenly grew sharper; and this enables discoveries such as the gaps in the disk around HL Tauri. This is only the first such image using these large separations, and ALMA's new, sharper views of the cosmos will soon start flooding in. ✶

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.

Second Light

A Multiplicity of Stars

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

When I was a teenage amateur astronomer, I used to enjoy the game of observing multiple-star systems to see whether I could find the dimmest or closest companion. I suspect that many readers have done the same. But did you ever wonder whether they formed in that configuration? Although I have no memory of wondering that myself, 40 years ago, in general, we know so much more about the process of star formation that it's very probable many readers have done so. Professional astronomers are interested in the topic, too, and Jaime Pineda of the Institute for Astronomy in Zurich, Switzerland, and his colleagues around the world, have just shed some fascinating light on the topic (see the 2015 February 12 issue of *Nature*). They have found a protostar surrounded by three other clumps of gas that will become stars in about 40,000 years. There is a close, binary pair between the protostar and one clump, with two more distant clumps that they expect will be lost to the system on a timescale of about half a million years.

Recent observations have shown that the "multiplicity" (a combination of the frequency of multiple-star systems and the average number of stars in such systems) is higher for protostellar and pre-main-sequence stars than it is in field stars, of which about half are in binary or multiple systems. The strong implication is that dynamical interactions early in the life of the stellar system remove some of the stars. But hitherto, there have been no direct observations of a multiple-star system in its earliest stages.

Inside the Perseus star-forming region, there is a dense core named Barnard 5. Star formation takes place inside such cores, where the molecular gas (out of which stars form) gets very dense. Barnard 5's core is known to have a filamentary structure, in which the densest knots of gas lie on curved lines, surrounded by less-dense gas. Pineda and his colleagues used the recently upgraded Jansky Very Large Array of telescopes in New Mexico to observe several transitions of ammonia

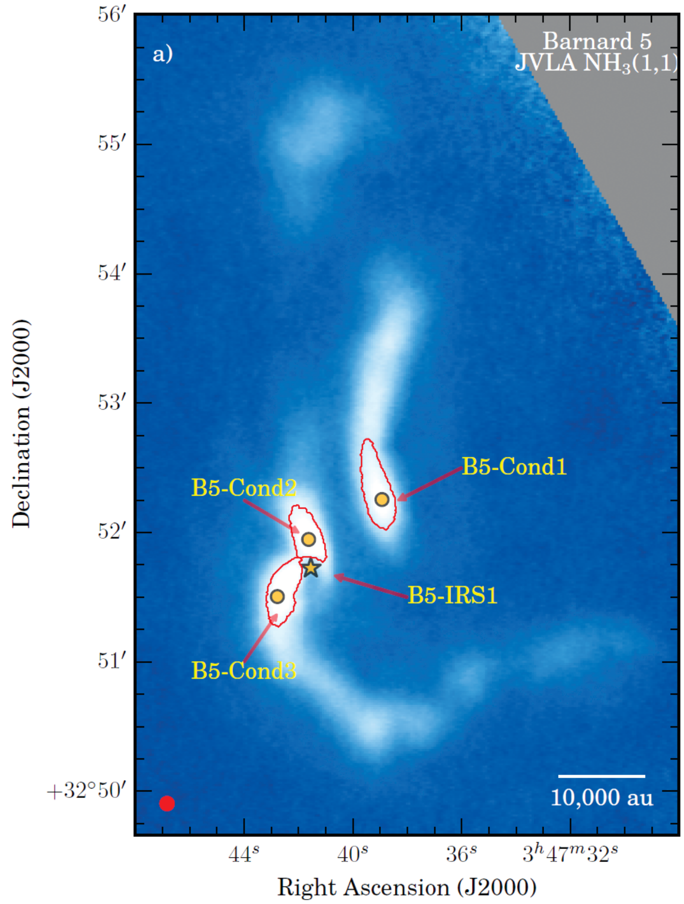


Figure 1 — The background blue and white shows the ammonia previously known. The red contours and circles indicate the condensation boundaries and centres, respectively, with the star symbol indicating the position of the protostar. The scale bar in the lower right shows the linear distance. The beam size is shown by the small red dot in the lower left corner. Image courtesy of Jaime Pineda and Nature.

molecules. Ammonia is particularly well suited to studying extremely dense gas in star-forming regions, because it is not too abundant. All someone would see would be the outer surface of the core, if they were using a tracer like carbon monoxide. It would be like trying to determine the shapes of buildings through a thick fog. Ammonia lines do not exist in a fog—they are a way to see through the fog, and determine the shapes of the underlying structures.

What Pineda found is that the filament resolves into three dense clumps of gas near the protostar B5-IRS1 (a contraction of Barnard 5-infrared source 1)—see Figure 1. He named the clumps B5-condensations 1-3. B5-cond2 is very close to the protostar—about 3300 AU away—while cond1 and cond3 are respectively ~5100 AU and 11,400 AU distant. Just because they are close, however, does not necessarily mean that they are physically bound to each other. To determine that requires measurements of their masses and velocities. The observed velocities are sufficiently close that there is little doubt they are associated with each other.

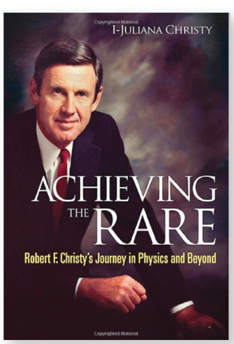
Determining the masses of the stars that will form from the clumps is considerably more tricky. When stars form, not all of the gas out of which they are born is expected to be accreted. Estimates range from about 25 percent to about 75 percent. Young stars usually power outflows of gas from their poles. But in this case, the extra gas in the filaments could well be accreted, in addition to the gas now in the condensations. Looking at the range of possibilities, Pineda concludes that the system will be gravitationally bound when the four stars have formed, but that only the binary formed by B5-IRS1 and B5-cond2 will survive longer than about half a million years—the other two will become field stars.

So the next time you are out observing from the list of binary and multiple stars in the *Observer's Handbook*, think about the fact that those systems probably were not born the way you are seeing them now. ✶

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

Reviews / Critiques

Achieving the Rare – Robert F. Christy's Journey in Physics and Beyond, by I.-Juliana Christy, xv + 349 pages, 16.5 × 24.5 cm, World Scientific Publishing, 2013. Price $38.00 USD (paper), $29.00 USD (e-book), ISBN: 978-981-4460-24-8.



Many graying scientists, like me, develop an interest in science history and biography, in part because we realize, from experience, that science is done by real people, within a real social context. It is especially important for educators to remember this, so we can encourage and mentor young scientists at every stage of their career, from school and university, through graduate school, and into and through their eventual career. In this context, *Achieving the Rare* is a wonderful account of the academic and personal life of Robert Christy—an outstanding physicist and astronomer—and the circumstances that led to his many and varied accomplishments. Author Juliana Christy is an accomplished astrophysicist, and his wife of four decades.

And why are we reviewing, in this *Journal*, a biography of a scientist who is best-known (or actually *not* very well-known) for his seminal work in theoretical physics, in the Manhattan Project, and in university administration *in the U.S.*? It's because he was born and initially educated in Canada, as was his wife and biographer. Indeed, Juliana and I were classmates at the University of Toronto (she was Inge Sackmann, back then), and their first brief encounter was in Toronto, in 1968. Christy also made fundamental contributions to the study of stellar pulsation—my own research area. His work was integral to my own research, teaching, and graduate supervision.

Robert Christy was born in Vancouver, B.C., on 1916 May 14. His father died when he was 2, and his mother died when he was 10. Although he was provided for financially and well cared for by his relatives, and is said to have had a happy childhood, these early losses must have had an effect. He worked diligently in school (and outside of school), and excelled at academics. He graduated from high school with the highest marks in the province, which netted him a much-needed tuition scholarship to UBC. The runner-up was language student Dagmar von Lieven, who he dated in university, and subsequently married in 1941. This marriage eventually faltered; they separated in the late 1960s, and divorced (amicably) in 1971.

Christy completed B.Sc. and M.Sc. degrees in physics at UBC, and then applied successfully for graduate studies at Berkeley to work with Robert Oppenheimer, the leading theoretical physicist in the U.S. at the time. He received his Ph.D. in 1941, taught briefly at Illinois Institute of Technology, then worked nearby as an assistant to Enrico Fermi and others at the University of Chicago, as they created the first nuclear reactor. Not surprisingly, when Oppenheimer was appointed director of the Los Alamos branch of the Manhattan Project in 1943, he recruited Christy to help. Among other things, he contributed the "Christy Gadget" (a euphemism for "bomb"), the mechanism by which a triggered implosion could make the bomb go critical and explode. This whole process is described in the book in intricate detail, illustrated by reprints of numerous documents (including patents that Christy received), diagrams, and photographs.

Like many others who worked on this project, and saw the results, he emerged from it as an opponent of further nuclear weapons proliferation. In the 1980s, he was an integral part of a study of the effects of radiation exposure from nuclear explosions, based, in part, on measurements at Hiroshima and Nagasaki.

After the war, Christy briefly worked at the University of Chicago, but was quickly recruited to the California Institute of Technology (Caltech), where he was appointed successor to Oppenheimer. He continued his research and teaching in theoretical physics, but was soon discovered to have a talent for administration. Starting in 1968, he served as Executive Officer for Physics, and as Chairman of the Faculty. In 1970, he became Provost of Caltech—the senior academic officer. In 1977, he was briefly Interim President when Harold Brown left to become U.S. Secretary of Defense.

Meanwhile, between 1962 and 1975, Christy published about 30 seminal papers and reviews on pulsating stars, based on his ground-breaking hydrodynamic simulations of stellar pulsation. In 1968, he was one of four invited speakers at the University of Toronto's annual "June Institute of Astronomy," which I was involved in organizing. His lectures were published in this *Journal* [63, 229 (1969) and 64, 8 (1970)]. I remember editing them; I was Assistant Editor at the time. It was at that meeting that Christy and his future wife first met. It was the beginning of an intercontinental romance that is described in this book in loving but frank detail. In 1971, Juliana moved to Caltech to work with Nobel Laureate Willy Fowler. She and Robert married in 1973.

Between age 64 and 70, Christy was able to transition to a relatively long and happy retirement and, with Juliana, to raise their two daughters. He and Juliana built a ranch and home in the hills, about 90-minutes' drive from Caltech. There, they were able to indulge in one of their favourite pastimes, horseback-riding. A series of health challenges eventually arose: macular degeneration in 1997, major surgery and the loss of a kidney in 2005, further intestinal surgery in 2009, new vision problems in 2010, and a series of falls. But again and again, he was able to rebound, and return to his ranch and other activities. His mind remained lucid and positive. In 2009, he attended one last conference on stellar pulsation, His presentation, and his presence, were inspirations to his colleagues, both young and old. I am sorry that I was not there. He lived long enough to welcome two new grandchildren in 2012 but, on 2012 October 3, he passed away. Juliana's account of this is one of many moving passages in the book.

Achieving the Rare is clearly an immense labour of love. It began as a book chapter, many years before Christy's death, but it was apparent that there was more than enough material for a book. The first draft of the book was written in 2011, while Christy was available to answer specific questions. There was also time to make and transcribe many interviews, by both Juliana and other family members. These are supplemented with unique source material from both Robert's and Juliana's personal papers.

The writing style is elegant, and the book is profusely illustrated with dozens of family photographs, many in colour, and many quite informal and intimate. Reproductions of dozens of documents, letters, and newspaper articles are also included. The quality of reproduction is very high, as are all aspects of the production of the book, save for the usual few typos (*e.g.* misspellings of names). Nevertheless, the level of detail can be quite overwhelming. I read the book chapter by chapter. Each one of them is equivalent to a short book!

The special and almost unique strength of this intimate biographical memoir is that the author has a deep understanding and appreciation of both Christy's scientific and administrative achievements and also—thanks to four decades as his wife and best friend—his personal qualities: energy, wisdom, passion, generosity, modesty, and grace. Fortunately, her own contributions to his life, as scientific colleague, as "first lady" of Caltech, and as his caregiver in later life come through clearly. She provided this support, even while pursuing her own scientific career (almost 50 research publications), raising their two children, and facing her own health challenges. Like Robert Christy, author Juliana Christy has truly "achieved the rare." ✶

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

How to Photograph & Process NIGHTSCAPES and TIME-LAPSES, by Alan Dyer, Amazing Sky Photography & Publishing www.amazingsky.net, pages 400, (ISBN 978-0-9939589-0-8). Apple iBook www.apple.com/ca/ibooks/—available exclusively through the iTunes store for $24.99 USD.

Alan Dyer brings impressive credentials to the subject of photographing nightscapes and producing time-lapse sequences. He spent his working life producing planetarium shows; he is Associate Editor of the Canadian astronomy magazine *SkyNews*; he has authored or co-authored traditional guide books for amateur astronomers; and he is a noted photographer and instructor in his own right. With this e-book, produced in Apple's iBook format, he has given his readers an invaluable resource. They can follow along with him on this grand adventure of producing beautiful photographs and time-lapse videos of the night sky using digital photographic gear and software that is now available to every consumer.

This 400-page e-book is very big, and it is only available through Apple's iTunes online store in Apple's iBook format, which can be viewed using Apple OS/X, running on Macs, and iOS running on iPads. The e-book is organized logically, and chapters can be read and worked through on their own as tutorials or as personal projects.

In addition to the integrated Table of Contents, there is a comprehensive Glossary at the end, and a section with Additional Resources with links to websites, other e-books, online forums, tutorials, and videos. There are many multimedia features of the iBook format of which Alan takes full advantage: clickable links that take the reader to other sections of the book or to external websites; tip icons that pop up when a quick hint is needed; and photo galleries and videos that are viewable in full screen and high definition. Several of Alan's time-lapse sequences are featured right inside the e-book.

Alan urges his readers to start with simple gear: a DSLR camera, wide-angle lens, tripod, and a remote shutter release. Readers can start with easy, yet rewarding projects so they don't lose interest. Shooting a sunset or twilight scene from your back yard is a whole lot easier than travelling to a dark site and spending all night fussing with fancy gear in the cold! Liberal use of example photos and videos help the reader to understand the sometimes obscure but important concepts, so that they can prevail and move on to more challenging projects. If you are new to photography or astronomy, be sure to read all the "101" sections, which explain basic concepts.

Nightscapes is in the title, and is defined as: "A scene shot at night, combining the night sky with landscape below as a framing element." This method of combining celestial objects and landscape started with the *International Year of Astronomy* in 2009 (IYA2009), where nightscapes were used extensively to show the public the night sky in stunning display images. *The World at Night* group of photographers (www.TWAN.org) grew out of IYA2009, and they continue to this day to produce innovative and beautiful nightscapes.

Work your way through this book, and you own the tools to produce excellent nightscapes. Pick a chapter or a subject within a chapter and then actually do it in the field. This will help build your confidence and provide motivation to go on to master another, more-challenging technique. Alan's book will give you all the basics you need to succeed. He is a master at simplifying complex subjects and giving enough information to succeed without overwhelming.

As someone who is already involved in astrophotography, you might ask what my takeaways from this e-book are. I suppose I could sum this up as getting more serious about night-sky photography (as Alan already is).

Learn to process RAW images (not jpgs). I already do this, but this is a key requirement.

Half the work in making great images is in the processing, so learn Alan's processing tips well or attend his workshops, or both. Be aware that Alan's methodologies don't always follow conventional wisdom. Make a leap of faith, and try his well-proven methods.

Be prepared to travel to scenic locations, and ensure you have the time available to stay there for a while. This is also known as the "*time-tapse lifestyle*" for some people who make a career out of time-lapse work. We don't have to take it that far, but getting serious about finding good scenic locations can pay big dividends.

Learn how the sky works so you can be in the right location, ready to capture interesting celestial events. Alan takes the reader through the meticulous planning he uses to ensure he doesn't waste time when he travels to a location. Learning the basics of weather prediction can't hurt either.

Sometimes Alan resorts to presenting some concepts as "just do it this way," but he is always careful to explain the reasoning and demonstrate the proof. Alan doesn't try to give generic instructions, so any image-processing software can be used. He tells you up front that he uses photography software produced by Adobe exclusively. His instructions will only work with their suite of products. Canon equipment is emphasized over all other brands. Alan gives good reasons why he has limited the scope of the e-book to Canon, but this will be of little comfort to people who have invested in other brands. That said, Nikon and other brands of gear are mentioned, and even recommended occasionally.

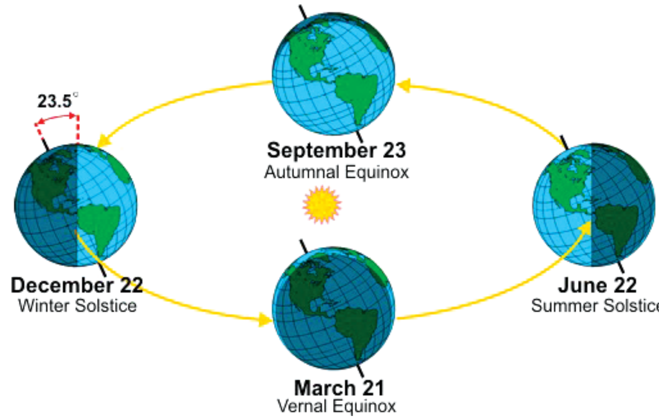
If you take Alan's workshops and work through this e-book, you will be well on your way to producing those publication-quality astronomy photos many aspire to, but so few achieve. ✶

Joe Carr is a Life Member of RASC and is an active member of Victoria Centre. He is fascinated with creating photographs of celestial objects in the night sky, and also photographing the fast-moving events happening on our nearest star, the Sun.

John Percy's Universe

Astronomy Education Research—A Brief Introduction

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



Research shows that the majority of people believe that seasonal changes in temperature are caused by the changing distance of the Earth from the Sun. Diagrams such as this one, which are two-dimensional, not to scale, and shown at an oblique and unspecified angle, do not help. Non-science students also have difficulty with three-dimensional concepts, and with ones that require them to change their frame or point of reference. Source: NOAA.

Most readers of this *Journal* will know how astronomy research is used to increase our understanding of the Universe. Observations with telescopes on the ground or in space, at various wavelengths, are compared with our existing theories, or with predictions from the laws of physics, often through sophisticated computer simulations of, for instance, stellar structure or galactic dynamics. The quality of our theories is based on the quality, quantity, and variety of evidence that they can explain.

Likewise, *astronomy education research* (AER) can be used to improve our understanding of astronomy teaching, learning, outreach, and communication, and lead to more effective, evidence-based education. Sadly, very few astronomers have training in astronomy education, and even fewer any have been exposed to astronomy education research. Fortunately, there are resources available: a how-to manual (Bailey *et al.* 2011), resource guides (*e.g.* Fraknoi 2012), and review articles (*e.g.* Lelliott and Rollnick 2010). There is even a journal, *Astronomy Education Review*, but it is presently dormant. Fortunately, the existing volumes are freely available on the Web[1]. Within my university and others, there is a growing interest in education research in general, or "scholarship of teaching and learning" (SoTL) as it is called.

Recently, my colleagues and I undertook an astronomy education research project (Reid *et al.* 2014) to study the impact of a small planetarium in a large (1500 students!) introductory astronomy course for non-science students. We recruited about 1000 students from the course and provided them three different kinds of small-group tutorials: teaching-assistant (TA)-led discussions, TA-led planetarium shows, and self-guided planetarium shows. We assessed their learning in each kind of tutorial and also their degree of engagement and interest. In this brief article, I will use this project to demonstrate some of the methods and challenges of AER. To deal with our own limited experience with AER, we hired two research assistants who were graduate students in science education, well-trained and experienced in education research. This proved to be a very effective strategy.

Subject Matter

Most AER deals with identifying and studying peoples' conceptions/misconceptions about astronomical topics, and developing effective strategies for teaching these and other topics, such as by using appropriate technologies, non-lecture, and "active learning" approaches. The most famous misconception is that seasonal changes in temperature are caused by the changing distance of the Earth from the Sun (Figure 1), but Neil Comins (2001) has identified over 1700 common misconceptions about astronomical topics[2]. Most AER studies have been about basic topics such as gravity, Earth-Moon-Sun relations, and visible astronomical phenomena, partly because these are most commonly found in the school curriculum. Less work has been done on conceptions about stars, galaxies, and cosmology (Lelliott and Rollnick 2010). There is also a need to study what affects peoples' *attitudes* to astronomy and astronomers, and the influence of socio-cultural background on learning and engagement. Most AER is carried out in formal education settings (schools and colleges), but it is also possible and desirable to study informal astronomy education and outreach.

Planning and Beginning the Study

AER is complicated, because people and groups of people are complicated. It's very important to start with a manageable, well-defined objective or hypothesis or "research question," and a general strategy for addressing it. Then, especially in a public, institutional setting, your study will have to be approved by an Ethics Committee. Your subjects will have to be told, clearly, about the nature and implications of the study and be "invited" to participate by signing a paper or electronic consent form. They have the right to *not* do so. If they are in a formal education setting, the researcher should *not* be an instructor who assigns marks. If some of the participants are to be taught with an "improved" technique and others with a more conventional technique, then it's important for *all* participants to be taught equivalently by the two techniques, otherwise, their assessment in the course will not be fair.

Sample

The sample consists of a number of people, each of whom has a variety of characteristics that may influence their results in the study. In clinical trials, researchers try very hard to match the experimental and control groups with regard to age, gender, lifestyle factors, *etc*. Even then, the groups may differ in significant ways. It is difficult to create control groups when AER is done *in situ*. There are ethical challenges, and it may be difficult to control for random and systematic differences between groups, especially as the sample is, to a greater or lesser extent, self-selected.

In our study, there were students of both genders, in a wide assortment of non-science programs, enrolled in years one to four. The students had a variety of ethnic, linguistic, and economic backgrounds, and degrees of confidence. This makes the results difficult to interpret—even with a sample of 1000 students.

Methodology

In testing an "experimental" teaching strategy, activity, or technology, the tried-and-true *quantitative* approach (as in a clinical trial) is to divide the participants into an experimental group and a control group, give each group a multiple-choice (MC) pre-test, teach the groups using the experimental and control (standard) techniques, administer an MC post-test, and see if the results, for the two groups, are significantly different. To study students' misconceptions, the MC questions would include "distractors" (common misconceptions), as well as the correct answer. But it is notoriously difficult to write clear, comprehensible MC questions, even with many years of experience. Also, students may do better on the post-test, simply because they are then experienced in writing that kind of test, or they remember the correct answers from the pre-test.

There are also *qualitative* methods such as interviews, focus groups, and journals, and mixed-method approaches. Short-answer questions, and simply talking with people, are good ways to identify conceptions in the first place. Qualitative methods allow for wider exploration of students' understanding and attitude but, for practical reasons, it is important to provide some structure for them. For our focus groups, we were fortunate to have, as research assistants, graduate students in science education who were experienced with such methods. We strongly recommend seeking out and finding such collaborators; it lowers our own intimidation level, and establishes beneficial partnerships. The students in our focus groups numbered about 40 in total, and were self-selected. We "rewarded" them with a $20 gift card.

Analysis

Analysis of quantitative data usually involves applying standard statistical tests, and determining whether there is any *statistically significant* difference between the experimental and control groups. Outcomes of focus groups and interviews are first transcribed, then coded and analyzed for specific themes or concepts, such as students' attitude, engagement, learning experience, and opinion about the instructor and TAs. The coding and analysis should be done by at least two independent readers, and checked for consistency. In our study, the focus groups were conducted by graduate students in science education who had no part in the teaching or evaluation of the course. They used a software package, *Nvivo*, that facilitated some of the thematic analysis. The focus groups often raised interesting topics that were outside of our initial research questions, and also produced some useful quotations to include in our project report.

Interpretation

Interpretation of data is complicated, even in the simplest of cases. I recommend Gary Smith's *Standard Deviations* (2014) to both scientists and the public. It documents the many ways that both groups can be misled by innocent-looking data: a self-selected sample, confounding variables, random "patterns," chance correlations, wishful thinking, and "data grubbing"—the more correlations or patterns you look for in a dataset, the more likely you will find one that is "statistically significant." We obviously tried to avoid such problems; having a research team helps.

In our study, we were aware that there were several confounding variables other than the diversity of the students: the TA who taught each group, the time of day of the tutorial, the group size, and the nature of the students in each tutorial (which may have been systematically different because of scheduling considerations). And as stated: the participants were to some extent self-selected, especially in the focus groups.

There were also challenges in having individual students self-guide the planetarium shows. It takes a finite time for a student to learn how to operate the planetarium—even with a controller that resembles a video-game controller—and to develop the confidence to use it for self-guided learning. Our tutorials were less than an hour long.

Results

In our study, we did not find any significant difference in the effectiveness of the three different tutorial formats. The students actually preferred the more traditional format, led by a TA. The students *did* enjoy the planetarium *experience*, however. We also found some interesting differences between the performance of males and females. As in many research studies, one question leads to others, and we recommended that "more research needs to be done"!

Acknowledgements

I thank my colleague Dr. Michael Reid for commenting on a draft of this article. Our research project was supported by the Higher Education Quality Council of Ontario. ✶

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

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Endnotes

1 http://portico.org/stable?cs=ISSN 15391515

2 www.physics.umaine.edu/ncomins/

2015 RASC Board Elections

Under our new organizational structure, The Royal Astronomical Society of Canada is electing three board members each year to fill open seats on our nine-member Board of Directors. The members of the RASC executive are drawn from the ranks of the Board, and the annual elections for three-year terms ensure that our leadership team is renewed each year.

Any RASC members interested in running in the 2015 board elections should place their nomination with the RASC Nominating Committee by 2015 May 15. The election will take place in June and the new Board members take office at the Halifax GA in July. More information is available at www.rasc.ca/elections or from the chair of the Nominating Committee, Chris Gainor, at cgainor@shaw.ca.

Chris Gainor
RASC 2nd Vice-President

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

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

Notes from the National Secretary

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

The Directors' responses on their RASC duties and backgrounds are continuing to trickle in. I can't say it's been a landslide, but on the other hand, I have barely started, as far as nagging goes. They are all on notice that I will make things up about them if they don't come through with the goods. Which may turn out more entertaining than not, so watch this space.

Our 2nd Vice-President is Dr. Chris Gainor, currently of the Victoria Centre, although I was pleased to hear that, originally, he was a member of my own home-town Centre in Edmonton. He serves as Chair of the Nominating Committee and has done so through the challenging years of our constitutional transition. He is also a member of the Finance Committee, which sets budgets and oversees our operations and investments, and of the History Committee, conserving and mining records of our considerable heritage. I'm not sure exactly how many meetings per year that adds up to, but it's more than you can shake a stick at, if that's your idea of fun.

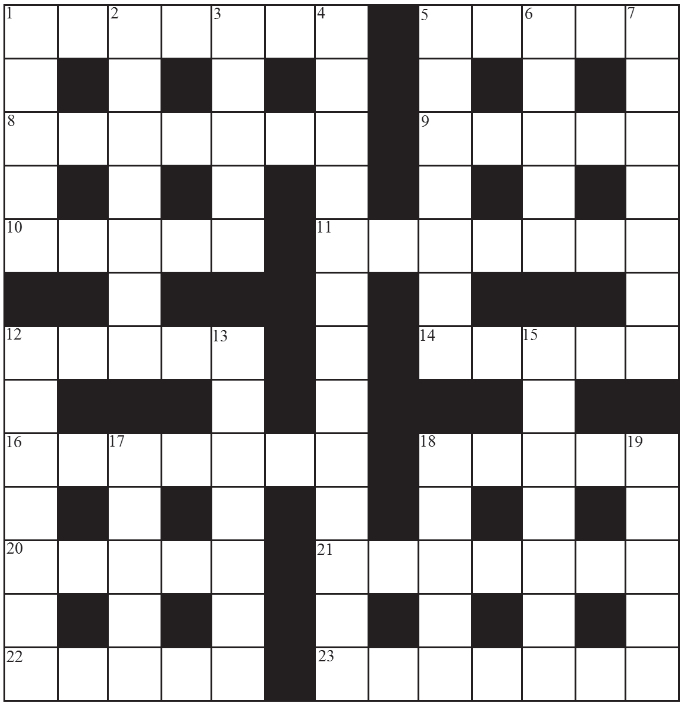
Chris is now a historian. After working in news media and government, he returned to university for graduate degrees in Space Studies and in the History of Technology. He has written four books, and is looking for a publisher for a fifth. In November, he began a three-year contract with NASA to write a history of the *Hubble Space Telescope*'s years in orbit. He also collects stamps and has been active in political affairs in B.C. Those who were present at the GA banquet last June may have noticed among the guests a reasonable facsimile of Winston Churchill; apparently Chris is known in Victoria for appearing as his alter ego at events supported by the local Churchill Society. He also drives a really cool, vintage taxi cab, a 1981 Checker.

Director Colonel (retired) Dr. Randall "Randy" Boddam, MD, is on his way to add M.Sc. (Astronomy) to that list of qualifications. For obvious reasons of efficiency, we just call him "Randy B." Since joining the Board last summer, he sits on the Observing Committee and the Awards Committee, and is currently helping to review our awards so that they are clear in terms of criteria and consistent with the activities of the Society. He is a RASC Life Member since 1989, now with the Belleville Centre, where he does solar astronomy and loves being involved with outreach activities.

A psychiatrist with more than 32 years service with the Canadian Forces, often abroad and including four tours to Afghanistan, Randy is now in private practice. His experience as Senior Psychiatrist for five Surgeons General and leading the mental health restructuring project for the Forces, not to mention the hand-grenade thing, leaves the rest of us quivering in our space boots. He boasts of having a perfect score (2 for 2) at being rejected by the Canadian Space Agency for astronaut training, but apparently consoles himself with digital photography, coin collecting, and board games. He also writes that he "embarrasses himself severely by attempts to play Jethro Tull on the flute." ✶

Astrocryptic

by Curt Nason



ACROSS

1. They make telescopes to measure mountain height in a short day (7)
5. Scope maker crossed to become a dealer (5)
8. Moochers resemble altered images of Hyperion (7)
9. Unusual thing to encounter after dark (5)
10. Scope maker holds the original astronomy club (5)
11. Telescopes dealer where one sees a train wreck in spectacles (7)
12. Space station at the extremes of unique *SkyNews* edition (5)
14. Type of meteorite taken from the South to New York (5)
16. Crater backs to crater front in one on Mercury (7)
18. Swear about prominent lunar horns (5)
20. Altair loses head of lasso but backs into one (5)
21. Unionized when nature is imbalanced by longshoremen's lead (7)
22. Sister gets orange star with one in Sagittarius (5)
23. Lens component made like iron (7)

DOWN

1. Coast around to find a cheap telescope (5)
2. Shattered solenoid lost nothing but autumn meteors (7)
3. Star to the north is not an omnivore (5)
4. Their closure will sadly soften science interest (13)
5. Minor changes in RA evident by silences around Nickelback concert (7)
6. A boring tool to use for cosmic rays (5)
7. Doomed to universal heat death, yet porn turns out to be the cause (7)
12. Make choice in flattener from this company (7)
13. Low point that is around back of the river (7)
15. See hot associations veer off (7)
17. Méchain excluded me from observing a line of craters (5)
18. You finally crack code for a stationary focus (5)
19. Big lunar formation theory from mountains uplifting before time (5)

Answers to February's Astrocryptic

ACROSS

1 QUESTAR (quest + Ar); **5** MAKES (Makemake); **8** ALPHA (2 def); **9** TITANIA (anag); **10** TELESTO (anag); **11** LETHE (le + the); **12** DMITRIEVICH (anag); **17** PLUME (plu + m(or)e); **19** ALNILAM (a + anag); **21** RADIANS (anag + S); **22** TIROS (anag, b=s); **23** LARVA (hid); **24** SERPENS (anag)

DOWN

QUANTA (hid); **2** EXPEL (Lee (rev) + XP; **3** TRANSIT (anag); **4** RETRO (2 def); **5** METAL (not helium); **6** KINETIC (kine + tic); **7** SEAGER (anag); **13** MAUNDER (ma + under **14** VENATOR (Rotanev (rev), anag); **15** SPIRAL (sp(IR)al); **16** AMUSES (A(muse)S); **18** ELARA (el + Ara); **19** APSIS (hid); **20** LYRAE (anag)

It's Not All Sirius

by Ted Dunphy

Introducing "RASC Tours"

Randy Attwood, Executive Director

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

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

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

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

PRICE, if deposited no later than 2015 MAY 1:
$2135 per person, double occupancy ($495 Single Supplement)

PRICE, if deposited after 2015 MAY 2:
$2395 per person, double occupancy ($575 Single Supplement)

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

ITINERARY:

Tuesday, November 3 – Arrival in Los Angeles

Wednesday, November 4 – Los Angeles
- A free morning to sightsee LA and Hollywood with an afternoon visit to Griffith Observatory
- Evening—dinner at the Magic Castle where the up-and-coming magicians train—magic shows in every room.

Thursday, November 5
- A free morning to visit other sights such as the Getty Museum with an afternoon visit to the California Space Science Center where the Space Shuttle Endeavour is on display.

Friday, November 6 – LA, Pasadena
- A guided tour of the famous Jet Propulsion Laboratory

Saturday, November 7
- A visit to the Mount Wilson Observatory

Sunday, November 8
- San Diego A visit to the famous Palomar Observatory

Monday, November 9 - Return home

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

Future RASC Tour Trips Planned

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

Wyoming/Idaho, August 2017: Total Solar Eclipse Expedition

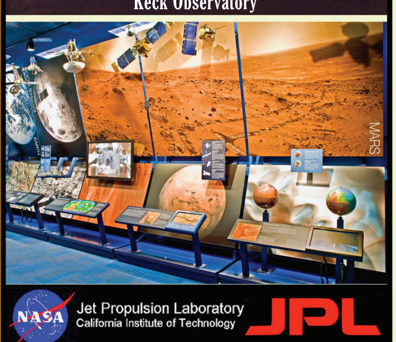
Arizona: Observatories, Meteor Crater, Grand Canyon, Dark-Sky Observing / Date: TBA

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

Yellowknife, NWT: Aurora observing / Date: TBA

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


Keck Observatory



Reservations & information:
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www.melitatrips.com
cst 2040611-40

RASC Tours

Royal Astronomical Society of Canada
invites you to visit various notable astronomical destinations.

Southern California Observatories
Los Angeles, Pasadena, San Diego
November 3 - 9, 2015

Visit: Griffith, Mount Wilson and Palomar Observatories
Space Shuttle Endeavour - California Science Center
Jet Propulsion Laboratory
Enjoy: Los Angeles tour and Magic Castle

HAWAII
Mauna Kea, Keck Observatory & Canada-France-Hawaii Telescope
June 20 - 25, 2016

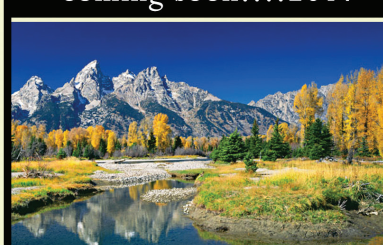
Enjoy Sunset Bay Dinner Cruise, Luau, and much more

COMING SOON!!

The Great American Total Eclipse
Grand Tetons and Yellowstone
August 14 - 23, 2017

$100 to hold your space.
When the brochure is announced in April 2015 a full deposit will be due.

MWT Associates, Inc.
Inspiring the Stargazer in You


Grand Tetons

Journal

Great Images

Medhi Bozo-Rey couldn't miss the triple shadow transit on January 24, and so left Toronto for Coe Hill to make a video recording of the event. His efforts were well rewarded as these images show; the eventual image files totalled more than 47 gigabytes. In the first image (upper left), Callisto and Europa can be seen beneath the disk of Jupiter (Callisto is the closest to the planet) and Io is visible as a gray smudge just beneath the central shadow—which is the combined shadow of two moons. Over the next 40 minutes, Callisto moves onto the disk (at 01h14m59s) and the double shadow gradually separates. All-in-all, a magical night for those with clear skies.