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Journal

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PROMOTING ASTRONOMY IN CANADA

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Inside this issue:

The Eastern Veil

The Best of Monochrome.

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

Barry Schellenberg imaged IC 5067 which is focused on the dark nebula region within the Pelican Nebula for a total of 60 hours.

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February / février 2019 | Vol. 113, No. 1 | Whole Number 794

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contents / table des matières

Dan Meek took this image of NGC 6992 from Calgary using a 5-inch refractor and a QSI583wsg camera on an iOptron CEM120EC2 mount. The image is 5½ hours with the colour assignment of H-α=Red, SII=Green, and OIII=Blue.

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.

Her Excellency the Right Honourable **Julie Payette**, C.C., C.M.M., C.O.M., C.Q., C.D., Governor General of Canada, is the Viceregal Patron of the RASC.

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President's Corner

by Chris Gainor, Ph.D., Victoria Centre (cgainor@shaw.ca)

The RASC Board of Directors has created a new Inclusiveness and Diversity Committee to help the RASC better reflect Canada as it is today, nearly two decades into the 21st century. The committee's terms of reference are still being discussed by the Board, National Council, and the people who have volunteered for the committee, but its mission can be summed up as providing a place for people who don't fit the traditional mold of RASC members to come together to promote diversity.

As my presidential predecessors and many others have pointed out, the RASC hasn't done as good a job as it could in attracting women and Canadians of different ethnic, cultural, gender, and religious backgrounds to its ranks. We are making progress, but if we are to celebrate our 200th anniversary as a bigger and better organization than we did for our 150th anniversary, we must ensure that all Canadians see themselves reflected in the RASC.

The new committee has become a matter of discussion among RASC members in various places. Some are taking advantage of these discussions to enlighten us about how our knowledge of the sky has been enriched by individuals and societies from varying backgrounds and different parts of the world.

Unfortunately, some others have expressed their expectations about the committee's work based more on their fears about the new committee than on the realities.

The terms of reference for the Inclusiveness and Diversity Committee talk of encouragement, education, representation, communication, and advocacy. There is no compulsion anywhere.

When I look at the history of the RASC, I see outstanding women, such as Ruth Northcott, Helen Sawyer Hogg, Mary Grey, Mary Lou Whitehorne, and many others playing crucial roles. Women everywhere are gaining overdue recognition for their numerous discoveries and their leadership roles in astronomy today.

Every time we talk about stars we pay homage to the Islamic contribution to astronomy. Growing numbers of people of different backgrounds are becoming astronomers and are showing up at our public outreach events. Many are taking leadership positions in RASC Centres and at the national level, including past president and *Observer's Handbook* Editor Rajiv Gupta.

Some members are working with First Nations to recover the rich heritage of astronomy originating with the people who lived in Canada long before anyone else. I hope to see RASC welcome more members from our First Nations.

One huge area where the RASC has fallen back in recent years was pointed out at our most recent General Assembly. We must work harder to serve French Canadians, who account for nearly a quarter of our population. We recently lost one of our two Francophone Centres, in Québec City.

The RASC's diminished presence among Francophones is a long and complicated story, and reversing this loss will involve a great deal of effort on our part. One place to start is our publications. Astronomy in Québec is very vital, and we in the RASC will enrich ourselves by strengthening our bonds with our Québecois and other Francophone friends.

Everyone who works to foster diversity in the RASC is united by our common love of astronomy. We all spend a great deal of time and energy in the RASC creating opportunities for our fellow Canadians to enjoy our skies. We must make sure that all Canadians, no matter who they are, where they come from, how they live, or what they believe, get a chance to look up and discover the Universe with us. ✶

News Notes / En Manchette

Compiled by Jay Anderson

New details from the Cygnus Loop

The Cygnus Loop or Veil Nebula is a supernova remnant, the detritus of the explosive death of a massive star about ten to twenty thousand years ago. Multi-wavelength observations combined with extensive modelling exercises in past years suggest that the Loop is a supernova remnant within a large cavity carved out by its progenitor star. The greatest unknown in this interpretation is the distance to the Veil; estimates range from 440 to 1400 parsecs (1435 to 4570 light-years) with 540 pc (1760 ly) the most cited value.

One of the techniques to determine at least approximate distances is to look for stars in front of and behind the nebula, which can be identified by the presence or absence of absorption lines in their spectrum. Stars behind the Veil will show the presence of certain absorption lines, while those in front will not. Once candidate stars have been identified, the distance to the front and back of the nebula can be constrained by the distances to the stars. The recent publication of stellar distances obtained by the *Gaia* spacecraft has allowed a refinement of existing distance measures to such stars and tighter constraints on the Veil's distance.

Harvard-Smithsonian Center for Astrophysics (CfA) astronomer John Raymond joined with four colleagues to apply the *Gaia* data to the problem of the Cygnus Loop distance by looking for absorption signatures from the gas in the two dozen stellar spectra. Of these, only three were identified as being behind the nebula, all on its eastern side. Two of the stars showed distinct red- and blue-shifted calcium absorption lines associated with the retreating far side and approaching near side of the nebula. The distance to each of these stars was nearly identical, at 735 +/- 25 pc (2420 +/- 80 ly); the third star was much farther behind at 864 pc. This distance of the two closer stars imposes a firm back limit to the nebula of 760 pc. This larger value reflects the fact that the absorption-line stars are not directly behind the centre of the Loop.

The CfA astronomers also identified a fourth star, at 767 pc, whose outflowing wind seems to be interacting with the expanding remnant. If this is the case, then the distance to the fourth star (767 +/- 27 pc) anchors the forward distance to the Loop, which can be no more than 794 pc. A fifth star, from previous research, fits with these measurements and helps to constrain the shape of the nebula. Together, the distance constraints give the Cygnus Loop a diameter of 37 pc (120 ly).

The requirement to fit the stars into their positions with respect to the nebula gives a range of distances to the Cygnus Loop according to the uncertainties in the Gaia measurements. The best model, according to the authors, is an aspherical

Figure 1 — Visible-light image of NGC 6960, the western side of the Cygnus Loop. In this image, west is at the top. The density of stars on the eastern side of the nebula (lower) is higher than on the western (top), a sign of an obscuring interstellar cloud across the top of the image that blocks light from more distant stars. The bright star is 52 Cygni. Image: Ken Crawford (www.imagingdeepsky.com)/Wikipedia.

nebula, tilted to our line of sight. In the end, the study team concludes that the nebula lies at a distance of 735 pc with a range from 725 to 745 pc.

The new distance result has several important implications. It means that the supernova that created the Loop had less energy than previously thought by perhaps as much as a factor of four (about as much energy as the current Sun would emit in six billion years). The aspherical model designed for the observations causes the eastern side to be closer to the Earth than the western.

The strange morphology of the Cygnus Loop, with prominent nebulae (NGC 6960, NGC 6995, and Pickering's Triangle) on one side and very little on the opposite, suggests an origin that is relatively unique for supernova remnants. The CfA team suggests that the supernova exploded in a low-density region of the galaxy, and that the visible nebulae are largely the result of interactions with local interstellar clouds. In particular, the west side is nestled up against a large interstellar dust cloud. RASC members with photographs of NGC 6960 will notice a modest reduction in the number of stars on the west side of the filament compared to those on the east.

All the light there ever was

Astrophysicists believe that our 13.7 billion-year-old Universe began forming the first stars when a few hundred million years had passed. Since then, the Universe has become a star-making masterwork. There are now about two trillion galaxies and a trillion-trillion stars. Using new methods of starlight measurement, Clemson College of Science astrophysicist Marco Ajello and his team analyzed data from NASA's *Fermi Gamma-ray Space Telescope* to determine the history of star formation over most of the Universe's lifetime.

"From data collected by the *Fermi* telescope, we were able to measure the entire amount of starlight ever emitted," said Ajello, who is lead author of the paper. "Most of this light is emitted by stars that live in galaxies. And so, this has allowed us to better understand the stellar-evolution process and gain captivating insights into how the Universe produced its luminous content."

Putting a number on the amount of starlight ever produced has several variables that make it difficult to quantify in simple terms. But according to the new measurement, the number of photons that escaped into space after being emitted by stars translates to $4x10^{84}$.

Despite this stupendously large number, it is interesting to note that with the exception of the light that comes from our own sun and galaxy, the rest of the starlight that reaches Earth is exceedingly dim—equivalent to a 60-watt light bulb viewed in complete darkness from about 4 km away. This is because the Universe is almost incomprehensibly huge and so the sky is dark at night, other than light from the Moon, visible stars and the faint glow of the Milky Way.

The *Fermi Gamma-ray Space Telescope* is a powerful observatory that has provided enormous amounts of data on gamma rays (the most energetic form of light) and their interaction with the extragalactic background light (EBL), which is a cosmic fog composed of all the ultraviolet, visible, and infrared light emitted by stars or from dust in their vicinity. Ajello and postdoctoral fellow Vaidehi Paliya analyzed almost nine years of data pertaining to gamma-ray signals from 739 blazars.

Blazars are galaxies containing supermassive black holes that are able to release narrowly collimated jets of energetic particles that leap out of their galaxies and streak across the cosmos at nearly the speed of light. When one of these jets happens to be pointed directly at Earth, it is detectable across extremely large distances. As high-energy gamma rays from the blazar jets collide with low-energy visible-light photons, they transform into pairs of electrons and positrons, leaving an observable imprint. This enabled Ajello's team to measure the density of the fog not just at a given place but also at a given time in the history of the Universe.

Because these particle interactions are detectable over immense cosmic distances, Ajello's group was able to probe deeper than ever into the Universe's star-forming productivity. According to NASA, *Fermi*'s ability to detect gamma rays across a wide range of energies makes it uniquely suited for mapping the cosmic fog.

"Gamma-ray photons traveling through a fog of starlight have a large probability of being absorbed," said Ajello, an assistant professor in the Department of Physics and Astronomy. "By measuring how many photons have been absorbed, we were able to measure how thick the fog was and also measure, as a function of time, how much light there was in the entire range of wavelengths."

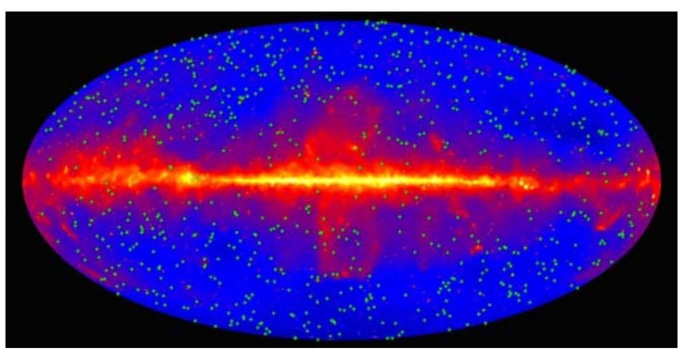

Figure 2 — This map of the entire sky shows the location of 739 blazars used in the Fermi Gamma-ray Space Telescope*'s measurement of the extragalactic background light (EBL). The background shows the sky as it appears in gamma rays with energies above 10 billion electron volts, constructed from nine years of observations by the* Fermi *Large Area Telescope. The plane of our Milky Way Galaxy runs along the middle of the plot. Credit: NASA/DOE/Fermi LAT Collaboration*

Using galaxy surveys, the star-formation history of the Universe has been studied for decades. But one obstacle faced by previous research was that some galaxies were too far away, or too faint, for any present-day telescopes to detect. This forced scientists to estimate the starlight produced by these distant galaxies rather than directly record it.

Ajello's team was able to circumvent this by using *Fermi*'s Large Area Telescope data to analyze the extragalactic background light. Starlight that escapes galaxies, including the most distant ones, eventually becomes part of the EBL. Therefore, accurate measurements of this cosmic fog, which have only recently become possible, eliminated the need to estimate light emissions from ultra-distant galaxies.

Paliya performed the gamma-ray analysis of all 739 blazars. "By using blazars at different distances from us, we measured the total starlight at different time periods," said Paliya of the department of physics and astronomy. "We measured the total starlight of each epoch—one billion years ago, two billion years ago, six billion years ago—all the way back to when stars were first formed. This allowed us to reconstruct the EBL and determine the star-formation history of the Universe in a more effective manner than had been achieved before."

"Scientists have tried to measure the EBL for a long time. However, very bright foregrounds like the zodiacal light (which is light scattered by dust in the Solar System) rendered this measurement very challenging," said co-author Abhishek Desai, a graduate research assistant in the Department of Physics and Astronomy. "Our technique is insensitive to any foreground and thus overcame these difficulties all at once."

Star formation, which occurs when dense regions of molecular clouds collapse and form stars, peaked around 11 billion years ago. But though the birthing of new stars has since slowed down, it has never stopped. For instance, about seven new stars are created in our Milky Way Galaxy every year.

Establishing not only the present-day EBL, but revealing its evolution in cosmic history is a major breakthrough in this field, according to team member Dieter Hartmann, a professor in the Department of Physics and Astronomy.

"Star formation is a great cosmic cycling and recycling of energy, matter and metals. It's the motor of the Universe," Hartmann said. "Without the evolution of stars, we wouldn't have the fundamental elements necessary for the existence of life."

Understanding star formation also has ramifications for other areas of astronomical study, including research regarding cosmic dust, galaxy evolution and dark matter. The team's analysis will provide future missions with a guideline to explore the earliest days of stellar evolution—using tools such as the upcoming *James Webb Space Telescope*.

"The first billion years of our Universe's history are a very interesting epoch that has not yet been probed by current satellites," Ajello concluded. "Our measurement allows us to peek inside it. Perhaps one day we will find a way to look all the way back to the Big Bang. This is our ultimate goal."

Compiled in part with material provided by Clemson College of Science.

Creeping up on the Milky Way's black hole

The European Southern Observatory's (ESO) exquisitely sensitive GRAVITY instrument has added further evidence to the long-standing assumption that a supermassive black hole lurks in the centre of the Milky Way. New observations show clumps of gas swirling around at about 30 percent of the speed of light on a circular orbit just outside its event horizon—the first time material has been observed orbiting close to the point of no return, and the most detailed observations yet of material orbiting this close to a black hole.

The GRAVITY instrument on the Very Large Telescope (VLT) Interferometer has been used by scientists from a consortium of European institutions, including ESO, to observe flares of infrared radiation coming from the accretion disc around Sagittarius A*, the massive object at the heart of the Milky Way. The observed flares provide long-awaited confirmation that the object in the centre of our galaxy is, as has long been assumed, a supermassive black hole. The flares originate from material orbiting very close to the black hole's event horizon.

Figure 3 — ESO's exquisitely sensitive GRAVITY instrument shows clumps of gas swirling around at about 30 percent of the speed of light on a circular orbit just outside a four million-solar-mass black hole—the first time material has been observed orbiting close to the point of no return. This visualization uses data from simulations of orbital motions of gas swirling around at about 30 percent of the speed of light on a circular orbit around the black hole. Credit: ESO/Gravity Consortium/L. Calçada

While some matter in the accretion disc—the belt of gas orbiting Sagittarius A* at relativistic speeds—can orbit the black hole safely, anything that gets too close is doomed to be pulled beyond the event horizon. The closest point to a black hole that material can orbit without being irresistibly drawn inwards by the immense mass is known as the innermost stable orbit, and it is from here that the observed flares originate.

"It's mind-boggling to actually witness material orbiting a massive black hole at 30% of the speed of light," marvelled Oliver Pfuhl, a scientist at the MPE. "GRAVITY's tremendous sensitivity has allowed us to observe the accretion processes in real time in unprecedented detail."

The GRAVITY instrument which made this work possible combines the light from four telescopes of ESO's VLT to create a virtual super-telescope 130 metres in diameter with a spatial resolution of 3 milli-arcseconds. Earlier this year, GRAVITY and SINFONI, another instrument on the VLT, allowed the same team to accurately measure the close fly-by of the star S2 as it passed through the extreme gravitational field near Sagittarius A*, and for the first time confirmed the effects predicted by Einstein's general relativity in such an extreme environment.

"We were closely monitoring S2, and of course we always keep an eye on Sagittarius A*," explained Pfuhl. "During our observations, we were lucky enough to notice three bright flares from around the black hole—it was a lucky coincidence!" The researchers were able to follow the three flares for 50-70 percent of a closed, circular, clockwise orbit.

This emission, from highly energetic electrons very close to the black hole, was visible as three prominent bright flares, and exactly matches theoretical predictions for hot spots orbiting close to a black hole of four million solar masses. The flares, lasting for 30 to 90 minutes, are thought to originate from magnetic interactions in the very hot gas orbiting very close to Sagittarius A*. The best determination of the orbit suggested the material was orbiting at a distance of 1.17 times the innermost stable circular orbit, commonly known as the event horizon.

Reinhard Genzel, of the Max Planck Institute for Extraterrestrial Physics (MPE) in Garching, Germany, who led the study, explained: "This always was one of our dream projects but we did not dare to hope that it would become possible so soon." Referring to the long-standing assumption that Sagittarius A* is a supermassive black hole, Genzel concluded that "the result is a resounding confirmation of the massive black hole paradigm."

Compiled with material provided by the ESO.

Chandra X-Ray Observations of the Neutron Star Merger GW170817: Thermal X-Ray Emission From a Kilonova Remnant?

by Samar Safi-Harb[1], Neil Doerksen[1], Adam Rogers[1,2] and Chris L. Fryer[3]*

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Abstract

The recent discovery of the neutron star merger and multi-messenger event GW170817 (also known as kilonova GRB170817A) provides an unprecedented laboratory in which to study these mysterious objects, as well as an opportunity to test cutting-edge theories of gravity in the strong field regime. Before this event, such tests of our understanding of the nature of gravity were not possible. In this study, we analyze the X-ray observations of GW170817 obtained with NASA's *Chandra X-ray Observatory* following the 2017 August 17 detection of the event by the Laser Interferometer Gravitational Wave Observatory (LIGO). Motivated by understanding the emission mechanism for X-ray light and the outcome of the merger event, we fit the *Chandra* data with both non-thermal (as done previously in the literature) and thermal models. We specifically explore thermal plasma models that would be expected from a kilonova remnant (KNR). We reproduced the non-thermal results which were recently published by Nynka et al. (2018). We also find that thermal Bremsstrahlung emission from hot plasma can account for the X-ray emission from this source. Furthermore, we consider models allowing for an intrinsic absorption from the merger event, yielding a softer power-law model photon index than previously published, or a lower plasma temperature. We also report on evidence for line emission, or excess above the continuum model, near 1.3 keV and 2.2 keV which sheds new light on the interpretation of the KNR and its nucleosynthesis products. We discuss the feasibility for the KNR as the origin for thermal X-ray emission at this stage of the kilonova evolution.

Introduction

The lives of massive stars more than eight times the mass of the Sun end violently in supernova (SN) explosions. The outer layers of these stars are scattered through interstellar space, forming complex supernova remnants (SNRs) which disperse the heavy elements (referred to as ejecta) created within the star during its evolution or via the explosion itself. Meanwhile, a portion of the stellar core survives compressed to a cinder of nuclear density. Under such intense pressures and densities, the core is converted into a neutron-rich material called neutron degenerate matter. This state, unique in the universe, provides a name for these enigmatic objects—neutron stars, which manifest themselves as a "zoo" when observed at different wavelengths (Hewish et al. 1968, Shapiro & Teukolsky 1983, Haensel, Potekhin & Yakovlev 2007, Harding 2013, Safi-Harb 2017).

Neutron stars exhibit a plethora of interesting and mysterious behaviours. They emit highly collimated jets of radiation in both the X-ray and radio portions of the electromagnetic spectrum. They have some of the strongest magnetic fields in nature, up to and beyond the quantum electrodynamics limit (Duncan & Thompson 1992, Kouveliotou et al. 2003). Their association with SNRs allows us to probe some of their most fundamental properties, such as magnetic field evolution (e.g. Rogers & Safi-Harb 2016). Neutron stars in binary systems can accrete matter from a main sequence companion, driving their rotation rates to millisecond periods (Backer et al. 1982). In addition, due to their high density, the effects of gravitational light bending, time dilation and redshift are substantial around these objects (Pechenick, Ftaclas & Cohen 1983, Beloborodov 2002, Rogers 2015). Given the diversity of interesting phenomena associated with them, there is no doubt that neutron stars are some of the most fascinating and exotic objects in the Universe.

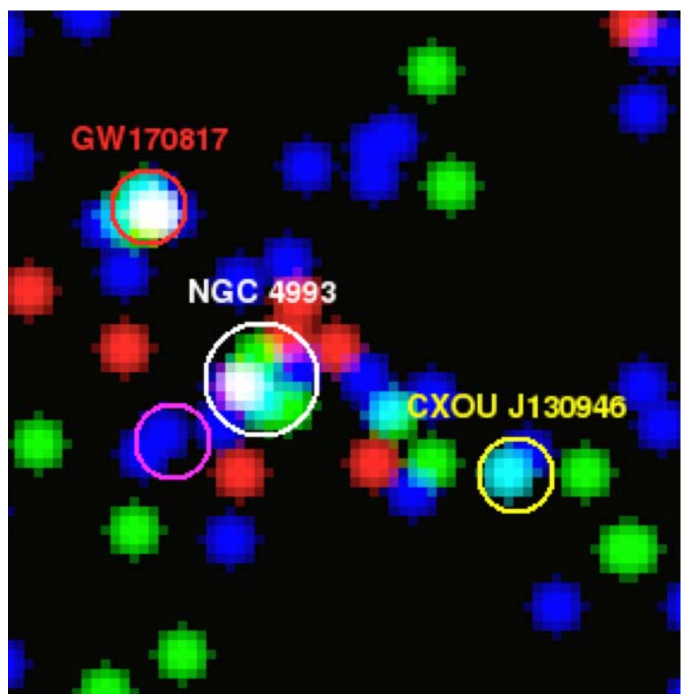
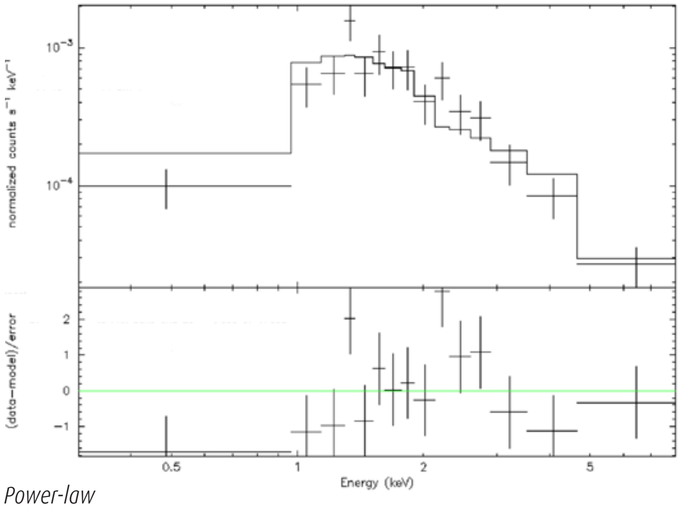
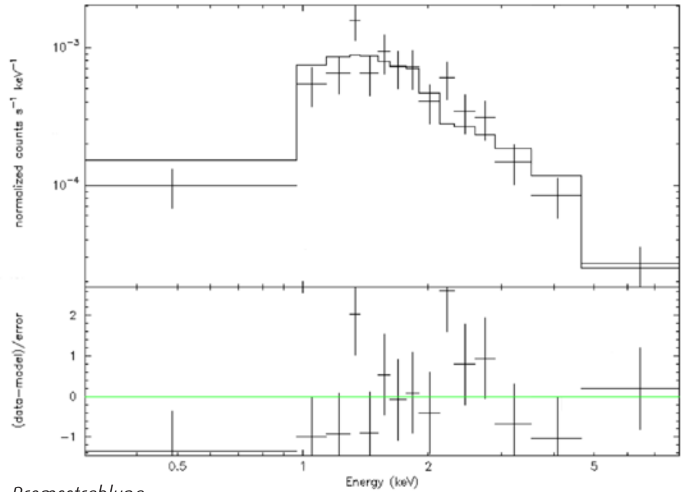


Figure 1 — RGB image of GW170817 at ~160 days post-merger (ObsID: 20945). Red = 0.5–1.2 keV, Green = 1.2–2 keV, Blue = 2–7 keV. The unlabelled, magenta region is the transient source CXOU J130948; CXOU J13046 is also a transient (Haggard et al. 2017).



Power-law



Bremsstrahlung

Figure 2 — The January 2018 merged observations fitted with a power-law (PL, left) and thermal Bremsstrahlung (TB, right) model. The column density and redshift were fixed (see text). In each figure, the top panel shows the data with the best-fit model. The lower panel shows the deviations from the best-fit model. The parameters of both models are summarized in Table 1.

Isolated neutron stars occupy the frontiers of our understanding of nature. However, the physical description of two such objects colliding is even more extreme. Since neutron stars are so compact, they provide ideal conditions for studying gravitational waves when they are found in binary systems. The first double-pulsar system discovered was observed to lose energy in accordance with the emission of gravitational waves predicted in 1916 by Einstein's theory of general relativity. This is the Hulse and Taylor binary (Hulse & Taylor 1974) which earned its discoverers the Nobel Prize in Physics in 1993. However, until the recent success of the Laser Interferometer Gravitational Wave Observatory (LIGO), gravitational waves had not been directly observed.

The direct detection of gravitational waves remained elusive for a century until the LIGO team detected them in 2015 from black-hole mergers, earning Weiss, Barish, and Thorne the 2017 Nobel Prize in Physics. In addition to black-hole binaries, GW170817 (a neutron star-neutron star merger) is one of the most exciting discoveries in the field of astronomy today. GW170817 is the first event of any kind in which both gravitational and electromagnetic waves were detected from the same event. It is also the first merger event to emit gravitational waves that involved objects other than black holes. The discovery of gravitational waves and light across the electromagnetic spectrum has led to the birth of a new era in "multi-wavelength, multi-messenger astrophysics" (Abbott et al. 2017a, b and references therein).

Following the LIGO discovery, the gamma-ray satellite Fermi detected the source seconds after the gravitational wave event, showing that GW170817 shares common properties to the short-duration gamma-ray bursts (Troja et al. 2017). The event is also referred to as GRB170817A. Optical and near-infrared telescopes located the source (Coulter et al. 2017, Shappee et al. 2017, Drout et al. 2017) within the host galaxy NGC 4993 (at a redshift z=0.0098) and a distance of about 41 Mpc (Hjorth et al. 2017). In X-rays, the source was first detected ~9 days post-merger (Troja et al. 2017, Margutti et al. 2017) and subsequently followed up at ~15–16 days post-merger (Haggard et al. 2017) using NASA's *Chandra X-ray Observatory*. Thanks to its superb imaging resolution, the gravitational wave event was localized in X-rays by *Chandra*. The source continued to be monitored in X-rays and radio, but it is now believed to be fading in the X-ray band (Nynka et al. 2018, Ruan et al. 2018, Haggard et al. 2018, Burnichon et al. 2018).

Despite the intense multi-wavelength campaign observing this event, the exact details of the aftermath of this neutron star-neutron star collision remain unclear. The production of a kilonova was observed (Arcavi et al. 2017), though the overall flux of this event was dimmer than expected (Troja et al. 2017). Interpretation of the observations include a synchrotron afterglow or the launching of an off-axis jet of material from within the cloud of debris produced during the collision. Over a year later, it is uncertain what remnant the neutron star merger has produced (e.g. Nynka et al. 2018, Pooley et al. 2018).

Motivated by understanding the product of this double neutron star merger (i.e. whether it made a heavy neutron star or a light black hole; see Pooley et al. 2018) and searching for nucleosynthesis products in X-rays, we have revisited the archival *Chandra* X-ray observations of GW170817. In our study, we model the data with the commonly assumed non-thermal, power-law model, as well as explore models of thermal plasma origin. We are able to reproduce previous published work on the non-thermal interpretation (Nynka et al. 2018). We compare our thermal models with those published in Ruan et al. (2018) and discuss thermal X-ray emission from a kilonova remnant candidate (KNR) that opens a new window for interpreting the aftermath of this merger.

Observations and Methodology

The observations used to analyze GW170817 were taken with the Advanced CCD Imaging Spectrometer (ACIS) on board *Chandra*. We analyzed the archival observations summarized in Table 1. In our work, we highlight the January 2018 observations (Obs ID: 20936/37/38/39/45, PI Wilkes) which were the brightest, allowing us to discover evidence for the presence of thermal X-ray emission.

The level two event files of the observations were processed using the Chandra Interactive Analysis Software (CIAO) v7.6. The RGB image presented in Fig. 1 was generated using the software DS9 v4.10. The energy band is 0.5–7 keV and the colours are chosen to reflect the low– (red=0.5–1.2 keV), medium– (green=1.2–2 keV) and high– (blue=2–7 keV) energy X-rays.

For processing the spectral data, CIAO was used to merge spectra from the same epoch (Table 1) to increase statistical results. The source spectrum was chosen from a region centered at the peak emission from GW170817 (RA = 13h 09m 48.077s; Dec = –23° 22′ 53.459″, J2000) with an extraction radius of 1.97″ (which corresponds to 90% encircled energy fraction near the *Chandra* on-axis position), as done in Haggard et al. (2017) and Nynka et al. (2018) (see also Margutti et al. 2017 and Troja et al. 2017). XSPEC (Arnaud 1996) v12.10.0c was used to model the data. The background was subtracted from a source-free region close to the GW event from the same CCD chip. The redshift (z) was fixed at 0.0098 (Hjorth 2017) and the column density (N_H) was fixed at 7.5×10^{20} cm^{-2} to compare our results to the most recent results by Nynka et al. (2018). The analyzed energy range was 0.3–8 keV for flux and the luminosity is quoted in the 0.5–10 keV band. Each spectrum was modelled using a power-law (for the non-thermal interpretation) and the Bremsstrahlung model (for the thermal interpretation).

Using the above values as input, we searched for the lowest reduced χ^2 value by trying a range of minimum counts per bin when grouping the spectrum, depending on the statistics of the observation. Cash statistics was also used for the low-count data, particularly the early observations (ObsID: 18955, 19294). Flux, luminosity, and count rates were recorded for the non-thermal and thermal models, with the power-law photon index (Γ_x) and plasma temperature (kT in keV) summarized for the power-law and Bremsstrahlung models, respectively. Our results are summarized in Table 1.

Results

Fig. 2 shows the best fit power-law and Bremsstrahlung model fits to the January 2018 merged spectra (corresponding to

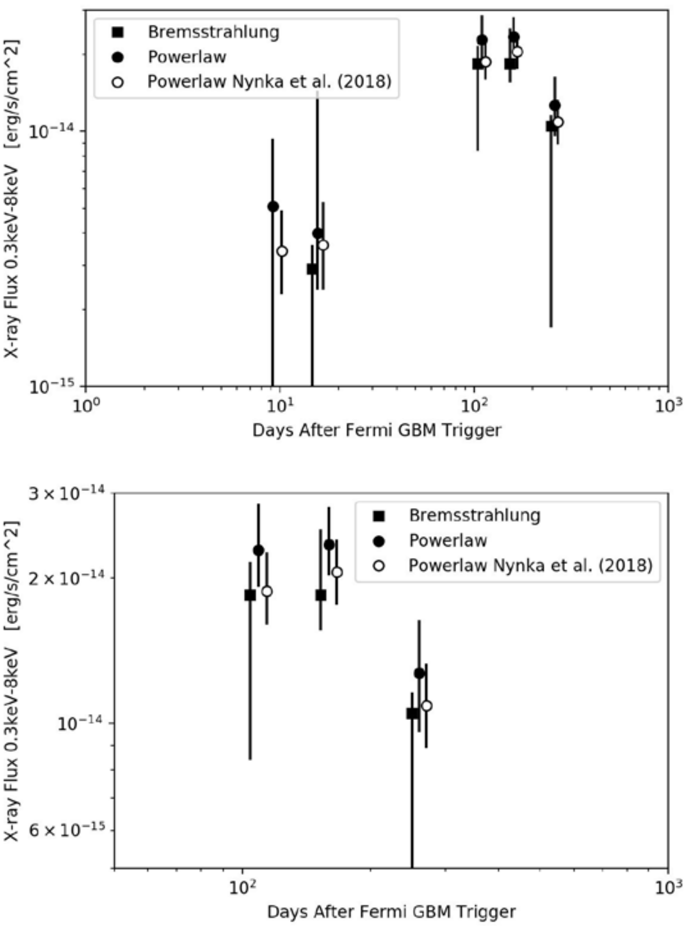


Figure 3 — Top panel shows all five sets of data from Table 1 along with data from Nynka et al. (2018). Bottom panel shows the three merged spectra from the latest 3 observation epochs at day >100 post-merger. The open circles are flux values given by Nynka et. al. (2018) using a power-law model. The dark circles are flux values extracted in this work using the same power-law model, and the black square symbols are the flux values extracted in this work using the Bremsstrahlung model. Note that the datapoints are displaced along the time axis only to ease visual inspection.

near-peak flux). The corresponding power-law photon index is 1.67 (1.39–1.95) and the thermal Bremsstrahlung temperature is 6.6 (3.8–17) keV, with the ranges quoted at the 2σ confidence level. These results are obtained when fixing the column density N_H to 7.5 x 10^{20} cm^{-2}. When allowing N_H to vary, we find a higher column density, a softer power law index, or a lower temperature for the thermal Bremsstrahlung models. In particular, for the January 2018 epoch observations, our power-law model fit yields N_H = 8.9 (2.3–16) x 10^{21} cm^{-2} (for Wilm abundances in XSPEC, Wilms et al. 2000) and a photon index of Γ = 2.3 (1.7–3.0). For the thermal Bremsstrahlung model, we find N_H = 5 (0.22–10) x 10^{21} cm^{-2} and a temperature of 3.7 (2.2–9.7) keV. These results suggest an additional intrinsic component from the merger absorbing the softer X-rays.

By comparing our power-law model fit results with those of Nynka et al. (2018), where the column density was fixed to 7.5 x 10^{20} cm^{-2}, we find that our values are consistent with theirs within error. Our thermal Bremsstrahlung model fits also yield acceptable fits, and in some cases, are statistically preferred over the power-law models. This suggests that the post-merger event can be described by hot plasma (kT~6.6 keV for the January 2018 observations), which was not considered previously in the literature. These temperatures would be lower (kT~3.7 keV) when allowing the column density to fit freely, as mentioned above. We note that Ruan et al. (2018) tested thermal blackbody models and found kT = 0.63 +/– 0.09 keV; however they disfavoured this model for explaining both the X-ray and radio emission.

Fig. 3 shows the evolution of the flux in both models (power-law and Bremsstrahlung) and highlights the comparison between our and the Nynka et al.'s results, confirming the consistency in our power-law model fits.

By further examining the brightest, January 2018 observations fitted with a power-law model, we note an excess of photons at energies around 1.3 keV and 2.2 keV. This is shown in Fig. 4, which illustrates the deviation from a pure power-law model. For this spectrum, the grouping was done by a minimum of 10 counts per bin and the column density was fixed to 7.5 x 10^{20} cm^{-2}. Adding two Gaussian lines near these energies improves the fit (from a reduced χ^2 of 1.177 (12 degrees of freedom) to 0.738 (8 degrees of freedom). However, the line centroids and equivalent widths are poorly constrained despite this being the brightest observation with the most counts (~150 counts in the 0.3–8 keV energy range). The limited number of counts prohibits us from constraining the model parameters. When fixing the widths of the lines, we find that the centroid of the line near 2.3 keV can be constrained to the 2.15–2.34 keV range (2σ confidence).

Our result is interesting but is severely limited by statistics. This is consistent with the conclusion reached by Ruan et al. (2018). To further verify our results, we tried the following:

(a) subtract another background (annulus around the source), (b) examine the individual spectra (as opposed to the merged spectra), and (c) allow the column density to fit freely. While the latter test led (as expected) to a softer photon index of ~2.2 (1.7–3.0) for N_H = 7 (6.6–15) x 10^{21} cm^{-2}, we find the same trend for the excess emission near 1.3–1.5 keV and between 2–3 keV, confirming the deviation from the pure power-law model. For the individual spectra, as expected, the (even) smaller number of counts prohibits us from any significant detection.

Discussion

The above-mentioned evidence for line detection as well as the thermal Bremsstrahlung model fits suggest a thermal origin or an additional thermal component for the X-ray emission, which would be at odds with the assumption that the X-ray and radio population arise from the same population of synchrotron emitting plasma that supports an off-axis structured jet (e.g. Alexander et al. 2018). When allowing the column density to fit freely, we find a much higher value than that assumed in the literature, suggesting internal absorption by the merger event (see also Pooley et al. 2018). Furthermore, in this model, the power-law photon index is Γ~2.2, i.e. steeper than the value of Γ~1.6 at the fixed column density. The line energies, or at least the excess emission detected in the 1–2 keV and 2–3 keV bands when fitting with a continuum model, hint at the presence of shock-heated ejecta from the kilonova remnant (KNR).

Next we discuss the feasibility for the KNR as the origin for thermal X-ray emission at this stage of the kilonova evolution. In Supernovae (SNe), it takes 10–100 y before the supernova light-curve evolves into a standard remnant with a reverse shock and high-temperature ions. However, the evolution of the KNR is much faster than a normal SN. Typical kilonova ejecta masses are 1000 times less than SNe and their expansion velocities are 10 times higher (Wollaeger et al. 2018). A key indicator of the remnant evolution is the timescale to sweep up the equivalent ejecta mass. The swept-up mass, M_{sw}:

$$M_{sw} = 4\pi/3\ \rho_{CSM}\ (v_{ejecta}t)3;$$

where t is the time, ρ_{CSM} is the circumstellar medium density (this medium is typically 10–10,000 times less dense for KNe than SNe; e.g. Fong et al. 2010) and v_{ejecta} is the ejecta velocity (the dynamical ejecta velocity is 0.2–0.3 times the speed of light, 10 times faster than SNe). The time to sweep-up an equivalent mass is:

$$t_{equiv} = (3M_{ej}/4\pi\rho_{CSM}v^3)^{1/3};$$

10–100 times shorter for KNe than SNe. The KNR will produce a reverse shock 10–100 times sooner than a SNR. This simple estimate suggests that a 100-day old KNR would have the properties of a 10 year-old SNR.

To understand this better, let's look at one of the key properties in remnant emission, the decoupling of ions and electrons. When ions and electrons decouple (for instance, when the coupling timescale is a fraction of the remnant age), the ions can get sufficiently hot to drive X-ray emission. The coupling timescale is inversely proportional to the density of the shock. Fitting formulae to plasma-kinetics calculations can be used to estimate this coupling time. Using the formulae in Gericke et al. (2002), we find that the ion-electron equilibration time for a 10 eV ion is 5 days, 50 days and 500 days roughly for densities of 10^{-20}, 10^{-21}, 10^{-22} g cm^{-3}, respectively. For our typical SNRs, the density at the shock front drops below 10^{-20} g cm^{-3} only at 10–30 y. The density of the shock front for a kilonova can be less than 10–22 g cm^{-3} at 10 days. This is illustrated in Fig. 5. As the remnant sweeps up mass and decelerates, the kilonova will produce both thermal and

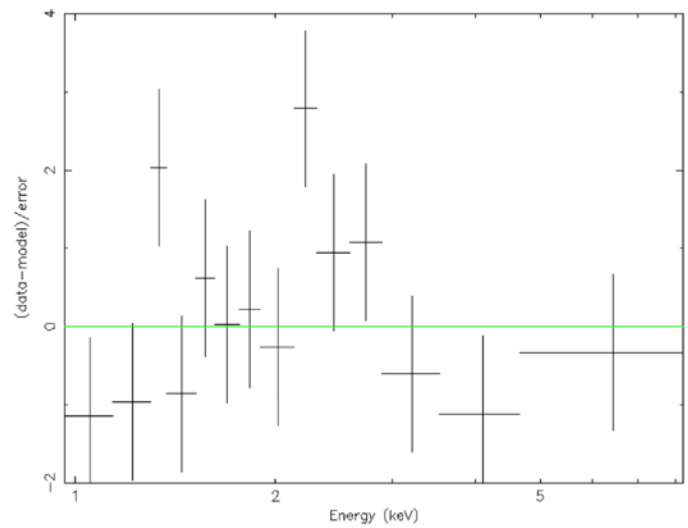


*Figure 4 — The deviations from an absorbed power-law model (green line) for the Jan. 2018 epoch data. The model used is tbabs*zpowerlw in XSPEC and the data were grouped by a minimum of 10 counts per bin. The column density was fixed at N_H=7.5x10^{20} cm^{-2} and the redshift at z=0.0098. The data (crosses) show excess near 1.3 keV and 2.2 keV. See the Results section for more details.*

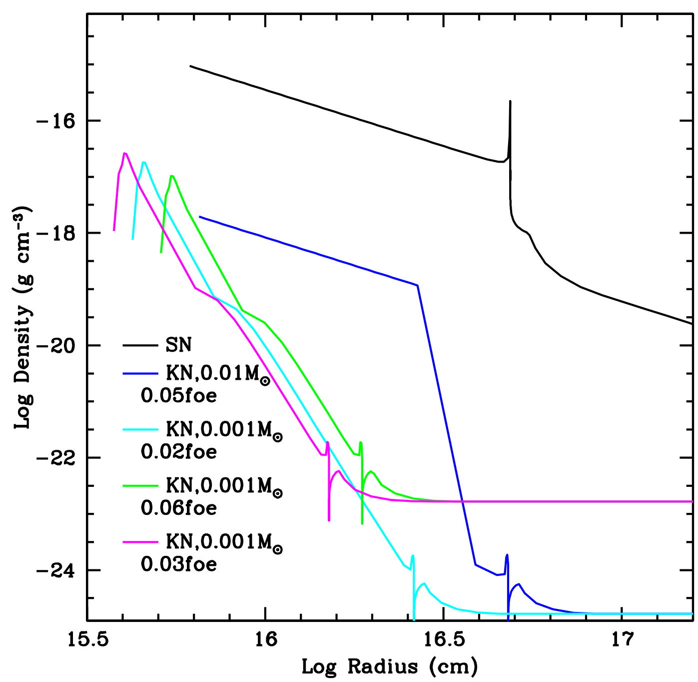


Figure 5 — Density versus radius at 100 days for a supernova explosion (M_{ejecta} = 10$M_\odot$, $E_{explosion}$ = 1.5×10^{51} erg, M_{wind} = 10^{-6} $M_\odot y^{-1}$) and a suite of kilonova explosions varying the density of the circumstellar medium (0.1, 10 cm^{-3}), kilonova ejecta mass (0.001–0.01 $M_\odot$) and kilonova explosion energy (0.02–0.06 x 10^{51} erg, or 0.02–0.06 foe). The simulations use a Lagrangian supernova explosion code (Fryer et al. 1996) assuming an ideal gas equation of state. The shock fronts can be seen at positions where the density varies dramatically. At 100 days, the density at the front of the kilonova shock is below 10^{-22} g cm^{-3} where the coupling timescale between ions and electrons becomes long compared to the evolution time of the shock.

synchrotron emission at 100 days that is comparable with an SNR more than 100 y old.

We conclude that the thermal emission could come from the KNR. However, a more detailed analysis and simulations of the evolution of a KNR will be left to a future, more in-depth statistical study that also takes into account all observations acquired to-date on this fascinating source.

Prospects for Future Studies

Upgraded LIGO will come online in 2019 and promises to discover more such events. As these events become more routinely observed in the gravitational wave field, questions regarding the nature of the merger remnant may be answered. For now, GW170817 remains the only known neutron star merger that happens to be a nearby source. It is also the first event that confirmed the connection between neutron star mergers and short-duration gamma-ray bursts. X-ray observations have shed new light on the nature of this merger and its evolution. The evidence for thermal X-ray emission reported here stresses the importance of, not just the need to follow-up these sources as they evolve, but also the need for deep imaging and spectroscopic X-ray observations to constrain any thermal emission that would arise from shock-heated ejecta or the interaction with the surrounding medium.

Despite the ambiguity of the end-state of the collision, GW170817 heralds the dawn of a new era in multi-messenger astronomy with applications in many fields, including cosmology (e.g. Wiggins et al. 2018), and holds special promise for neutron star studies using X-ray observations with excellent spatial resolution such as Chandra and in the future with missions like the proposed AXIS (Mushotzky et al. 2018) and Lynx (the Lynx Team 2018).

Acknowledgments

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ObsID	Exposure [ks]	Post-Merge [a] [days]	Count Rate [10^{-4} cts·s^{-1}]	+/-	Flux [b] [10^{-14} erg·s^{-1}·cm^{-2}]	+/-	plasma temp. [keV]	+/-	Luminosity [c] [10^{38} erg·s^{-1}]	+/-	Red. χ^2	cstat	D.O.F.
19294	49.41	9.2	3.46	0	**	**	**	**	**	**	**		**
20728	46.69	15.4	2.81	0	0.29	-0.22	1.4	0	6.48	-5.18	2.28	2.86	1
20860 20861	74.09 24.74	109.2	14.77	1.2 -1.2	1.85	0.31 -1.01	6.79	13.48 -2.99	41.89	4.51 -17.24	1.02	6.09	6
20936 20938 20937 20939 20945	31.75 15.86 20.77 22.25 14.22	159.7	14.12	1.16 -1.16	1.85	0.68 -0.29	6.52	15.53 -2.97	41.68	4.08 -18.55	1	7.14	7
21080 21090	50.78 46	260	8.16	0.92 -0.92	1.05	0.11 -0.88	6.39	30.94 -3.26	23.71	4.85 -6.89	0.98	3.77	4

ObsID	Exposure [ks]	Post-Merge [a] [days]	Count Rate [10^{-4} cts·s^{-1}]	+/-	Flux [b] [10^{-14} erg·s^{-1}·cm^{-2}]	+/-	Photon index Γ	+/-	Luminosity [c] [10^{38} erg·s^{-1}]	+/-	Red. χ^2	cstat	D.O.F.
19294	49.41	9.2	2.57	0	0.51	-0.01	1.75	0.29	11.48	4.11	0.18	0.18	1
20728	46.69	15.4	2.81	0	0.4	0.88	2.25	-0.07	9.05	12.31	2.55	3.36	1
20860 20861	74.09 24.74	109.2	13.66	1.18 -1.18	2.29	0.56 -0.37	1.62	0.3 -0.3	51.63	14.65 -10.77	1.24	7.6	6
20936 20938 20937 20939 20945	31.75 15.86 20.77 22.25 14.22	159.7	14.69	1.18 -1.18	2.35	0.46 -0.32	1.58	0.25 -0.25	53.13	8.29 -10.09	1.15	8.16	7
21080 21090	50.78 46	260	8.16	0.92 -0.92	1.27	0.37 -0.31	1.69	0.37 -0.37	28.68	5.23 -8.34	0.79	3.29	4

Table 1 — Power-law (top) and Thermal Bremsstrahlung (bottom) model fits for the post-merger GW170817 event. The column density was fixed to 7.5 x 10^{20} cm^{-2} and the redshift to 0.0098.

a Average post-merger date as in Nynka et al. (2018)

b Absorbed flux in the 0.3-8 keV band

c Luminosity in the 0.3-10 keV band

Smooth or Grained? The loopy explanation of gravity: How can general relativity and quantum theory both be correct when they contradict each other?

by Khalil Kurwa, Grade 7, student of Strathcona-Tweedsmuir School and member of RASC Calgary Centre, Youth Group

Abstract

This research project first explains how general relativity describes the four dimensions of spacetime as distorted by large masses. We then explain quantum theory as a description of the Universe as made up of finite particles that interact with no influence of gravity. We then describe the contradiction of general relativity and quantum theory when considering a black hole. Then, we look at loop quantum gravity theory, which combines the description of spacetime as a fabric of the Universe with the concept of quanta or particles of spacetime. We briefly review the alternative string theory.

We outline the implications of loop quantum gravity theory in explaining the origins of the Universe, as an explanation of fast radio bursts and Hawking radiation. We consider the problems with loop quantum gravity theory.

Conclusion: The Universe is very complex and interesting. To understand it fully, we need a theory that explains the Universe from the quantum level up.

Introduction

Research Question: How can general relativity and quantum theory both be correct when they contradict each other?

Hypothesis: That spacetime must obey a theory of everything that can be found by referencing both quantum theory and general relativity.

General Relativity

General relativity, proposed by Einstein, states that gravity is not a force, it is a result of the curvature of the fabric of the Universe. The curvature appears where matter is and to the matter's density. So, space and the Universe curves where matter occurs (Figure 2). So, the three dimensions of length, width, and depth can be changed by mass. He also proposed that time was a 4th dimension, and so the fabric of the Universe is spacetime.

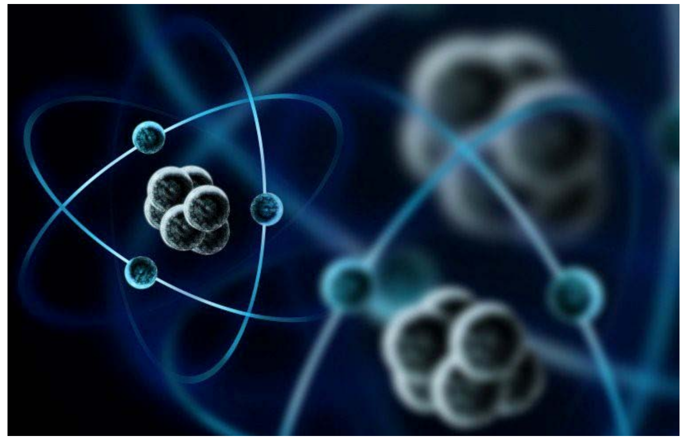

Figure 1 — Inside the atom, https://yaletownnaturopathic.com/quantum-physics-biology-and-healing

Quantum Theory

Quantum theory, on the other hand, says that everything is made up of particles, and that information is finite and everything, including space itself, can be reduced to the size of a small packet. That small packet's length is called the Planck length. In sum, quantum theory describes the Universe as a *chaotic playground* of individual particles (Figure 2). The rub between these two realities is, as *The New Scientist* states: "… quantum theory treats forces as coming in discrete chunks called quanta, but general relativity treats gravity as a smooth and continuous force."

Both theories have been proven true. So, the question is, which one is right: Quantum theory or general relativity? They both are so successful it's hard to say which one is wrong. Indeed, Einstein spent years trying to prove quantum theory wrong, yet he did nominate it for the Nobel Prize.

The rub becomes apparent in a black hole, where a star greater than 25 times the mass of the Sun collapses under the force of gravity pulling spacetime into an infinitesimal point, such that anything near it, even light (the fastest known entity), gets sucked in and cannot escape. Hence a "black" hole.

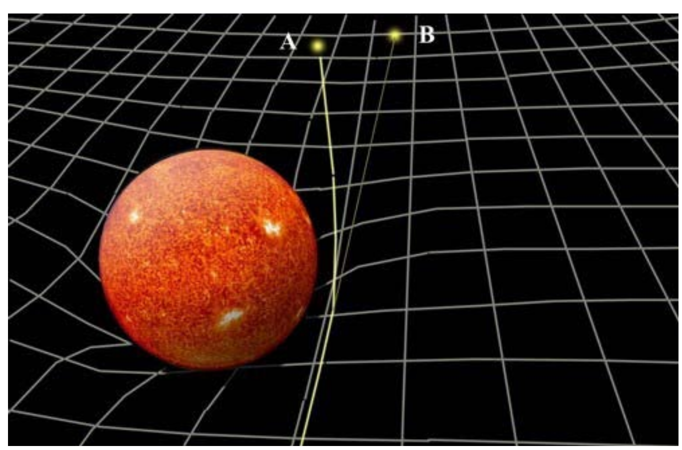

Figure 2 — Effect of gravity: Mass affects less-massive object, www.physicsoftheuniverse.com

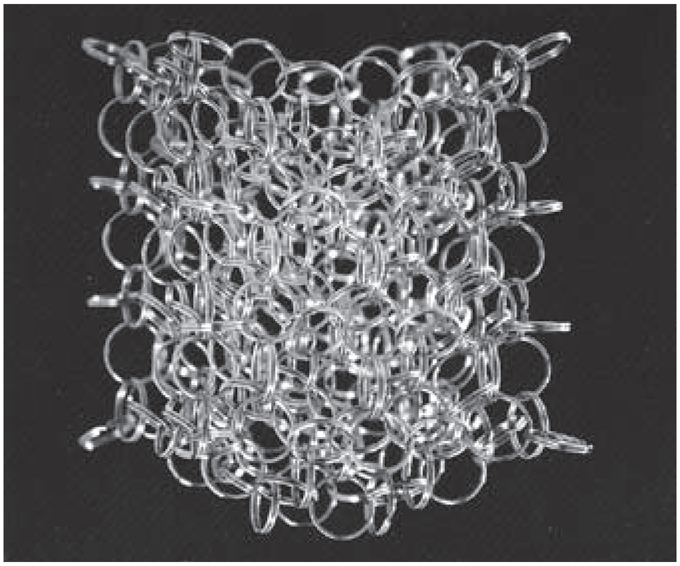

Figure 3 — Loops as chainmail, www.cpt.univ-mrs.fr/~rovelli

Black Holes and Loop Quantum Gravity Theory

The question is: what happens in a singularity? Does it obey general relativity and go on forever, or does it obey quantum theory and reach a finite size of spacetime? It's impossible to observe as if you were ever near a black hole, there is a point at which it is certain you will get sucked in and go through a process called spaghettification: The Event Horizon. Loop quantum gravity theory proposes that spacetime is made up of quanta, which are loops or rings of spacetime. These loops are the smallest area of spacetime you can get. A "Planck-length" of space. They are loops because they are connected to one another, forming a fine series of relationships (defined by the Wheeler-DeWitt equation) that make up the fabric of space time and the Universe. It is comparable to chain mail, except the loops/rings are so fine, that from afar they look like a smooth surface, if we could perceive them (Figure 3). Spacetime still follows the rules of general relativity—the notion that space curves with matter. Therefore, a singularity cannot go further than a loop. So, the loops at the base of a singularity would create an outward pressure and spring back, ejecting the matter consumed by the black hole into space. It would create a hole that, instead of consuming matter, like a black hole, ejects matter becoming a "white hole." What would such a white hole look like? From inside a singularity, it would be a powerful and fast explosion of dense matter. However, Einstein's theory of special relativity tells us that, as we move away from a point of dense gravity, time dilates. So, from Earth, such an explosion would take centuries!

Implications

Have we seen anything like this? Scientists have shown that our Universe is expanding, but not why. What if our Universe comes from a "white hole" created at the beginning of time?

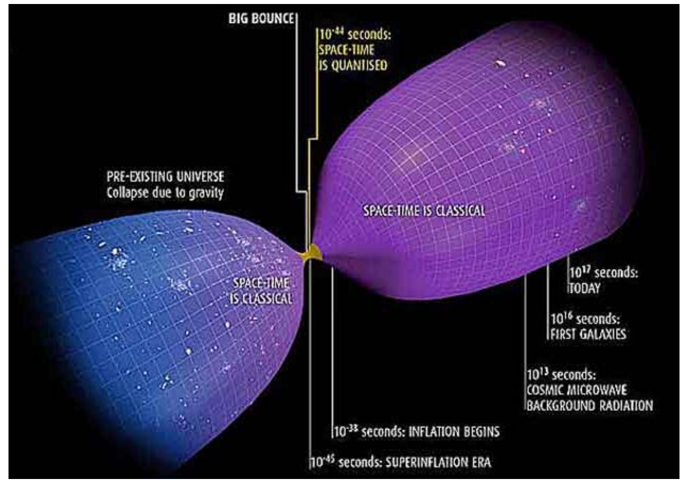

Figure 4 — The Big Crunch and the Big Bounce, New Scientist

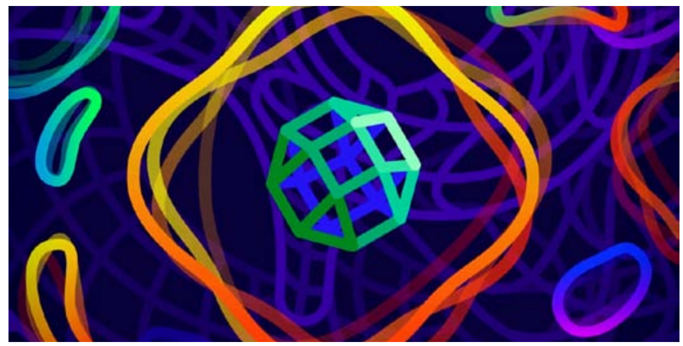

Figure 5 — Loops according to string theory, https://epicmountainmusic.bandcamp.com/track/string-theory

Our Universe, instead of starting with a "Big Bang," could have started with a "Big Bounce" (Figure 4). Is there any evidence for this?

Primordial black holes, being small, have weaker gravity than massive black holes. As a result of the effect of gravity on time—time dilation—the explosion of small, primordial black holes into a white hole, would occur more quickly than the explosion of massive black holes. This means we would see the explosion of a primordial black hole earlier in cosmic history. We would then see bursts of short wavelengths, radio waves, from deep in space, beyond our galaxy. This could be the source of the observed fast radio bursts (FRBs). Fast radio bursts are much discussed in the world of science. Another type of energy signal that an exploding black hole may emit is a blast of high energy light (photons), such as gamma-ray bursts. Scientists are building powerful telescopes to look for such unusual energy bursts, but it will take until 2023 to get these working.

Hawking radiation is mysterious radiation and heat coming from a black hole. Perhaps it represents matter beginning to come out of a white hole.

A competing theory is "string theory." This describes all particles as a string-like figure (Figure 5). Different particles represent different vibrations or oscillations of the string. This introduces a new view of particles, including a particle of gravity called the "graviton." String theory proposes many particles that have not been detected and, so far, attempts at finding these particles at the Large Hadron Collider have failed. Loop quantum theory does not require new particles to be found, but we still need to prove the theory through learning more about energy bursts in space.

Conclusions

Loop quantum gravity is a worthy candidate for this theory of "everything." It could explain why the Universe is expanding, why we see sudden bursts of radio waves or gamma rays, even why time does not exist. But it remains a conjecture. ✶

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Have You Seen a Neutron Star "Wave"?

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Abstract:

This research article explains what stars are and how they are created through the balance between gravity and nuclear fusion energy due to the fusion of hydrogen into helium and other elements into more elements. I review what happens when a star's particles finally fuse into iron (which can't fuse further) and gravity causes the star to collapse and cause a supernova. I then talk about how they can sometimes create neutron stars. I describe the key features of a neutron star, how they are detected and what happens to them over time, including neutron stars colliding with other stars and with other neutron stars. My research explains gravitational waves and describes how gravitational waves have been detected from neutron stars colliding. We explain stellar nucleosynthesis and how heavy elements can be formed by the rapid capture of neutrons by atoms (R-Process) during neutron-star collision.

Introduction:

My main research question was: how do neutron stars generate gravitational waves?

My hypothesis was: if a neutron star explodes, then it will create a gravitational wave because it will release so much energy that it will create a ripple in space-time

What are stars?

In the Universe you have molecular clouds that contain hydrogen. Gravity pushes those clouds together, forcing them

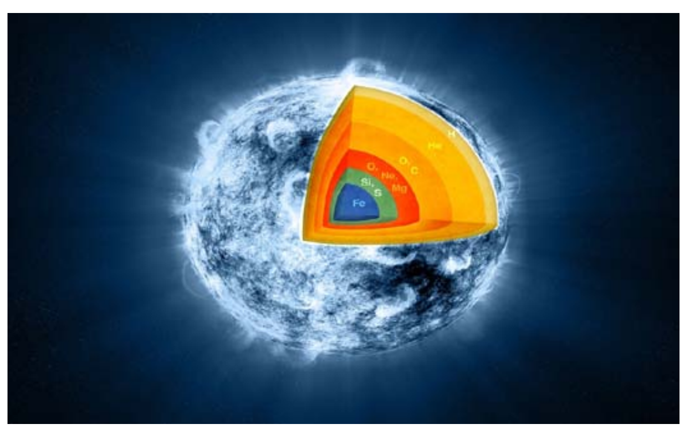

Figure 1 — Neutron star and its core, http://chandra.harvard.edu

into a spinning mass. They spin closer and closer until the hydrogen molecules fuse, creating helium. As well as creating helium, this creates a burst of energy called nuclear fusion. Then more of these elements fuse—hydrogen with hydrogen, helium with helium, hydrogen with helium. This creates more bursts of nuclear fusion. Now, we have a balance of gravity (pushing in) and nuclear fusion energy (pushing out), which is basically a star. But eventually, in large stars, fusion halts at one element: iron. There is not enough pressure and temperature to fuse iron. In smaller stars, fusion stops at carbon. If the star is less then 1.4 x the mass of the Sun, then it will shrink into something called a white dwarf. If the star is 25–40 x the mass of the Sun, then it will become a black hole. If the star is more than 40 x the mass of the Sun, then it will go through a long process to eventually become a black hole. But, if the star is 1.4–25 x the mass of the Sun, then sub-atomic particles called protons and electrons fuse into neutrons because it is under such pressure. Gravity is pushing in so hard it creates a big burst of nuclear fusion. The outer layers of the star are blown off in an explosion brighter then 10 billion Suns and we are left with a dense ball of neutrons—a neutron star (Figure 1).

Neutron Star

Neutron stars are very dense. Imagine 1–3 Sun squished into an area 25 km wide. That is equal to 500,000 Earth masses; 1.3 million Earths are equal to one solar mass but an object smaller than the Earth, manages to fit 1-3 solar masses inside it. Another mind-blowing fact is their speed: they can spin very fast, from 30 times per second (Hz) to 716 Hz. A neutron star also has a huge magnetic field, 1 trillion times stronger than our Sun.

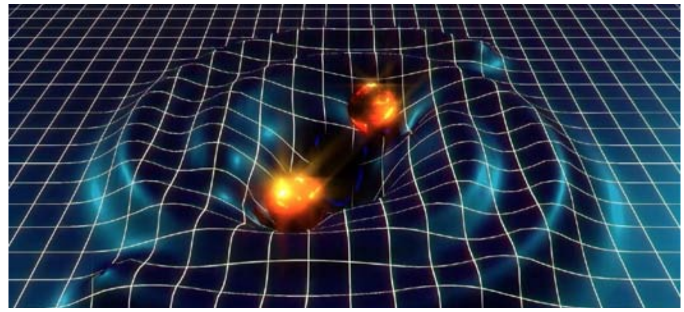

Figure 2 — World Science Festival/YouTube, www.youtube.com/watch?v=xj6vV3T4ok8

Because of their density, a neutron star's massive gravitational pull is 2 x 10^{11} (200,000,000,000) more than the Earth's. A neutron star can pull in a nearby star's energy, which makes it spin faster.

Neutron Stars and Gravitational Waves

As they are so small, neutron stars are very difficult to see, but there are still two ways to detect them. The first way is by their colossal gravitational pull. If an object in space floats by a neutron star, an astronomer will see that object zoom toward the neutron star, but not see the actual neutron star.

The second way to see neutron stars is by their spin. Spinning neutron stars are called pulsars. When they spin, they emit bursts of electromagnetic radiation (hence the name), which can be detected from Earth.

But here's a mystery: in theory, pulsars have enough energy to spin 3000 times per second, but the fastest-spinning neutron star—PSR J1748-244ad, found at the centre of the Milky Way—spins 716 times per second! This was observed by Canadian astronomer Jason Hessels.

Something prevents them from spinning faster than 716 times per second and that is space-time. The spinning of the pulsar "rubs" against space-time making "waves" called gravitational waves. But what are they?

Gravitational Waves

Imagine space as a big pond. If you throw a stone into it you'll get ripples. These ripples are gravitational waves. Space gets bent like clay because of the mass or energy of an object. Whenever you move, you create gravitational waves. But they are really, really small.

These ripples in spacetime were first predicted by Albert Einstein in 1916 (Figure 2).

Gravitational Wave Astronomy

So now we know what's stopping them from spinning 3000 Hz! But there is still a problem: how do we detect them? Gravitational waves happen most strongly in areas were gravity is intense but PSR J1748-244ad is 18,000 light-years away, so by the time gravitational waves reach Earth, you would need a machine that could detect a change in space that was about a

Figure 3 — The LIGO Experiment, Image credit: LIGO, Caltech, MIT, NSF

millionth of the diameter of the nucleus of an atom. And if an atom was the size of a soccer field, the nucleus would be the size of a pea in the middle and the electrons would be as big as fruit flies! But there is a solution: LIGO stands for Laser Interferometer Gravitational Wave Observatory. It has two poles at 90 degrees from each other (Figure 3). They bounce lasers from one end to the other. When the gravitational wave comes, it stretches and squeezes the poles just as it stretches and squeezes space. Then the lasers take longer or faster to get from one end of the pole to the other. This is because the speed of light is fixed.

So far LIGO has had two successes:

- On 2015 September 14—LIGO first detected gravitational waves from two black holes colliding 1.8 billion light-years from Earth.
- In August 2017, LIGO detected, for the first time, gravitational waves from the collision of two neutron stars, 130 million light-years from Earth. These were detected along with a burst of gamma rays and the first evidence of heavy elements, like gold, being produced by the colliding neutron stars.

How are these heavy elements created? Well, when two neutron stars collide, there is an outburst of neutrons. These neutrons hit the nuclei of lighter elements. The type of element is determined by the number of protons and

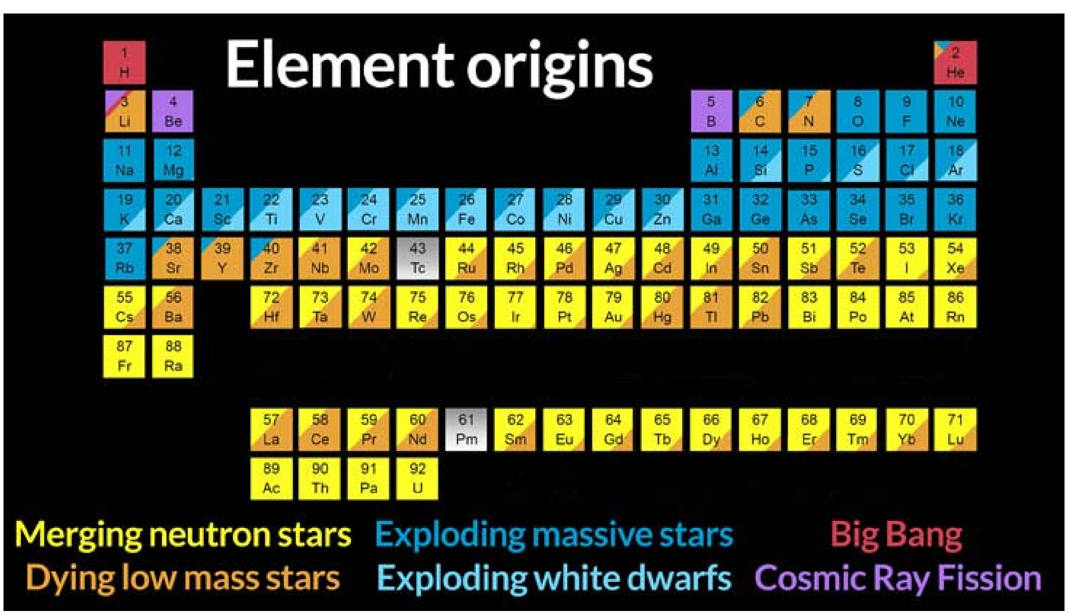

Table 1 — The Periodic Table explained pictorially, Image Credit: Robert Hurt/IPAC/Caltech

neutrons in the nucleus. The more protons and neutrons, the heavier! So, when the neutrons hit the nuclei, there is a sudden increase of neutrons, making them heavier. This is called the R-process (R stands for rapid) or Stellar Nucleosynthesis (Table 1).

Conclusions

My hypothesis was partially correct. So far, gravitational waves have been detected when neutron stars collide. Furthermore, we have never actually seen a neutron star explode. On the other hand, gravitational waves have only been discovered in the last few years, so we are still finding out about them. We may even be able to detect gravitational waves from *spinning* neutron stars. In fact, an on-line project called "Einstein at home" (einsteinathome.org) is trying to do just that. Gravitational wave astronomy is so important. It's a whole new way to see the Universe. We can now see things that we have never seen before. The era of gravitational wave astronomy has begun!

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Great Images

By Bruce Hamilton

Bruce Hamilton took 160+ images at Litchfield, near his home overlooking the Bay of Fundy. He writes "There was a bit of aurora and I put the camera in auto mode, captured 168 twenty-sec. photos. Stacked in Photoshop without star alignment. Lots of colour. The heavy white line on the horizon is the Digby scallop fleet dragging up and down the bay."

Student of Star-Law: Albert Durrant Watson and the RASC

by Marlene Macke

A member of the Royal Astronomical Society of Canada and its predecessors since 1892, Dr. Albert Durrant Watson (1859–1926) served as the President in 1916 and 1917. This article surveys the poetry and papers he contributed to the Society's *Journal*, revealing his world view of the connection between reason and faith.

"The sense of wonder and joy, begotten by the harmony and amplitude of the unboundaried field of astronomical research," Albert Durrant Watson wrote, "helps the mind to discover and to reveal in those modes of being and motion ever emerging to our ken, and leading us in humility and light to wider worlds of imagination and vaster fields of thought…. That surely is a sublime kingdom which lies before the master artist who would sing for us the new canticles of the sky" (Watson 1922, 46).

Whether Watson developed an appreciation for astronomy before he met his future father-in-law, Samuel Clare, in 1876, study of the stars later proved a prominent pastime throughout his life.[1] Astronomy appealed to his sense of orderliness in the universe, deeply complemented his spiritual perception of that same Universe and fed his poetic muse.[2]

In 1868 the Toronto Astronomical Club formed with Samuel Clare serving as one of the founders and the club's Secretary-Treasurer. "The first minute book of the Society has now reached almost its jubilee year," Watson recalled in his President's address 50 years later, "but it would be too hard to find anywhere minutes couched in handwriting more beautiful than that in which Mr. Clare recorded the transactions of this pioneer club" (Watson 1917, 56). The original club evolved into the Toronto Astronomical Society and, in turn, into The Royal Astronomical Society of Canada (RASC). The Society elected Watson to its membership in May 1892.

A King Street optician sold Dr. Watson an imported 3-inch refractor telescope made by the French manufacturer, Bardou (Chant 1926, 154). Family lore had it that Watson cut a hole in the roof of his house through which to aim the telescope. The attic served not only his observations of the skies but also as a studio for his wife Sarah, a gifted sculptor.

"This telescope proved to be of excellent quality and was used continuously and efficiently by Dr. Watson," wrote Clarence A. Chant, a professor at the University of Toronto credited with the establishment of a lasting tradition of astronomy education at the university level in Canada. Chant added, "He seldom lost an opportunity to observe any objects or phenomena which were referred to in his reading of astronomical literature, and thus he attained a certain assurance in handling cosmic problems which is reached only through practical acquaintance with the subjects discussed." As an example, Chant remembered, "[I]n the early morning of October 16, 1892, Dr. Watson had observed Jupiter apparently with only one satellite—two being in transit and invisible and the fourth one behind the planet" (Chant 1926, 154).

Watson read his first two papers to the Society in 1896 and both were published in the *Journal*. He wrote the first paper, a brief commentary proposing adjustments to the existing grading of the scale on thermometers "for the purpose of simplification" with the intention of evoking discussion among scientists (Watson 1896, 91-92). The other more extensive paper entitled "The Reformation and Simplification of the Calendar" reorganized the calendar into 13 months in the year, each having 28 days, with one extra day in each common year and two extra days in each leap year. These extra days were to be considered holidays without weekday names.

"… [I]nstead of the fourteen different calendars [from various parts of the world] now required to set forth our frozy [sic] method of presenting our process of days and months and years, we should have one simple form of year which would be so easily remembered that no printing of the calendar would henceforth be necessary for all time," Watson wrote. "The changes of the moon would be so nearly coincident with the months that it would be known just when the new moon would occur in every month even from the beginning of the year. Dates also would occur always on the same days of the week throughout all time" (Watson, 1896, 65).

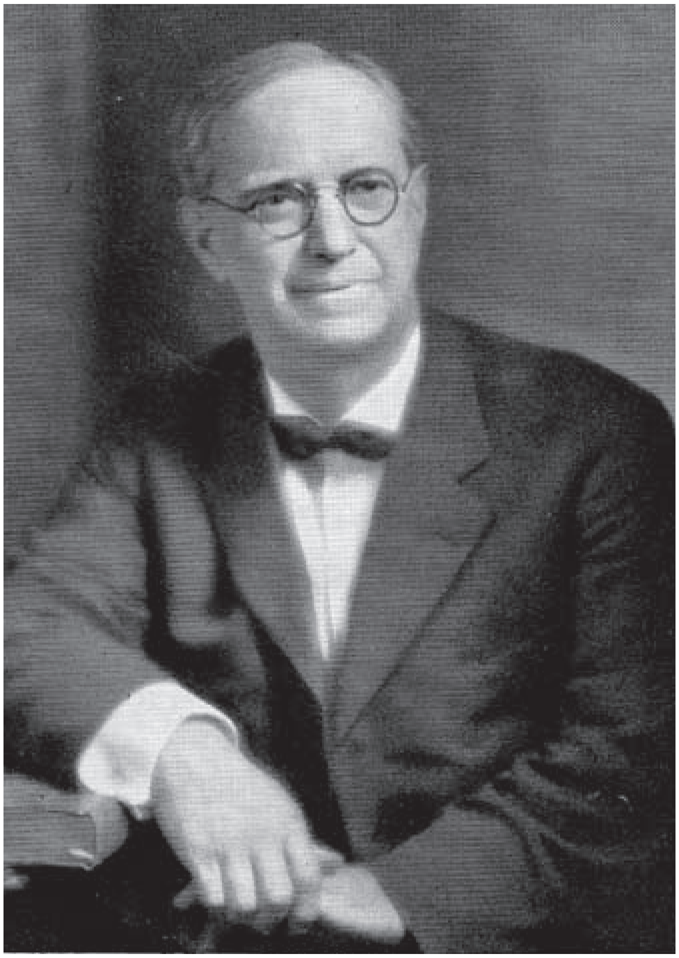

Figure 1 — Frontispiece in The Poetical Works of Albert Durrant Watson, 1924

"This proposal has been much discussed since then, its greatest advocate being Mr. M. B. Cotsworth, of Vancouver, B.C., who has prepared a statement regarding it for the League of Nations and has received letters from the leading ecclesiastical authorities expressing approval of it," Chant later wrote. "Many business houses are also favourable to the proposal and I think men of science generally would be glad to see the new calendar introduced, but I fear it would come as a shock to the great mass of the people" (Chant 1926, 154). Alas, the proposal sank into obscurity. Years later, the lack of success in implementing his calendar still rankled. In his 1917 President's address to the Society, Watson commented:

> … This paper was received with enthusiasm by the Society, which printed it in full in its transactions, but it would seem that
> *"No might of armies and no rage of storms can turn"*
> one little habit from its track, however foolish it may be, if once ingrained into the customs of the race. The world will still use its anomalous method of calculating its astronomical day from noon and its fourteen foolish calendars, as it has done for so many centuries" (Watson 1917, 66).

Occupied by writing poetry, volumes of Christian commentary from the Methodist point of view, a busy medical practice, and his growing family, Watson's output for the Society was sparse for the decade following 1896. He read only one paper on the "Pleasures of the Telescope" in 1903, which was not printed in the *Journal*.

Five years later a spate of poetry and papers followed. The poem "Northern Lights" was published in 1908. Meanwhile, after a period of 76 years since its last appearance, astronomers eagerly awaited Comet Halley's reappearance in the spring of 1910. Watson's paper "Halley's Comet and its Approaching Return" described the likely genesis of Halley's, its journeys in our Solar System and enumerated recorded sightings since 130 BCE. He detailed the 1682 calculations of Englishman Edmund Halley (1656–1742) who correctly predicted the comet would return in 1758. Watson's own calculation pegging the nearest approach of Halley's to 1910 April 8 (subsequently adjusted to May 12 by Greenwich Observatory astronomers) was impressive for a sophisticated amateur astronomer.

The paper eloquently summarized Watson's beliefs:

> There are few of us who get any unified concept of the universe. And yet our universe is also diverse, our comets, as expressions of universal law, are a far call from our planets, and still further from our Sun, nevertheless the same laws are operative in all cases and no particle of matter, whether it be a speck of dust in the tail of a comet, or a blazing sun dominating a great system at the centre of the cosmos, can escape the great universal laws which Copernicus and Galileo, Kepler and Newton, have brought to light (Watson 1909, 218).

Watson's attraction to great astronomers and scientists manifested itself in a series of papers and poetry over the next decade. In 1910 he wrote about Heinrich Wilhelm Matthias Olbers (1758–1840), a German medical doctor and amateur astronomer. Contemporary and future astronomers highly regarded Olbers' observations and theories, many considering him the chief authority on the subjects of comets and the minor planets (Watson 1910, 272).

Re-purposing his early research into calendars that he had undertaken prior to writing "The Reformation and Simplification of the Calendar," Watson published "Calendars Ancient and Modern" in 1911. This paper comprehensively reviewed calendars devised by Egyptian, Babylonian, Jewish, Chinese, Greek, and Roman peoples. "Reform of the calendar is not excluded by the nature of astronomic law or motions, but by the inertia of conservatism, the vis a tergo which drives us on in the old courses, the skeleton hand of the past which holds us back when we would change or improve," he wrote. "There will, doubtless, some day be a thoroughly scientific calendar

Continues on page 24

Pen & Pixel

Figure 1 — This image of M27, the Dumbbell Nebula, was taken by Kimberly Sibbald using a ZWO ASI071MC Pro cooled camera on a Celestron CGEM II mount and an 8-inch Edge HD telescope.

Figure 2 — Accomplished astrophotographer Ron Brecher imaged the Pacman Nebula (NGC 281) using his Sky-Watcher Esprit 150 f/7 refractor, QHY 16200A camera, Optolong Hα, R, G, and B filters, on a Paramount MX. 16x5m R, 15x5m G, 15x5m B, and 9x10m Hα (Total = 5hr 20m).

Figure 3 — Comet 46P/Wirtanen made its closest approach to Earth in December. Roman Kulesza managed to catch the interloper as it neared in November. The image was taken from Bathurst Observatory using T-68 iTelescope.net. A Celestron 11-inch RASA telescope at ƒ/2.2 and ISO 1600 C OSC (One Shot Color camera). This is stack of 6 subframes, 60 seconds each in MaximDL and processed using MaximDL and Photoshop.

Figure 4 — Stuart McNair says of this image: "The image was taken at 6:18 a.m. EDT, 2018 October 19 looking southeast from a location southeast of Kirkfield, Ontario. The dim, winter Milky Way is barely visible as a vertical area of denser stars above the cloud invading from the southwest. The zodiacal light was easily visible to the naked eye just as its nickname of 'false dawn' would suggest." Stuart used a Nikon D810, Sigma ART 14-mm lens at ƒ/2 for 20 seconds, ISO 1600. The ground was post processed to lighten it and make details like the road and fence line visible.

Continues from page 21

in use throughout the world.… Meanwhile, we rest in the assurance that whoever gets the credit for devising a scientific calendar we, of the Royal Astronomical Society of Toronto, shall deserve it" (Watson 1911, 176).

The *Journal* printed a poem on Kepler in 1911 and two lengthy poems, "Copernicus: A Monologue" and "Galileo: A Monologue," followed in 1913. And in keeping with Watson's fascination with history and its people of influence, he next published a paper on "Horrox" in 1915. Jeremiah Horrocks (1619–1641) was the first person to accurately predict and observe a transit of Venus in 1639, an event that led to a centuries-long effort to establish the scale of the Universe. Watson believed this young English tutor figured as a true prodigy who in a brief five-year period achieved what other astronomers might take a lifetime to achieve. He acclaimed Horrocks as "one of the most remarkable scientific geniuses of the ages" (Watson 1915, 270).

News events such as the growing conscription crisis in the middle of the Great War sometimes inspired Watson's poetic muse. As an example, the *Journal* published a poem entitled "The Bugle," addressing those who had not yet enlisted in the Canadian Expeditionary Force (Watson 1916, 40).

Later that year, Dr. Watson's paper "Companions of the Sun" described the Solar System grounded in the knowledge of the day. He wrote, "The companions of the sun comprise eight planets, twenty-seven moons, hundreds of comets, and thousands or even millions of meteors and tiny particles of world-stuff, all floating along with the great household of the sun." In what may have been the first use of the evocative word "star-stuff," Watson noted, "…we too are composed of star-stuff, and are essential parts of the whole cosmos." The paper also included Watson's speculations as to the types of habitation that may have been on some of the planets (Watson 1916, 384-401).

Dr. Watson revisited Copernicus with an 18-page paper that he read to the Society in May 1919. In reviewing the life and findings of Copernicus, he pointed out that the theories of Copernicus revolutionized science but were ridiculed in his lifetime. Watson's remarks might be taken to reflect some of the turmoil of his own life. He had suffered public ridicule over the two books he compiled alleging psychic revelations from the "Twentieth Plane." However, the life of Copernicus appealed to him on several levels. "…Copernicus is almost monotonously noble," Watson wrote. "He deliberately determined that his life should exclude all that was unworthy, and the resolution was rigidly kept." Few "immortals," as Watson liked to style these great historical figures, could be more inspiring to the standard he himself strived to mirror. "Thus was Copernicus a mathematician, a doctor of canon law, a doctor of medicine, a secular canon of the church," he wrote, "and incidentally, though most important of all, an astronomer." And this particular connection between the practice of medicine and the study of astronomy was not lost on Watson. He would have been inspired by how Copernicus practiced medicine not just for the wealthy and noble, noting that "the medical skill of Copernicus was ever at the command of the poorest in his town" (Watson 1919, 266). Long after his prestige and position in society grew and friends urged him to move to a more stylish address, Dr. Watson refused to leave his working-class patients who now lived in his neighbourhood. (Watson was writing, of course, from information available to him in his time; Copernicus, according to later researchers and writers, did not graduate from any medical school and there is no evidence that he acted as a doctor to the poor.)

Figure 2 — Albert Durrant Watson, 1926

To this point, there were few professional astronomers in Canada and just one significant observatory, the Dominion Observatory in Ottawa, Ontario. Dr. Watson and C.A. Chant collaborated to establish a first-class astronomical observatory in Toronto. This was but one in a series of efforts to establish such an observatory in Toronto but was a project especially dear to the hearts of Chant and Watson through the years leading up to World War I.

"The outline of this project, which is intended to supply the needs of the University of Toronto for teaching and for research, the Royal Astronomical Society of Canada and the citizens of Toronto and of the province, was drawn up in Watson's office early in 1914," Chant wrote. "The Great War intervened and checked the carrying out of the scheme; but it is so desirable, and indeed so necessary, an addition to the equipment of the University and to the educational facilities of the Province, that it must be brought to a successful issue in the near future. The writer will always associate Dr. Watson's name with this great project" (Chant 1926, 157). Another 20 years passed before their dream of a worthy local observatory eventuated with the opening of the David Dunlap Observatory in 1935 but, sadly, Dr. Watson had died by then.

Elected Vice-President of the governing council of The Royal Astronomical Society of Canada in 1912, Watson subsequently served as President in 1916 and 1917 (Broughton, 1994, 101). For his inaugural President's address, Watson chose as his subject "Astronomy in Canada," delivering a 30-page review of the history of Astronomy in Canada including its people, growth, and achievements. In his address as outgoing President a year later, Watson chose as his subject "Astronomy: A Cultural Avocation," a beautifully written paper, very poetic in its prose.

> [Astronomy] is not merely, in a literal sense, the loftiest of the whole circle of the sciences. The awful sweep of its majestic motions, its serene and absolute order, the simplicity and wonder of its laws, the blazing splendor of certain of its objects, and still more, the restraint with which the true astronomer regards the unspeakable sublimities of his science, all go to make star-law the first in importance of all those agencies which give the human mind its glory and vision in a field so vast that we may never know its boundaries (Watson 1918, 82-83).

That year, the *Journal* published another of Watson's poems, "The Stars are Waiting." It later served as the epitaph in Watson's obituary written by *Journal* editor C.A. Chant. Then from 1918 to 1921, Dr. Watson found himself immersed in the Twentieth Plane psychic phenomenon and the writing of two books recording the alleged trance sessions.[3] However, in 1921 after publicly renouncing any further involvement with psychic phenomena, Watson resumed writing poetry and papers that were published in its journal.

THE ASTRONOMER

> When crooning breezes whispered
> Their lullabys of rest
> The evening star was sinking
> To cloudlands of the west,
>
> And tired folk lay breathing
> 'Neath brooding wings of sleep
> While through his lens of wonder
> The star-man scanned the deep.
>
> There, spread the dome of knowledge
> Inverted to his sight,
> The dark, mysterious concave,
> The all-revealing night,
>
> Where tranquil planets floated,
> Each in its fitful track –
> Those vagabonds of heaven
> That dot the zodiac;
>
> And, more intensely burning
> In horde and fiery clan,
> Far up the gleaming archway
> A starry pageant ran.
>
> The bright celestial torches
> Glowed with a pomp sublime;
> The star-man marked their motion
> And called its measure "time."
>
> One truth in beauty blazing,
> Graved on the night he saw,
> A truth the stars were singing–
> The sovereignty of law (Watson 1921, 137).

In 1922, in what may have been Dr. Watson's most heartfelt paper, the *Journal* published "Astronomy in a Poet's Life." To advance his thesis of the wonders of the Universe, he quoted from the poetry of well-known contemporary Canadian poets, Bliss Carman and Robert Norwood, thereby linking astronomers and poets in their espousal of great universal laws. "Both the astronomer and the poet perceive unseen laws of government and life in the silent and mysterious movements of nature…. The very word astronomy suggests law," Watson wrote. "The student of star-law recognizes everywhere the reign of order, and in a certain sense, astronomy carries the quest of law to its farthest limits. The astronomer explores the most distant frontiers of space in his search of law. It is his passion" (Watson 1921 (1), 7). Going beyond a simple accounting of the connection between poetry and astronomy, Watson outlined his world view of the interconnectedness of all humanity's pursuits:

> … A series of interesting papers has recently been presented before this society, showing the inter-relation existing between astronomy and the other arts and sciences. Inasmuch as all science and art, all religion and ethic, arise in one universal Source, what is more natural than that we should find evidences of their unity in all our investigations.
>
> "In view of the international efforts now being made to disarm the world and abolish war from land and sea, it seems appropriate that in all arts and sciences, religion and commerce, politics and industry, as well as in our international and social relations, the great principle of

> mutuality should be observed. All prejudice should be abolished, while those movements which serve to unite the human race should be strengthened. All divisive policies, all offensive actions, even narrow patriotisms should be scrutinized with suspicion, especially if they be our own, for all men and all nations are from one Source.
>
> "The day of conference and counsel has come. In cleaning up the muss [sic] that has been made of civilization, while recognizing the claims of the larger justice, it is sincerely to be hoped that we shall abandon all self-righteousness. We know there can be no peace on earth for anyone till there is good-will in his own heart. What is true of one individual is also true of the nation and the world. Not until there is kindliness in our hearts towards all can we take the position of the astronomer and the poet, and, scrutinizing our own disposition and practice, enquire: "How will this look in the universe?"
>
> Who loves his native land is wise.
> More glorious he whose visioned eyes
> Doth see our God in every face
> Beneath the blue and bending skies.
>
> One God is ours, one earth, one air,
> One sea; one sky is everywhere.
> The world is not so very wide,
> And heaven hath only one bright stair
> (Watson 1922 (2), 46-47).

And speaking, no doubt, of himself and his friends in the RASC, Watson remarked, "Even those astronomers who live in cities are somewhat austere in their habits. They are never known as addicts of the cabaret. They avoid the races. They are not often seen at functions. They live in almost eremitic retreat and dwell in 'worlds more wide' (Watson 1922 (1), 7).

Dr. Watson's next paper, "The Norse Discovery of America (in A.D. 1000)," illustrated his wide-ranging personal interests. Some 38 years before the archaeological discovery of the Viking settlement in L'Anse aux Meadows on the tip of the Great Northern Peninsula in Newfoundland, he came to his own conclusions. Watson's paper to the RASC meeting, an article in The Globe reported, had made "an intimate study of the documents and archaeological monuments pertaining to the Norse discovery of this continent, and [he] disclosed the results of his studies in one of the most interesting papers read this year.… The question of the actual location of the places visited by this Viking chief has been a matter of much controversy, but after much research and consultation, Watson concluded, these were Labrador, Newfoundland and Nova Scotia" (The Globe, 3 May 1922, 13).

"… the story of the discovery of America by the Norsemen nearly a thousand years ago was long regarded as a fabulous or legendary exploit involving more romance than truth," Watson wrote. "The more recent appearance from unsuspected sources of accounts independent of each other, of expeditions to a land which could have been none other than America, has shown at least a nucleus of authentic history and confirmed the earlier traditions of these interesting expeditions. One central fact stands undisturbed by criticism. It is the assurance that Leif Ericsson of Iceland landed on this continent during or about the year A.D. one thousand" (Watson 1923, 257).

As well as the documentary evidence available to him, Dr. Watson noted the Norse navigators had neither clock nor compass by which to establish their locations. He asked Joseph A. Pearce, a friend and life-long member of the RASC, to calculate the lowest latitude the Norsemen could have been situated. Pearce reported, "The latitude must have been at least 58°North, and therefore Vinland could not have been farther south than Labrador" (Watson 1923, 264).

That year saw another poem published, "The Dawn of Night (On Mt. Hamilton)," written while Watson travelled in California on one of his book tours promoting The Poetical Works. He had taken the opportunity to visit Joseph Pearce who had accepted a fellowship with the Lick Observatory, an important astronomical observatory located on Mount Hamilton in northern California. This poem was Watson's last published work in the *Journal*.

His anthology of poetry, The Poetical Works of Albert Durrant Watson, had been published to great acclaim. C.A. Chant wrote in the *Journal*'s Review of Publications,

> … Dr. Watson is a capable amateur astronomer and has been connected with the R.A.S.C. for many years, being its President in 1916 and 1917. As one might expect, he is a lover of nature in all its manifestations, and we continually see references in his verses to the sky, the wind, the tides, the silver moon, the stars. In his later poems, there is somewhat of the mystical element. A distinguishing feature, however, is that in everything he writes he ever keeps before him the beautiful and the good—peace, love, harmony, the higher life (Chant 1924, 176-177).

Dr. Albert Durrant Watson hosted his weekly gathering of intellectuals on Sunday, 1926 May 2, and then, at the age of 67, passed away early the next morning. The death certificate listed the cause of death as acute myocarditis or inflammation of the heart. C.A. Chant wrote a five-page obituary in the *Journal* describing Watson's life of service in medicine and astronomy, his extensive body of work in poetry and prose, and his serious endeavours in investigating psychic phenomena. Chant's obituary confirmed Watson's unwavering conviction in the harmony between science and the spiritual, a world view amply lived in his life and work.

In summary, Dr. Watson's pursuit into the "Twentieth Plane" psychical research lasted barely three years and, while it generated much publicity at the time, it serves largely as a negligible blip in his life. His poetry lasted longer—his first volume of poetry was published in 1908 and he continued writing poetry until his death in 1926—but already in the mid-1920s poets employing a new style of modernist poetry began to overtake Watson's style of traditional lyric poetry. While appreciated during his life, today his poetry is forgotten.

However, Dr. Watson's zeal for astronomy remains his enduring legacy. As a member of The Royal Astronomical Society of Canada for 34 years, he employed his scientific curiosity toward wide-ranging thinking and investigation into the majesty and mysteries of the night sky. His perception of a spiritual Universe permeated all his papers and poetry, uniting science and reason with supernal faith. His world view inspires us today. Dr. Albert Durrant Watson truly deserves to be memorialized as a student of star-law. ✶

Acknowledgement

And with acknowledgment and appreciation to Stephen Bedingfield, Antonio Martinez, and Randall Rosenfeld for explaining and clarifying several points of the science of Astronomy and its history.

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Endnotes

1 Albert Durrant Watson met Samuel Clare when he enrolled in the Normal School in Toronto in 1876 where Clare taught writing and bookkeeping. In 1879 Watson entered medical school at Victoria University, graduating in 1883. Two years later he and Sarah Anne Grimshaw Clare married. Sarah was one of Samuel Clare's daughters.

2 A Renaissance man who pursued poetry, philosophy, and mysticism,
Dr. Watson travelled in literary, academic, and scientific circles in Toronto. He wrote several volumes of poetry and philosophical thought and co-edited the first collection of Canadian literature for use in schools. He supported several of the social justice issues of the day. As a young man, Watson served actively in the Methodist Church, although in later years, he broke away from church membership and hosted a weekly gathering of intellectuals on Sundays in his home.

3 Along with a number of other men of science in that era, Dr. Watson had been interested in testing the validity of psychic phenomena through scientific study. He even served briefly as President of the Canadian Society for Psychical Research, a secular research group of mostly medical doctors and academics operating in Toronto between 1908 and 1916. In 1918, when Louis Benjamin, one of Dr. Watson's friends, claimed to have received messages from a lofty place in the afterworld called the "Twentieth Plane," a seance was planned at Watson's home. The messages Benjamin allegedly received were sufficiently compelling that Dr. Watson had them taken down verbatim. He subsequently published two volumes of the proceedings, *The Twentieth Plane: A Psychic Revelation* in 1918 and *Birth Through Death: Ethics of the Twentieth Plane*, *A Revelation Received Through the Psychic Consciousness of Louis Benjamin* in 1920. Thousands of copies, particularly of the first volume, sold in Canada, the United States, and the United Kingdom. However, several intellectuals and sceptics ridiculed and spoofed the first book in letters to the editor and in magazine articles. As time passed, it became apparent that Louis Benjamin seemed to be drawing the information contained in his messages from biographies of great people and other sources such as the Encyclopedia Britannica. Dr. Watson withdrew from further association with Benjamin. In fact, in 1921, Watson publicly renounced his involvement with trance readings and the pursuit of psychic phenomena. He did this through articles and interviews in the local newspapers, letters to friends, and in one last book published in 1923 entitled *Mediums and Mystics: A Study in Spiritual Laws and Psychic Forces* that cautioned readers to avoid mediums and their services.

Dish on the Cosmos

Invisible Light Pollution

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

As astronomers, one of our favourite things is a dark night far from the city lights giving a clear window into deep space. Often, we worry about how the night sky seems foreign to people in the city, where light pollution washes out all but the brightest stars. Yet, the novelty of a clear night can be particularly striking to these people when they encounter it through their lives. Light pollution does hamper our appreciation of the sky and deeply limits the astronomy that most of us can do from our homes. But we cannot deny how useful it is having lights at night for allowing us to get around and extend our waking hours.

Radio astronomers have growing concerns about a different kind of light pollution. The problems are quite similar in both the radio and the visible parts of the spectrum. Both radio waves and visible light are electromagnetic radiation, with the key distinction between them being the frequency of the wave pattern. The frequency is how fast the electric field in the wave oscillates back and forth every second. Radio waves range from thousands to trillions of Hertz (Hz, cycles per second) and most radio waves are in the range of megahertz (MHz) or 1 million Hz. In contrast, visible light oscillates 1000 times more frequently than the fastest cycling radio waves. The colour of visible light that we see is actually the frequency of the radiation with red light having a lower frequency than blue light. Our eyes cannot see radio waves, of course, but those waves also have a range of frequencies that determines the "colour" of the radio wave.

Just like visible light, radio waves have vast uses within our technological civilization. They are key to long-distance communications that span the globe. We use radar stations to sense the movement of weather and airplanes, and these operate at relatively low frequencies of radio waves. The principles of radar are so useful that radar waves are used for automatic doors or even collision-avoidance systems in modern cars. We rely on radio waves for cellular telephones, radio stations, television, and wireless internet.

Given all of these uses, we need a way of separating the signals that are used for different purposes. This is accomplished through the frequency of the radio wave: for each use, a broadcast device has a dedicated frequency of radiation that it is allowed to transmit and receive at. The system is analogous to communicating with flashing visible lights: if we allocated red light one type of communications and blue light to another, we can keep the signals separated (side note: this is exactly how fibre-optic cables work for transmitting multiple streams of digital data down a single fibre).

There is nothing in the laws of physics that makes one frequency of radiation special, so there are human laws in place that forbid the use of devices that emit strong radio radiation outside frequencies that are assigned for use by that type of device. Every device that communicates using radio waves is certified as compliant with broadcast restrictions. Terrible consequences could ensue if, for example, your microwave oven was broadcasting radiation at the same frequency as the runway beacon of the local airport. The laws that sort out different frequencies is an esoteric corner of international law, but the process has produced a relatively well-established system with fairly good international agreement among nations.

An example of the radio frequency allocations is shown in the chart in Figure 1. This is a portion of a graphic produced by Industry Canada for how the spectrum is allocated to different uses. A tiny section of the band is allocated to radio astronomy for the study of atomic hydrogen gas. This spectral line has been featured in this column before and was the first crucial indicator that we lived in a spiral galaxy. It has since been a key tool in understanding many other problems in astronomy. But, like a city block with condominium buildings filling in around a tiny old house, the spectrum near the hydrogen window has become crowded with the electrical signals of our civilization. Like starlight in the visible sky, the radio whispers of the Universe are faint, so our telescopes must be incredibly sensitive, amplifying signals a trillion-fold to detect them. When stray radiation bleeds into a radio astronomy band or when scientific goals require observing outside frequencies allocated to radio astronomy, stray broadcasts will saturate our detectors, swamping the sensitive electronics.

The growth of wireless technology has introduced crowding through the spectrum. Mobile telephone usage has exploded and every call or communication with a cellular tower requires a clear pattern of frequencies to distinguish itself. Mobile-phone engineers have developed a suite of techniques to maximize efficient use of allocated bands. Major shifts in the spectrum occur when a block of frequencies is shifted from one use to another. The government will usually auction the right to broadcast at certain frequencies, bringing in hundreds of millions of dollars in the most recent auctions. New wireless technologies are constantly being developed from self-driving

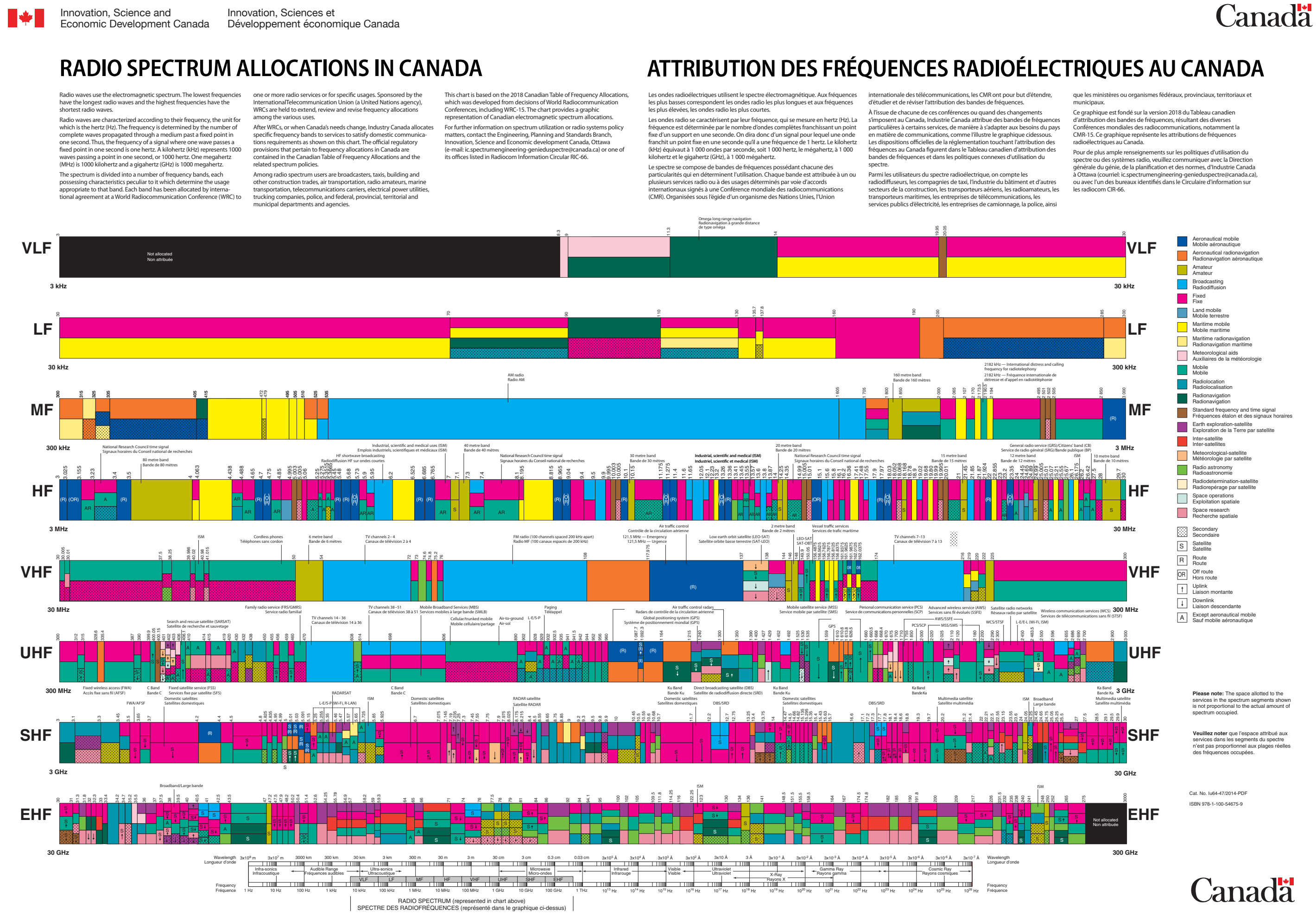

Figure 1 — Section from the Canadian Table of Frequency Allocations over the range from 1000 MHz to 1610 MHz. The frequency allocation is shown across the top of the spectrum and is divided into small frequency bands with major allocations indicated in text. Different colours indicate different allocations and the light green block in the middle of the stack of the 1400 to 1427 MHz band is a radio astronomy allocation to protect the signal from atomic hydrogen, making this one of the most valuable radio astronomy "windows" in the entire spectrum. Note that this reproduction has not been produced in affiliation with, or with the endorsement of the Government of Canada.

cars to 5G wireless and all of these technologies require new spectrum allocations and the answer is usually to go up in frequency, reaching 20,000 or 30,000 MHz (20 to 30 GHz). At these frequencies, there is a wealth of information found in the spectral emission lines of molecules. We suspect that clear signals of biological precursor molecules will be found at these frequencies. There are thousands of spectral lines and it is impossible and inappropriate to try to protect the whole band for radio astronomy.

Fortunately, at high frequencies, radio transmissions are easily blocked by land and we can resort to the age-old trick of optical astronomers: build your observatories far from cities. However, we face a concern about the dark radio sky not yet seen in the optical: satellites and balloons. Space-to-ground transmissions are a key link in our communications network, but these same signals flood our radio telescopes. Project Loon is deploying balloons to provide internet to remote parts of Africa through flying transmitters. However, these transmitters will also be broadcasting at the frequencies observed by the Square Kilometre Array, the next-generation radio telescope that is also being built in Africa. It remains difficult to balance all our needs across the radio spectrum and astronomy is just one tiny domain among those needs. Even so, every time I read about a clever new use of radio waves for some cool new technology, I cannot help but think that the radio sky becomes just a little harder to see.

Explore the Canadian radio frequency allocations here: www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10759.html

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

Skyward

Inner Starlight

By David Levy, Kingston and Montréal Centres

In 1994, *Star Trek: The Next Generation* was one of the most popular shows on television. The episodes were so good that it was easy to tell that the cast was especially enjoying themselves. One of the episodes that year was "The Inner Light." It was a beautiful story in which a strange probe approaches the *Enterprise* and attaches a beam to Captain Picard, who loses consciousness and has a dream in which he is living on a distant planet. He enjoys a full life there, with a wife, two children, and a grandson, and he becomes politically active in his community. He even outlives his wife. One day his daughter asks him to watch a rocket launch. He hesitates, but then his deceased wife and best friend appear. The Captain then exclaims, "It's the probe that was sent for me!"

After enjoying this episode many times, I was reminded of another beautiful story. Written by Nathaniel Hawthorne in 1824, it is called *The Great Stone Face* and concerns a large natural face-like structure hanging near Franconia Notch, across some granite rocks in New Hampshire's White Mountains. The site was magnificent, at least until a few years ago when the face fell down in a big heap. The cliffs are still there, but no more face.

The night sky is much like *Star Trek*, and much like Hawthorne. We look at a group of stars, perhaps a constellation or two, and our brains begin to make connections. On *Star Trek*, we share the idea of travelling through space, even if all we have to warp through space with are our two good eyes and a telescope. Some of us may even remember chapter 12 of Hawthorne's masterpiece, *The Scarlet Letter*, in which the "A" is likened to a meteor crossing the sky at midnight: "…before Mr. Dimmesdale had done speaking, a light gleamed far and wide over all the muffled sky. It was doubtless caused by one of those meteors, which the night-watcher may so often observe burning out to waste, in the vacant regions of the atmosphere. … And there stood the minister, with his hand over his heart; and Hester Prynne, with the embroidered letter glimmering on her bosom; and little Pearl, herself a symbol, and the connecting link between those two."

Was the meteor an interpretation of the scarlet A parading across the sky? The night sky is full of messages, and only some of those messages come from astronomers. The rest come from people like you and me, people who have innocently stood up a looked at the stars, and who have wondered. The rest come

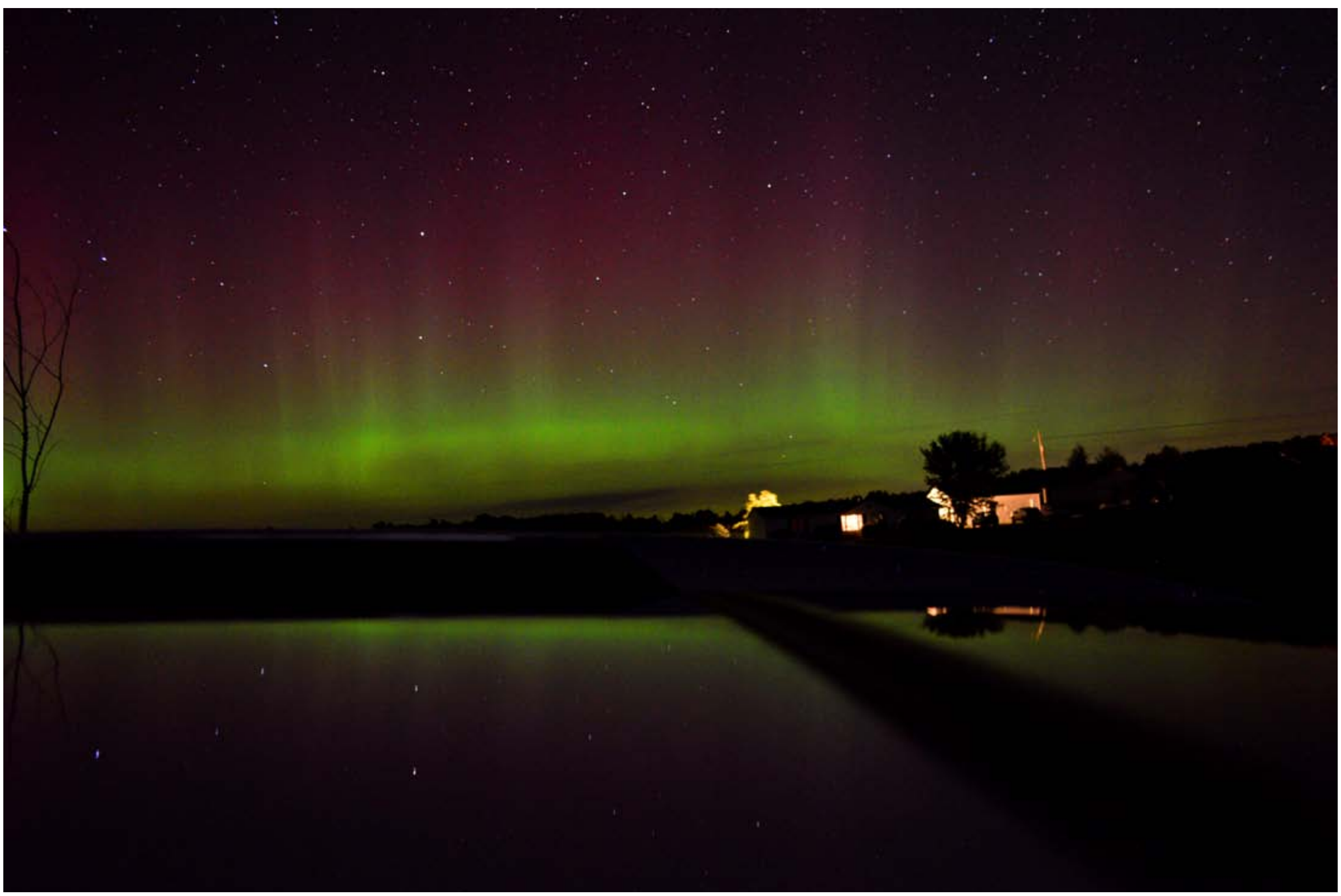

Figure 1 — Aurora Borealis, seen from East Jordan, Michigan. Photograph by David H. Levy on Thursday, 2014 September 18.

Figure 2 — The Caesar comet coin. Thanks to Jeff Struve for his magnificent image of the coin with Caesar's comet engraved upon it.

from Shakespeare, and Tennyson, and perhaps even Nathaniel Hawthorne.

The next time you look at the stars, picture yourself not just watching them but reading them. Learn the stories they tell, as interpreted by your favourite writers, whether they be Shakespeare, Tennyson, Hawthorne, or even you. What sparks your imagination can be something as simple as a story you have heard, seen, read, or even written. Even in our modern age, the message could indeed be written in the stars.

More than 2000 years ago, getting loose change was about as easy as it is today. Hand a shopkeeper a silver dollar in today's world, and you can expect four quarters in change. What isn't the same as today is the design of the coin one might want to get change for. Hand the same shopkeeper a Roman coin from the first century, especially one with a bright comet engraved on its head, and one of two things might happen: either you'd get thrown out of the store, or the shopkeeper would treat you

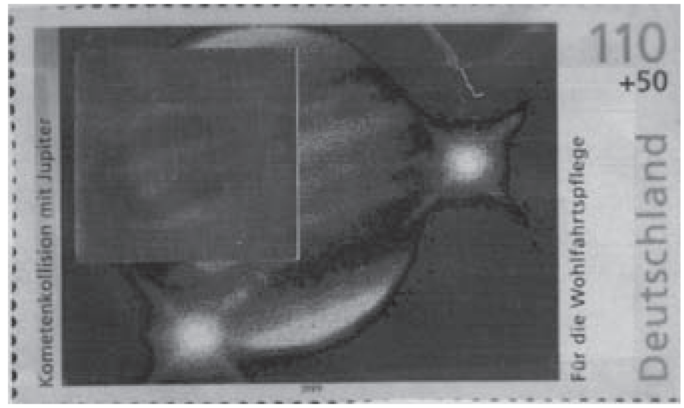

Figure 3 — An image of the Shoemaker-Levy 9 impacts imprinted on a German stamp.

to dinner and then bequeath his children to you. After all, if the shopkeeper had read Shakespeare, he would know that the coin celebrates Julius Caesar's Great Comet, the comet that appeared in the northern sky during the games held shortly after the assassination of Julius Caesar on the Ides of March. In Shakepeare's tragedy *Julius Caesar*, Calpurnia even predicts the murder and the comet:

> *When beggars die, there are no comets seen;*
>
> *The heavens themselves blaze forth the death of princes.*

In Shakespeare's play, Caesar is assassinated on the Ides of March, 44 BCE. The play mentions neither the games nor that they were played in celebration of the new emperor, Augustus Caesar. A bright comet was visible in the northern sky during those games. It was widely interpreted as Julius Caesar's soul on its way to the stars. At the time, comets were omens. Calpurnia was well aware that her husband's death could be preceded or followed by a bright comet. And decades later, Seneca, in his anxiety to avoid execution by the suspicious Emperor Nero, insisted that the bright comet of 61 CE was a favourable omen to Nero. (It didn't work; Nero had Seneca put to death.)

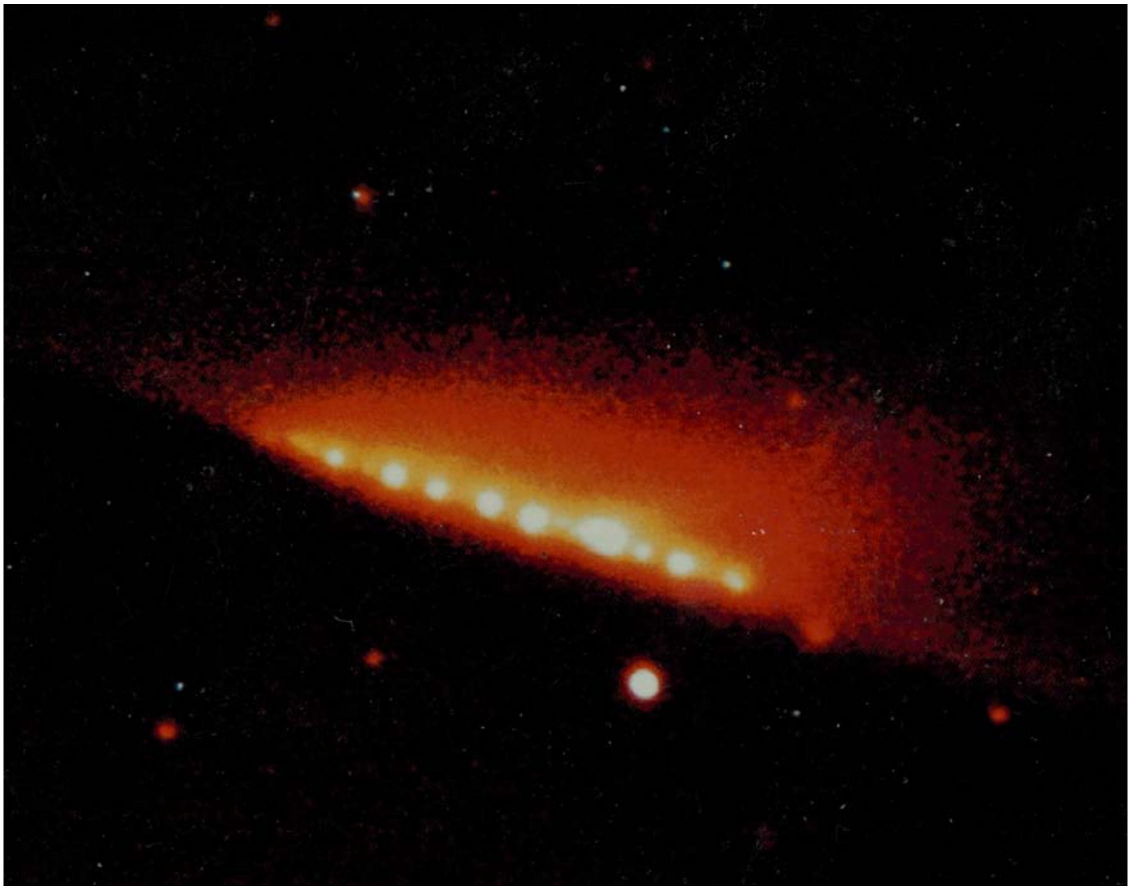

Figure 4 — An early NASA image of Comet Shoemaker-Levy 9.

To engrave a comet on a coin may seem strange, but in fact, most people never get to see a bright comet, an apparition in the night with a head and flowing tail, in their entire lives. I have. My nights under the stars have been brightened by the light of more than two hundred comets. Only a few of these comets were visible without the aid of a telescope, and most were only barely seen as specks of slowly moving haze. But even these were magical.

Comets have appeared in literature all over the world, in almost all languages, because writers since time began have seen comets and have become fascinated by them. Writers like Geoffrey Chaucer, like Alfred, Lord Tennyson, like James Joyce, and like me. I caught the comet bug when I was twelve years old. Our teacher in the sixth grade, Mr. Powter, wanted us to give speeches. The topic I chose was comets. I was interested in their appearances in the sky, their appearances in history, in art, and in literature. What I knew nothing about was their role in the origin of life on Earth. I was far too young to consider the possibility that when comets collided with the Earth, their debris included the CHON particles—Carbon, Hydrogen, Oxygen, and Nitrogen—the alphabet of life. Thirty-four years later, one of the comets I helped discover taught me that lesson as it careened into Jupiter in one of the biggest events in the history of science. This comet didn't get onto a Roman coin, or even a modern one, but it did find its way onto a German stamp. Not too bad for a tiny comet that wandered through the Solar System for eons, gradually got attracted into an orbit about Jupiter, and then, in a series of explosions, reconstructed our understanding of how life could begin on a world. ✶

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

Observing Tips

The Amateur Astronomer (oral presentation, 1966 January 26)

by Michael Burke-Gaffney (1986–1979)

Figure 1 — The Reverend Michael Walter Burke-Gaffney (1970, SMU Archives).

[Note from Dave Chapman, RASC Observing Committee Chair: We take a slight detour for this issue, by sharing the script of a talk by the Reverend Burke-Gaffney of Saint Mary's University presented to the original RASC Halifax Centre in 1966, on the virtues of being an amateur astronomer. That Centre eventually folded and was resurrected in 1970 by Roy Bishop and others. I found the script online at the Nova Scotia Public Archives. The speaker's intent was to highlight the contribution to astronomy made by amateurs, and he started off by telling the story of Charles Messier. This is an oft-told story, but I liked the spin that Father Burke Gaffney put on it.]

Before speaking of the amateur astronomer of today, I would like to remind you of an amateur astronomer of the 18th century.

Charles Messier was an amateur all his life. He observed what he liked, when he liked to, and because he liked to. He was attracted to comets by the return of Halley's Comet. On Christmas Day, 1758, Halley's Comet was sighted on its first predicted return. There was great excitement. Edmond Halley was vindicated. Comets were not messengers from heaven, they were members of the Solar System following the laws of gravitation.

The return of his comet was observed, as I have said, in December 1758. But, on that return, it passed perihelion in March 1759, so that return is listed in catalogues of comets as Comet 1759 I.

Among the many intrigued by the return of Halley's Comet was Charles Messier. He acquired a telescope to see if he could pick up any of the other comets that Halley said were floating around. Messier discovered Comet 1759 II. This was something of beginner's luck, for he did not discover another for four years. But he stuck with it. During forty-three years (1759–1801) all he did, in the way of astronomy, was look for comets. In order to illustrate a point, I would like to divide this period into two periods.

In the first twenty-two years (1759-90), of 17 comets discovered, 9 were definitely first found by Messier, and were called after him. In the next twenty-one years, of 26 comets discovered, only 4 were attributed to Messier. Meanwhile, two changes had taken place: first, there were more comet-hunters; and second, the others had larger telescopes. Messier had a telescope of about 60 mm diameter (or about 2.4 inches). In his last 22 years of observing, he was competing with such professionals as Olbers, Encke, Tuttle, and Pons, to say nothing of Caroline Herschel, who discovered her first comet in 1786 with her brother's 300 mm telescope.

Going back to 1759, before Messier started looking for comets, he had read something about them. He learned that a comet did not develop a tail until it was close to the Sun; that if discovered early in its journey towards the Sun, it looked like a fuzzy star; or if picked up very early, like the glimmer of a tiny bit of nebula.

Therefore, when Messier started comet-hunting first, if he saw a nebulous object, he realized that it might be a comet or, on the other hand, it might not be a comet. At first, he would just make a mental note of where he saw it, and then look the following night to see if it was still there. If it was in the same place, he wrote it off as a nebula. If it had moved, he judged that it was a comet. But as years went by, he found himself picking up a nebula, thinking it was a comet, only to realize afterwards that it was a nebula that he had mistaken for a comet one or two years before. So he decided in the future to measure the position of any nebulous object, and keep a list of nebula to which he could refer, and so perhaps to be able the same night to recognize an object as a nebula, instead of waiting until the following night.

In 1780, after he had discovered what was to be the ninth comet called after him, he went to the observatory. The director asked to see him. He wanted to congratulate Messier. He said that at the observatory not a few people came claiming to have discovered comets, and more often than not they had seen a nebula. "But," said the Director, "you never make a mistake. We marvel." "There's nothing to it," says Messier. "I have made a list of nebulae, with their positions." "You have?!" said the Director. "I'd like to see it." So Messier brought over his list, and it was published, with his permission in the *Connaissance des Temps* (the equivalent of our *Observer's Handbook*): "Catalogue des Nébuleuses et des Amas d'Etoile Observées à Paris" (*C. de Temps*, Paris, 1781).

The list was published as an aid to comet-hunters. It turned out to be of much more value. In December of the year in which it was published, it was put into the hands of William Herschel, by one Watson of the Royal Society, who considered it significant. Herschel observed all the Messier objects and resolved about half of them into stars. Failing to resolve some of them, he became a nebula hunter, and birth was given to the theory of external galaxies.

Now let us turn to the *Observer's Handbook* 1966. On page 90, we have a list of Star Clusters [pages 310–313 in OH2019]. This is a list of the more conspicuous star clusters. There are 25 clusters in the list. Of these, 21 are from Messier's catalogue.

The clusters not in Messier's list include the two clusters in Perseus. These were obviously clusters, and Messier never mistook them for comets. Then there is the Hyades, which again, could not be mistaken. It may be a bit of a surprise to find the Pleiades. This suggests to me that Messier did, now and again, see a glimmer of nebulosity in the Pleiades. We have in Messier's list M13 and M22, which are both faintly visible to the naked eye, on a good night. Messier's telescope should have resolved, at least some of M13 into stars. We believe it did, but he put it on his list, because on a bad night, it might not be resolved, and might be mistaken for a comet. I may mention here that although Messier's Catalogue is most frequently spoken of as a Catalogue of Nebulae, it appeared in print with the title "Catalogue of Nebulae and Star Clusters."

The fourth object in our list and not in Messier's is Omega Centauri. It is so far south, that Messier never saw it. Neither can we see it from Canada. One might argue that it should not be included in this Canadian Observer's list. On page 91, we have a list of 25 Galactic Nebulae [now A Deep-Sky Selection—From Near To Far, page 309 in OH2019]. Nine of these are from Messier's catalogue. One of those which is not is the Coalsack Nebula, in the constellation of Crux (the Southern Cross), 63° south of the Equator. The Coalsack nebula is the earliest known of the dark nebulae. It is often mentioned in astronomical literature. It is probably included here to satisfy the curiosity of amateurs who might be surprised not to find it in a list of galactic nebulae. This suggests that the inclusion of Omega Centauri in the list of clusters could be for the same reason.

Figure 2 — Father Burke-Gaffney observing the Sun on the roof of the McNally Building (1957, SMU Archives).

Some of the galactic nebulae not in Messier's list are so large that they could not be mistaken for comets. Others may not have been reached by his telescope.

On page 92 of the *Observer's Handbook*, we have a list of 25 External Galaxies [page 333 in OH2019]. 17 of these are from Messier's Catalogue. These 17 can be all picked up on a clear night, as a little wisp, much as Messier was then, with the aid of 7 x 50 binoculars. If instead of using binoculars, 150 mm telescope is used, not much difference is made, except in size.

To establish the fact that these are galaxies of stars, it took photographs by the 100-inch telescope at Mount Wilson. (E.Hubble, "The Spiral Nebula as a Stellar System—M33" *ApJ 63*, 19 (1926))

Nobody has ever seen the Andromeda Nebula as it appears on photographs from Mount Palomar. Our eye sees only an instantaneous picture. Photographic film keeps registering as long as it is exposed. A time-exposure photograph with a telescope registers details not seen by the instantaneous shot of the eye. In a sense, telescopic pictures of galaxies are photos of the invisible.

Two years ago in Ottawa, I met an amateur astronomer who had set himself the project of photographing every object listed in Messier's Catalogue. This, it seems to me, would be a nice souvenir, for the man to have for himself. I do not see that it would be any contribution to astronomy. He had a 300 mm telescope. He could purchase better pictures made with larger telescopes.

What I do think might be a contribution would be an attempt to take picture illustrating the objects seen by Messier as seen by Messier. This would be difficult. If I were to attempt it, I would start with the spiral nebulae, or external galaxies, and I think that I would use a 50 mm telescope. With the minimum of exposure, one might get close to what Messier saw. A little over exposure would not make significant difference in these faint and nebulous objects.

When it come to the galactic nebulae, some experimenting would need to be done. Some of them, notably the Orion Nebula, then looked at through a good-sized telescope, show colour. Even though the colour may not be seen with a 50 mm telescope, the sensitive film might well record a picture different from what the eye sees.

In taking photographs of the Star Clusters one would have to be very careful not to overexpose, or one would definitely pick up detail not seen with the naked eye.

Here I may say if any of you would wish to experiment on the effect of exposure, a good object would be M13, the Globular Cluster in Hercules. A ten-minute exposure will photograph more stars in the cluster than you see with the eye through the same telescope. Twenty minutes will show more, and half an hour still more. Of course, for photography of stars, or Messier objects, one needs an equatorial mounted telescope and a clock drive.

While on the subject of photography and how it differs from what we see, I think that I should mention the photographs of Comet Ikeya-Seki which appeared in the *Sky & Telescope* for December 1965. On the cover was a beautiful photograph taken with ten seconds exposure. Inside, there were photographs taken with various exposures. One was taken with 18 minutes exposure. What is to be remembered is that none of the photographers saw the comet as it is depicted in these pictures.

[Editor's Note: This is only the first part of the author's presentation. Father Burke-Gaffney carried on to speak of the value of variable-star observing, and he refers to several other articles in the Observer's Handbook that he thought would be of special interest to amateur observers. I encourage you to read his full script (including handwritten corrections) at memoryns.ca/the-amateur-astronomer-a-lecture-by-father-burke-gaffney. One interesting observation he made was that only about 20% of RASC members attended meetings of their Centre, which I reckon is about the same fraction as today. The Nova Scotia Archives holds more than two dozen similar lectures by Father Burke-Gaffney.]

Biography

(Adapted from smu.ca/academics/archives/burke-gaffney.html) Michael Walter Burke-Gaffney was born in Dublin, Ireland in 1986 and died in Halifax, Nova Scotia, Canada in 1979. He initially studied engineering, and subsequently studied theology and joined the Jesuits in 1920. After receiving his Doctorate in Astronomy from Georgetown University in Washington, he taught in several Canadian cities (Toronto, Regina, and Winnipeg) before joining the faculty at Saint Mary's University in Halifax. Following a successful research and academic career, he retired to emeritus status in 1965. In 1964, he received the RASC Service Award. The Burke-Gaffney Observatory (smu.ca/academics/departments/astronomy-physics-burke-gaffney-observatory.html) at SMU is named in his honour. ✶

Chris Beckett is a long-time aficionado of binocular and wide-field telescopic observing of the deep sky, and author of WIDE-FIELD WONDERS in the RASC Observer's Handbook*—that list would make a great observing project for those looking for a new challenge. He enjoys observing under the dark skies of Grasslands National Park, which, with his help, became an RASC Dark-Sky Preserve in 2009. Chris will take over editing this column in the April issue.*

Binary Universe

Explore the Exoplanets

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

Exoplanet research absolutely fascinates me, on many levels, and I have been following the discoveries since the mid-90s. There are a couple of websites, such as NASA's https://exoplanets.nasa.gov/, that I visit periodically. You may recall me mentioning JPL's *Eyes on Exoplanets* back in February 2017. I've little need for Apple and their products today but I wish in this case I had a new iPad. There's an amazing app for exoplanets and exosolar systems on the iOS platform and it stands heads and shoulders above the crowd. Sadly, I have not found a good facsimile for Android users.

I believe the gold standard for exosolar system planet information for mobile devices is *Exoplanet* from the Apple App Store by Hanno Rein. The version shown in this article is 17.1.0. Years ago, I used an earlier incarnation of the tool on my iPod Touch. I thought it impressive then and I really enjoyed the push notifications. Today it looks even better. This app lets you learn about exoplanets in general, find them, study their properties, remain current, and simulate flying through the galaxy so to visit and explore them.

On launching *Exoplanet*, you will likely see database updates are processed. Then you will be presented with the main screen, which shows the different available modes (see Figure 1). I am going to discuss these in an order a bit different than shown.

For absolute beginners, you should head to the Background Information screen (Figure 2). Here you can learn about this relatively new branch of astronomy, what exoplanets are, how we currently detect them, and how we might consider candidates to be habitable. While extensive, the information is presented in a clear way. That said, I have not been able to find an index or legend of the planet symbols. I have figured out some by inference—for example, the stripy red one is for Hot Jupiters.

When I viewed the News section, I thought I'd see late-breaking reports from NASA and information on the TESS mission and perhaps a swan song for the *Kepler Mission*. Alas, I found notes about software updates.

When you tap the Database button from the main screen, you are shown a list of exoplanets (Figure 3), with the most recently updated entries at the top. Initially, every system will appear. With over 7600 entries in the database, that makes for a lot of scrolling! In theory, it will only continue to grow with TESS coming online now and when NASA's *James Webb Space Telescope* and ESA's *Plato* instruments are launched.

List entries are shown with a couple of technical details like the mass and orbital period. The rendered planet image to the left gives a sense of the type of exoplanet. Again, you'll need to figure out what the symbols means. They refer to Jupiter, Neptune, and Earth-sized planets.

At first, I did not think it possible to search for a specific system from the database listing. You can. After swiping down from the top of the list, a small search box appears.

Happily, the list of all database entries can be reduced and sorted to suit your preferences. Tapping the Options button shows an extensive list of parameters.

Figure 1 — The main screen of Exoplanet with mode buttons.

Figure 2 — The Background Information screen explaining exoplanets and discovery methods.

At the top of the options are the Available Lists where you can indicate what you want the app to draw data from. Do you want to see the Confirmed exoplanets only? Do you want a short list with only the *Kepler* objects of interest? Perhaps you want to view only binary systems. Even Retracted candidates can be listed.

After indicating what to include, you may sort the list using the wide variety of choices including name, orbital period, mass, size, temperature, density, discovery year, distance from us, or when the database entry was updated. Then you can indicate whether to sort in ascending or descending order.

Finally, more filters can be applied. For example, you can restrict the list to only show planets in the habitable zone, those that were detected by direct imaging, or that are orbiting a specific class of star (say G, like our Sun).

Having set the source, sorting, and filtering criteria, when you return to the Database list screen you will see a customized list (presumably shorter) in the order you want. Similarly, the Milky Way display will show exosolar systems based on your criteria.

Speaking of which—and this is perhaps my favourite part of the app—when you select the Milky Way mode in *Exoplanet*, you will see an immersive three-dimensional presentation of exosolar systems in our galaxy (Figure 4). Your first impressi on may be that there's been a massive explosion but what you're seeing is a graphical display of all the selected system as denoted by red dots (Earth-size planets) and green dots (gas giants) with red lines drawn to each candidate from our home system.

orbital movement or suppress all the *Hipparchos* stars so to concentrate on exo systems.

Use the search button (magnifying glass) in the 3-D Milky Way screen to find a particular system.

Another feature available in the Milky Way screen is virtual reality (VR) mode. This moves you to the Earth and simulates the overhead sky. You should see recognizable constellations and the sky peppered with coloured dots.

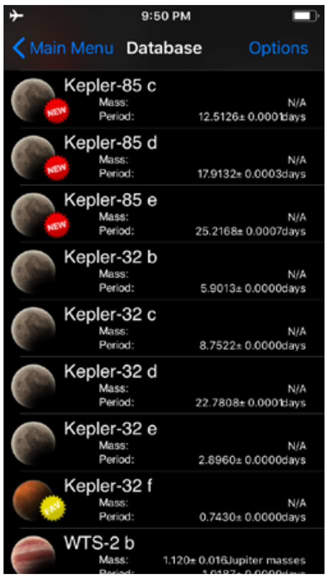

Figure 3 — The Database list screen can be filtered, sorted, and searched.

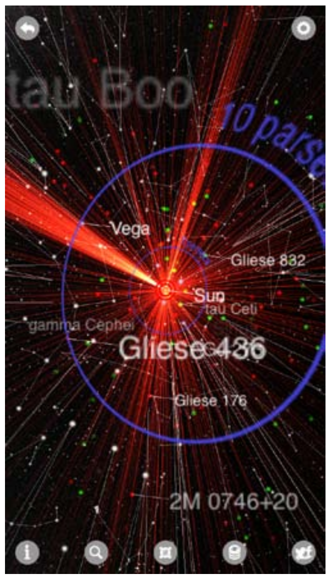

Figure 4 — The three-dimensional Milky Way screen showing exosolar systems surrounding us.

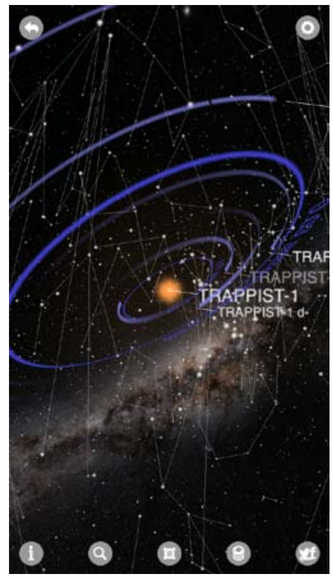

Figure 5 — Centred on a M-class star with multiple orbiting exoplanets.

Figure 6 — The information screen for an exoplanet with name, type, and description.

Strong concentrations of red lines indicate where some missions like *Kepler* and K2 focused.

Not surprisingly, you can pinch the display to zoom in and out and pan any which way by swiping. Tapping a coloured point selects and centres on the specific exosolar system.

The blue rings show milestones in terms of distance using parsecs. You may switch to light-years if you prefer. When much closer to a system, the measure automatically changes to astronomical units.

When you draw near to a particular star system, the star in the centre is rendered in the colour for its spectral class and you should see the known exoplanets whirling around the host (Figure 5). Sometimes you will see yellow arcs drawn when in a binary or multi-star system.

The settings for this 3-D screen are accessible via the gear button. This allows the user to toggle on and off various options. For example, you may want to disable the constellation lines when far from Earth as the stick figures will become increasingly distorted. Then again, maybe you want to leave them on to see just how different the constellations will look from the alien world. You can speed or slow the exoplanet

VR mode also becomes sensitive to the Apple mobile phone's meters, the compass and accelerometers, so that when you face a different direction or change the angle of the phone the sky shifts on the display. Like many planetarium or augmented-reality apps, this lets you aim your phone to an area of interest.

When you have selected a specific exoplanet or accessed the VR mode from the exoplanet information screen, an arrow shows on the display telling you where to aim you phone. When you zoom in sufficiently, you should see a Telrad cross-hair pattern—handy when you want to aim your telescope at one of these most interesting stars.

Ideally you want an active Wi-Fi or data connection when using VR mode so that it can detect and use your current location.

Tapping on an entry in the database table or the "disc" button in the Milky Way view pulls up an information screen for the particular exoplanet (Figure 6). Here you will find a wealth of information on the exoplanet and system including a description and perhaps an artist's rendering. You will note the simulated star colour. The orbital path as well as the observed wave form for redshift oscillation or light curve from a transit

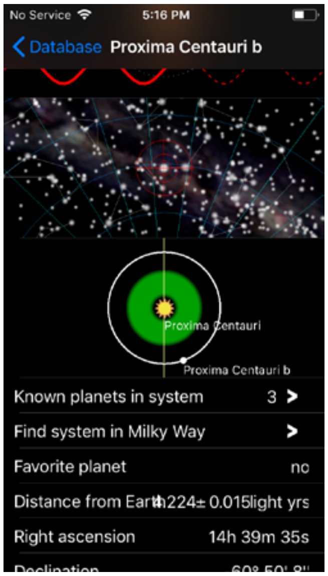

Figure 7 — Further down the exoplanet information screen showing star chart and other details.

is plotted and animated. For some exoplanet entries in the app, the exoplanet itself is shown as a sphere beside other planets. This comparison panel helps you gauge the size of the distant world against our planets.

Further down the page, a star chart is shown to indicate the location of the system, if you're looking for it in binoculars or a telescope (Figure 7). If you tap on this panel, you are switched to "VR" mode.

The habitable or "Goldilocks" zone will be shown, if applicable, along with various parameters of the star system.

It is quite impressive all the data gathered here, including up-to-date information on the physical properties of exoplanets and the host stars. And if you are hungry for more, the page also offers website links.

In this long information panel, you can mark your favourite exoplanets. Later this setting can be used in a filter back in the Database list screen. Tagged entries are denoted with a gold seal.

For those curious about the characteristics of all the discovered exoplanet systems, you can mine the data and graph the parameters. The app offers the Correlation diagram, which lets you pick data for the x- and y-axis values (Figure 8). That alone, you could tinker with for a while.

When you head back home and zoom into plethora of planets around Sol, you'll notice some purple paths tracing out from our Solar System. Our humble slowly departing little space probes, the *Voyagers* and the *Pioneers*, are plotted. Viewing this in 3-D is quite fun.

Exoplanet on your iPhone or Apple tablet supports push notifications, sounds, and badges. You might be interested in the notification banners if you want to be immediately informed of new discoveries.

All this is free. The iOS *Exoplanet* app is very impressive.

That said, I do wish this app had another comparator display showing the exoplanet system beside our Solar System at the same scale so to emphasise the orbital differences. I have seen it done elsewhere.

Another little nit is that the app tosses your database list settings if you restart your device. Too bad the configuration of your filter and sort settings couldn't be saved.

If you wanted to extend the capabilities of *Exoplanet*, additional data can be loaded into the tool via in-app

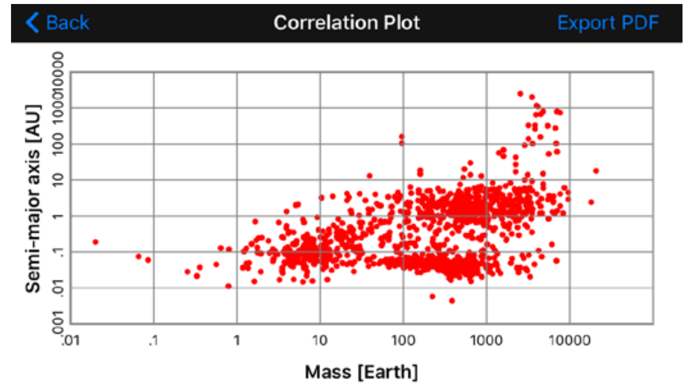

Figure 8 — A user-generated scatter plot for mass versus orbital parameter.

purchases. For example, you can incorporate information from the first data release (DR1) produced by the European Space Agency's *Gaia* probe. You can also add asteroids and moons for our Solar System.

A fascinating capability I could not try is to use the app to change the colour of a Wi-Fi Philips *hue* LED lamp. This fun feature would let you mimic the colour of an exosolar system star!

I have looked many times for similar apps in the Android camp but not found anything nearly as thorough or feature-rich at no cost. Perhaps the best is *Exoplanet Explorer* by Burlock, but I haven't looked at the app lately and the free version no longer appears in the Google Play store.

Unfortunately, while apps abound, exoplanet software is only as good as the data. Many of the tools that I tested did not include recent discoveries like TRAPPIST-1, Proxima Centauri b, or the tau Ceti planets. The aforementioned Android product hasn't been updated for over 2 years.

Hanno Rein from the University of Toronto has worked hard on the *Exoplanet* iOS application but I noted the app proper has not been updated since early 2018. He shared with me in July this year that he finds it a "struggle…keeping the database up-to-date." Hopefully he'll keep it going. There are many new worlds yet to be discovered! See his website http://exoplanetapp.com/ for more information.

Bits and Bytes

SkyTools 4 Imaging is out! See https://skyhound.com/ for more information.

Amazing AstroSpheric added ISS flyover icons in the October 2018 update. ✶

Blake's interest in astronomy waxed and waned for a number of years but joining the RASC in 2007 changed all that. He volunteers in education and public outreach, supervises at the Toronto Centre Carr Astronomical Observatory, sits on the David Dunlap Observatory committee, and is a member of the national observing committee. In daylight, Blake works in the IT industry.

CFHT Chronicles

2019: 40 Years at the Top of the World

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

At 2 a.m. on 1979 August 7, the Canada-France-Hawaii Telescope saw its first light. A few days later on August 11, the first image was taken and then debuted at the IAU general assembly in Montreal. The official inauguration of the CFHT was held on September 28. As we enter 2019, CFHT's 40th year of world-class observations, let us take a look back on our early years.

Figure 1 — The dedication of CFHT on 1979 September 28.

As a note, I have heavily borrowed from the CFHT annual reports for this article and the University of Hawaii Institute for Astronomy's website on the origins of astronomy in Hawaii (www.ifa.hawaii.edu/users/steiger/epilog.htm). Reports from 2004 to current are available on our website, but 1974–2003 are in our archives. By no means is this article a complete history of CFHT or even a complete history of the early years, I have 2000 words give or take. For those deeply interested in the early years of CFHT, I recommend the CFHT Oral History, *Gathering the Forgotten Voices,* created by our retired librarian Liz Bryson.

When talking about the story of CFHT, we do not start in 1979, but rather a decade earlier. Both Canada and France decided to undertake parallel projects for 4-metre telescopes: the Queen Elizabeth II telescope and the telescope project of the 5th and 6th Government Plans. I will leave it up to the reader to figure out which was the Canadian project. Neither project advanced past the technical studies and the purchase of primary mirror blanks.

According to the 1974 CFHT annual report, economic difficulties of the late 1960s caused the agencies responsible for the two telescope projects to consider joining forces in a telescope venture constructing a single large telescope in a first-rate site. The two countries, with the provision that new partners would be entertained if the selected site was outside Canada or France, would share the "new" telescope.

Meanwhile in Hawaii…

In the early 1960s, Gerard Kuiper was on the hunt for a site for a new telescope for the Lunar and Planetary Laboratory in Tucson. He and master optician Alika Herring conducted site surveys on Haleakala, the highest peak on Maui. The seeing on Haleakala is extraordinary, but the mountain is only 10,000 feet (3048 m) in elevation, slightly above the inversion layer at 8,000 feet (2400 m). The close proximity to the top of the inversion layer leads to Haleakala being susceptible to fog. As the story goes, Kuiper and Herring could see the peak of Maunakea rising above the clouds from across the channel separating Maui and Hawaii Island even when the fog was rolling in on Haleakala. They wondered if Maunakea was the site they were looking for.

The Hawaii Chamber of Commerce invited Kuiper to consider Maunakea as the site for his observatory. Kuiper brought Herring with him to survey the site after the governor of Hawaii, John A. Burns, released funds to create the Maunakea Access Road. Today, the summit access road is named after Gov. Burns. Herring set up his telescope and a small dome on Pu'u Poliahu and began his survey. Herring described the seeing on Maunakea as perfect at times.

(The story of Alika Herring and his mirror-making ablitities is incredible. I highly encourage interested readers to read up on his work.)

According to the IfA page on the subject, Kuiper submitted a proposal to NASA to build a telescope on the mountain. NASA opened the the door to other proposals, explicitly inviting Harvard and the University of Hawaii to submit their own proposals. An upstart UH received the funding for the 88″ (2.23 metres) telescope and the rest is history…

In 1973, UH began preliminary discussions with Canada and France to join their 4-metre telescope project, which now would be located on the summit of Maunakea at 4200 metres. In May 1973, the Canadian government announced their participation in the project. By July of that year, the CFHT project office opened its doors on the grounds of the Meudon Observatory and work continued on the memorandum of understanding, which ultimately morphed into the Triparte Agreement signed on 1974 February 22.

The first CFHT annual report lists the personnel of the corporation and project office as of 1974 December 31. The staff of CFHT was small, 5 staff members and 18 in the project office. The executive director and associate executive directors of CFHT in 1974, Roger Cayrel and Graham Odgers, remained with the project and wrote the 1979 annual report as director and associate director.

1.5. LIST OF PERSONNEL OF THE CORPORATION 31 DECEMBER 1974

Executive Director	: R. CAYREL(*)
Associate Executive Director	: G. ODGERS(*)
Administrative Manager	: C. BERTHOUD (hired on 1 July 1974)
Accountant	: M. DOLE (hired on 1 November 1974)
Secretary	: R. DUFAUX (hired on 12 November 1974)

(*) Not remunerated by the Corporation

1.6. LIST OF PERSONNEL OF THE PROJECT OFFICE 31 DECEMBER 1974

Project Officer	: R. CAYREL (CNRS)
Associate Project Officer	: G. ODGERS (NRC)
Chief Engineer France	: P. BELLY (CNRS-INAG)
Chief Engineer Canada	: O. FEDOSIEWICH (NRC)
Mechanical Engineer	: B. BERTIN (CNRS-INAG)
Instrumentation Engineer	: P. BOURLON (CNRS)(*)
INAG Engineer on request	: M. BOURDET (Optique), Y. ACKER (thermal) SOLLOGOUB (Structure)
Draughtsman	: R. BIRAUD (CNRS-INAG)
Civil Engineer	: K. SIDDIQI (NRC)
Software Engineer	: J. WOLFE (NRC)
Hardware Engineer	: G. BEAUMONT (NRC)(*)
Electrical Engineer	: D. OVERHILL (NRC half-time)
Planning Engineer	: M. MacFARLANE(*)
Administrator (Canadian contracts)	: J. BRANDY (NRC)(*)
Secretary P.O. Meudon	: A.M. WALIULLAH(*)
Secretary P.O. Meudon	: J. GUELLEC
Secretary P.O. Ottawa	: M. CEDERBERG
Driver P.O. Meudon	: A. DUTAC

(*) Recruited during the current year

Figure 2 — The listing of the staff and the CFHT project office on 1974 December 31.

Jumping ahead to 1979…

The annual report describes the night of first light and some of the subsequent activities in the weeks following. According to the report:

"The first image was obtained on 7 August at 2am. The seeing, which was rather bad at that time, prevented an assessment of the telescope's optical quality from being made."

"The first photographs were taken without corrector on 11 August, just before the general assembly of the International Astronomical Union in Montreal."

"The following weeks were devoted to the mounting of the ultraviolet corrector and to remedying a problem with the opening of the mirror cover."

"The ultraviolet corrector was in place in September and the first photographs with the correcter were taken at the end of the month, before the dedication of the telescope."

The dedication ceremony is similarly described in the annual report. Over 160 people attended, many from Canada, France, and the US mainland. They were driven by 40 four-wheel-drive vehicles and accompanied by a detachment of the Hawaii National Guard to the summit. "The day was warm and sunny with little wind and the large audience experienced very little discomfort, although the ceremonies were kept as brief as possible."

Under an open dome, the event kicked off with the playing of all the anthems, "O Canada," "La Marseillaise," "Hawaii

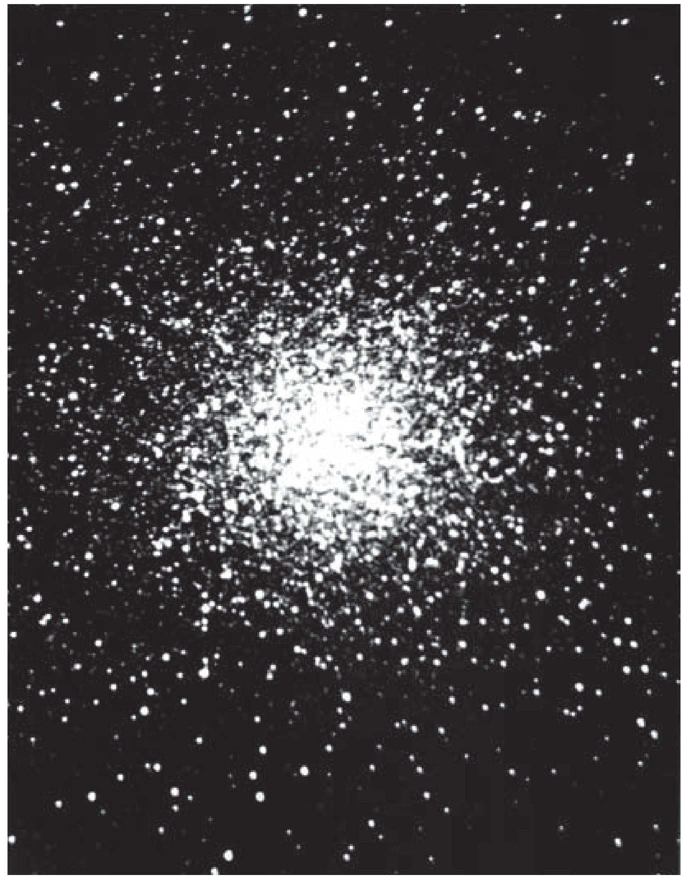

Figure 3 — The first CFHT image taken on 1979 August 11.

Pono'i" (the state song of Hawaii), and the "Star Spangled Banner." Speeches were made by Roch LaSalle, the Minister of Supply and Services of Canada, Pierre Aigrain, Secretary of State for Research of France, and George Ariyoshi, Govenor of Hawaii. As seen in the first photo of this article, the telescope was draped with three maile and orchid leis. At the completion of the speeches, the three dignataries untied the lei. The telescope was then slewed to an almost horizontal position, giving the crowd a view of the primary mirror.

As I read the description of the dedication ceremony, I thought about the people in the audience. I give lots of tours, for high school students, for grad students, to community members, VIPS, the list is endless. If a CFHT staff member runs into a tourist visiting from Canada or France while on their way to the lunch shack at the summit, they often offer to show the person around. (Please do not take this as an invitation to fly to Hawaii and just hang around the dome until someone opens the door.) In every tour I give, people gasp at two points. The first—when the telescope silently begins to move. It is astonishing to see a telescope the size of CFHT move, but not hear any sound. I imagine the people at the dedication ceremony felt that same sense of awe of engineering as our visitors 40 years later. The second gasp is the view from our catwalk, four stories above the ground with the single best view on the mountain.

Figure 4 — The view from the CFHT catwalk.

The dedication ceremony moved to the lower altitude of Waimea where everyone enjoyed “an excellent lunch of the best Hawaiian beef and Bordeaux wine.” Clearly, the CFHT love of a good party was ingrained into our DNA from day one. Nobel Laureate Dr. Gerhard Herzberg delivered an address to the audience before everyone in attendance watched a film chronicling the main phases of CFHT’s construction.

The 1979 annual report contains the full text of Herzberg’s address. He mentions CFHT is the largest telescope at such a high altitude and the first major telescope “built by the collaboration of the old and the new world, that is France on the one hand and Canada and Hawai’i on the other.” Today, multinational collaboration is the norm in astronomy projects. The old and new worlds combine with nations across Asia, Africa, and Oceania to fund projects that are redefining our knowledge of the cosmos.

Herzberg specified two questions in astronomy he foresaw CFHT answering. First, he suggests using the “new and promising” radial-velocity method to detect planets around nearby stars. Herzberg said it’s “a sobering thought to realize that there is as yet no unambiguous proof for the existence of a single planetary system similar to our own.” The unambiguous proof of exoplanets would arrive years later, but as regular readers of our column know, CFHT is embarking on a massive survey to discover and characterize planets around cool, red stars using SPIRou. The astronomers on that project hope to discover an Earth-like planet, the next step in answering the question that lies at the heart of Herzberg’s prediction—are we alone in the Universe?

The second question Herzberg saw CFHT working on is the shape of the Universe. Do we live in an open or closed Universe? As it turns out, data from WMAP, *Planck*, and a number of other ground and balloon-based experiments show that the Universe is flat with a 0.4% margin of error. While open vs. closed vs. flat may be resolved (or as resolved as anything in astronomy ever gets), astronomers are exploring the curvature of space and the global Universe structure.

As we move into our 40th year on Maunakea, astronomers using CFHT are still studying both of Herzberg’s questions, plus probing countless other hypotheses to aid in our understanding of the Universe. Over the course of 2019, we will reflect on the people, instruments, and discoveries of CFHT, but also look forward to the exciting science ahead. I will end this first look back with Herzberg’s final words in dedication speech: “To me, however, the overriding point is the support of intellectual endeavours that try to understand the structure of the Universe and the nature and role of man in it.” ✶

Figure 5 — (l to r) Dr. Cayrel, Dr. Locke, Senator Abercrombie, and Professor Herzberg toast at the post-dedication lunch in Waimea.

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

John Percy's Universe

Introducing AAVSO

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

From June 13-16, 2019, the RASC will hold its annual General Assembly in Toronto, jointly with the spring meeting of the American Association of Variable Star Observers – AAVSO. For those of you who are not familiar with this remarkable organization, here is a brief introduction. See www.aavso.org for much more detail about AAVSO and about variable stars and the value in observing and analyzing them.

AAVSO is a private non-profit research organization, headquartered in Cambridge, Massachusetts, but with members and observers in over a hundred countries around the world. It is led by a Director, who reports to an elected Council of professional and amateur astronomers. The mission of AAVSO is "to enable anyone, anywhere, to participate in scientific discovery through variable star astronomy. We accomplish our mission by … observation and analysis of variable stars, collecting and archiving observations for worldwide access, forging strong collaborations between amateur and professional astronomers, and promoting scientific research, education, and public outreach using variable-star data."

The famous astronomer Friedrich Argelander (1799-1875) pointed out in 1844 that, as far as variable-star astronomy was concerned, "could we be aided in this matter by the cooperation of a goodly number of amateurs, we would perhaps in a few years be able to discover laws in these apparent irregularities (of variable stars) and then in a short time accomplish more than in all 60 years which have passed since their discovery".

His appeal was heeded by the British Astronomical Association which founded its Variable Star Section in 1890, and then by Edward Pickering (1846-1919), who was Director of the Harvard College Observatory. With his support, a small group of amateur variable-star observers led by William T. Olcott (1873-1936) founded the AAVSO in 1911. AAVSO enables amateur astronomers to be "citizen scientists." Its Centennial history (Williams and Saladyga 2011) outlines its illustrious history.

I became aware of AAVSO when I joined the RASC in 1961, partly because its "Variable Star Notes" were published bimonthly in this *Journal.* Helen Sawyer Hogg, my mentor and eventual colleague, had served as AAVSO President from 1939-41. Within a few years, variable stars became my main topic of research but, at the time, I was more concerned with small-amplitude variable stars that were not ones AAVSO observers could normally observe.

In 1974, I met AAVSO Director Janet Mattei at a joint meeting of RASC and AAVSO in Winnipeg (Percy 2005). We were on a city bus as part of a conference tour. She had just become AAVSO Director; I had just become RASC Vice-President. We were two young astronomers with shared interests in variable stars, amateur astronomy, and education. We were colleagues and good friends until her untimely death in 2004. I joined AAVSO in 1977.

One might have thought that the 1970s would be the end of AAVSO. The space age was beginning. Satellites were the new and exciting tool of astronomy. What use were visual observations? Surprisingly, in the first 25 years of the space age, the demand for AAVSO data *increased* by a factor of 25! As satellites monitored variable stars at non-visible wavelengths, there was a need to monitor their visual brightness changes at the same time. Satellite observations of "cataclysmic variables" or CVs—dwarf novae, novae, and supernovae—ushered in a new field of "high-energy astrophysics." But CVs were unpredictable. Amateur astronomers could watch for, report, and study their outbursts. And much more.

Currently, AAVSO collaborates with professional astronomers, using ground-based and satellite telescopes, in many different ways. AAVSO data are used in about 250 professional research papers each year. The AAVSO's on-line, century-long archive of over 37 million quality-controlled variable-star measurements is freely accessible to anyone, for scientific or educational purposes, along with charts and manuals that enable observers around the world to contribute to it. And every measurement in the archive has an observer's name attached to it!

The 1970s were also the dawn of the computer age. AAVSO observations were digitized, and could be displayed and analyzed. Petrusia Kowalsky, Elizabeth Waagen, Janet, and I undertook a massive analysis of 75 years of observations of almost 400 Mira stars, leading us to discover phenomena in these large-amplitude pulsating red giants that we still do not understand (Kowalsky et al. 1986).

By the 1980s, photoelectric photometers could be purchased "off the shelf," and AAVSO joined the photoelectric photometry (PEP) revolution. I assisted Janet in setting up a PEP observing program, which has generated tens of thousands of precise observations. These, as well as visual observations, have provided the raw material for dozens of projects and publications for my undergraduate research students, and even for talented high school students (Percy 2018).

Janet shared my interest in science education, and the belief that variable star observing and analysis could be used to develop and integrate students' math, science, and computing

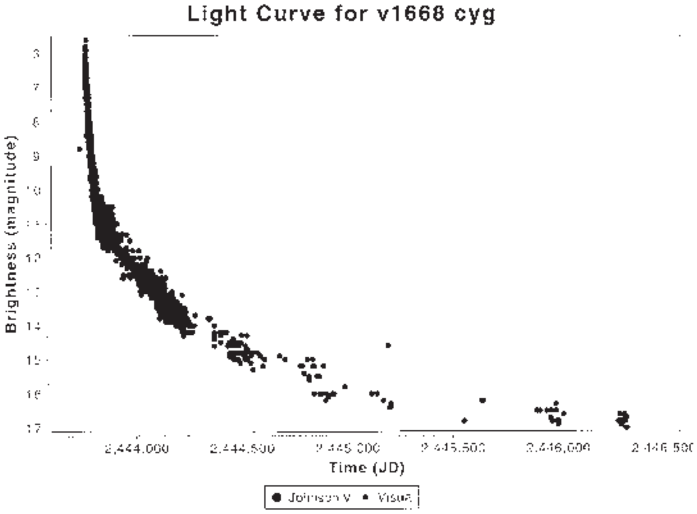

Figure 1 — The AAVSO light curve of Nova Cygni 1978 (V1668 Cyg), discovered visually by Canadian amateur astronomer Warren Morrison.

skills, motivated by doing real science with real data. In 1992, we received a major grant from the US National Science Foundation to develop *Hands-On Astrophysics*, a resource that did just that. HOA has since morphed into *Variable Star Astronomy* (1), an on-line resource is used by many educators, including the US Physics Olympiad program.

After Janet's death, Arne Henden became Director in 2005. He had many years of professional experience in photoelectric and CCD photometry. With AAVSO staff and volunteers, he oversaw a series of groundbreaking AAVSO projects. AAVSOnet (2), begun in 2009, is a network of remote, robotic telescopes, for use by AAVSO members, but also producing data which are publicly available. APASS (3) is a public repository of millions of multicolour CCD measurements of variable stars, based on over 400,000 images. VSX (4) is an online open-access database/catalogue of variable star information, created largely by Christopher Watson, and now including about 500,000 stars.

These projects cost money, but Arne and previous AAVSO Directors have been very successful in obtaining funding from government agencies, foundations, corporations, and individual donors.

A resource which has been extensively used by me and my students is VSTAR (5), a software package to analyze the periodicity and other properties of variable stars – those in the AAVSO on-line database, or in the users' own files. VSTAR was created as part of *Citizen Sky,* the AAVSO's flagship project for International Year of Astronomy 2009. It used the 2009-2011 eclipse of Epsilon Aurigae to attract new (and older) "citizen scientists" to observe and analyze this and other variable stars.

Stella Kafka became Director in 2015, and has brought her own experience and enthusiasm to the position. It is a time of consolidation, and planning and building for the future. She will quickly imprint her "stamp" on the Association, as previous Directors have done.

I served on AAVSO Council from 1982-93, and as President from 1989-91. For the last decade, I have served the AAVSO as Editor of its journal *JAAVSO*, as a frequent contributor to their quarterly *Newsletter*, as an advisor to their Long Period Variable Star section, and as a heavy user of AAVSO data. But I'm winding down these activities. The June 2019 joint meeting will be a wonderful opportunity for me to reflect on and appreciate two organizations—AAVSO and RASC—which have been central to my life as an astronomer for half a century. ✶

Acknowledgement

I thank Michael Saladyga and Elizabeth Waagen, AAVSO, for reading and commenting on a draft of this article.

Notes

1. VSA: www.aavso.org/education/vsa
2. AAVSOnet: www.aavso.org/aavsonet
3. APASS: www.aavso.org/apass
4. VSX: www.aavso.org/vsx/
5. VSTAR: www.aavso.org/vstar

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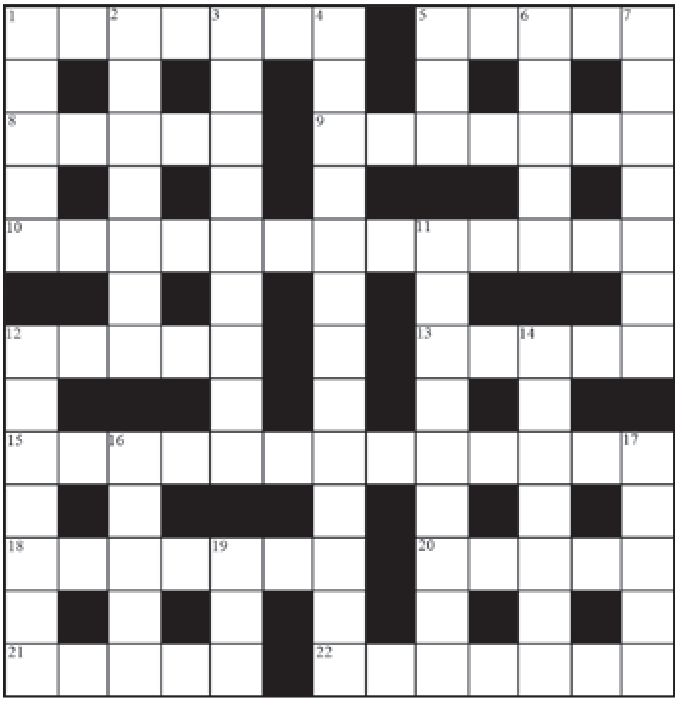
John Percy FRASC is Professor Emeritus, Astronomy & Astrophysics and Science Education, University of Toronto, a former President (1978-80) and Honorary President (2013-8) of the RASC, and a former President of AAVSO (1989-91).

Astrocryptic

by Curt Nason



ACROSS

1. Dig back around a collapsed mine, but you won't find a meteorite from it (7)
5. Significant part of two constellations (5)
8. Times a changing close to Jupiter (5)
9. Space station and a satellite at Uranus (7)
10. Odd hoop wing leads Grus to an endangered bird (7,5)
12. A sea roils around north of Saturn's extensions (5)
13. Casual dance loses a lava lake (5)
15. Room with medicine containers like Antares and Eagle (5,7)
18. Rotating, Quaoar drops round two eyes of a water bearer (7)
20. Indian in south of France heading west (5)
21. Bohr really had his lines crossed (5)
22. Invalidate the hypothesis fully in an unusual way (7)

DOWN

1. Big Banger hit the hay pile after our annual event (5)
2. Remote possibility before summer starts of seeing one in daylight (7)
3. Sensory detector part of an imaging adapter (9)
4. Show rotation of Demon Star on it (13)
5. Mira lost its tail when it came down in 2001 (3)
6. Hinds star of youth outreach (5)
7. Optical tools for some followers of the JRASC (7)
11. Ceres changes right to left and gains a bent tail in our sphere (9)
12. Shania turned 50 in the eagle's head (7)
14. Church boy backs in the father of meteoritics (7)
16. Entertain Urania (5)
17. Haas observed doubles in the Tharsis system of ridges (5)
19. Old eyepiece standard of our overseas forerunner (3)

Answers to December's puzzle

ACROSS

1 SAGITTA (anag); **5** MENSA (anag); 8 NADIR (anag); **9** TUTHILL (tut+hill); **10** URANIUM (2 def); **11** NODES (anag); **13** EIDERS (anag); **15** ICE CAP (IC+rev); **18** KONIG (KO+in(rev)+g); **20** STELLAR (2 def); **22** ANNULAR (an+anag); **23** GREGO (erg(rev)+go); **24** ARIES (a+anag); **25** SPECTRA (an(ec)ag)

DOWN

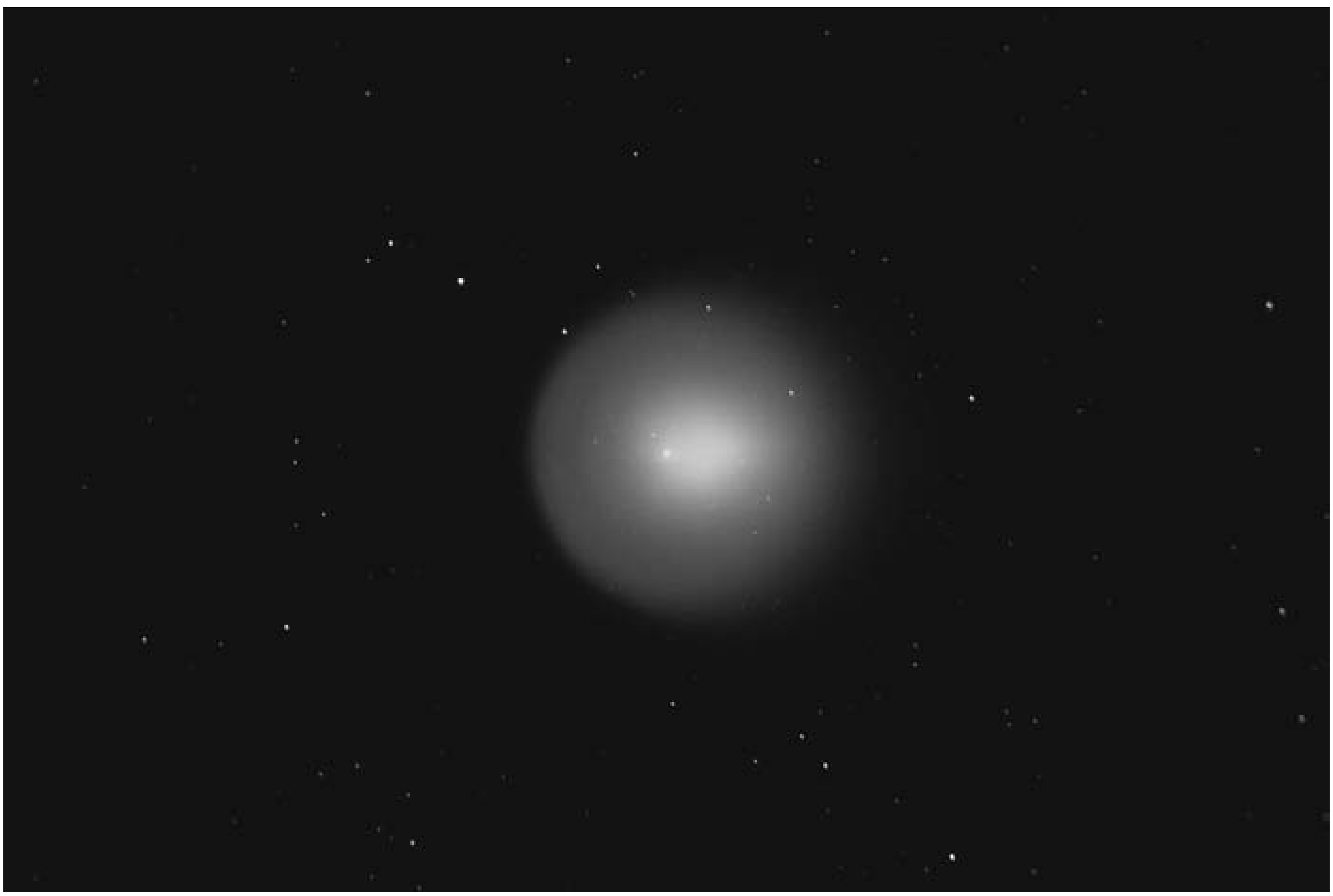
1 SANDULEAK (anag); **2** GODDARD (an(odd)ag); **3** TARSI (anag+i); 4 AUTUMN (an(um)n); **5** METONIC (anag); **6** NAIAD (anag); **7** ALL (2 def); **12** SUPERNOVA (anag); **14** REGULUS (Reg+rev); **16** COLDEST (C+oldest); **17** ASTROS (2 def); **19** NUNKI (nun+KI); **21** EAGLE (Beagle-B); **22** ARA (2 def)

It's Not All Sirius

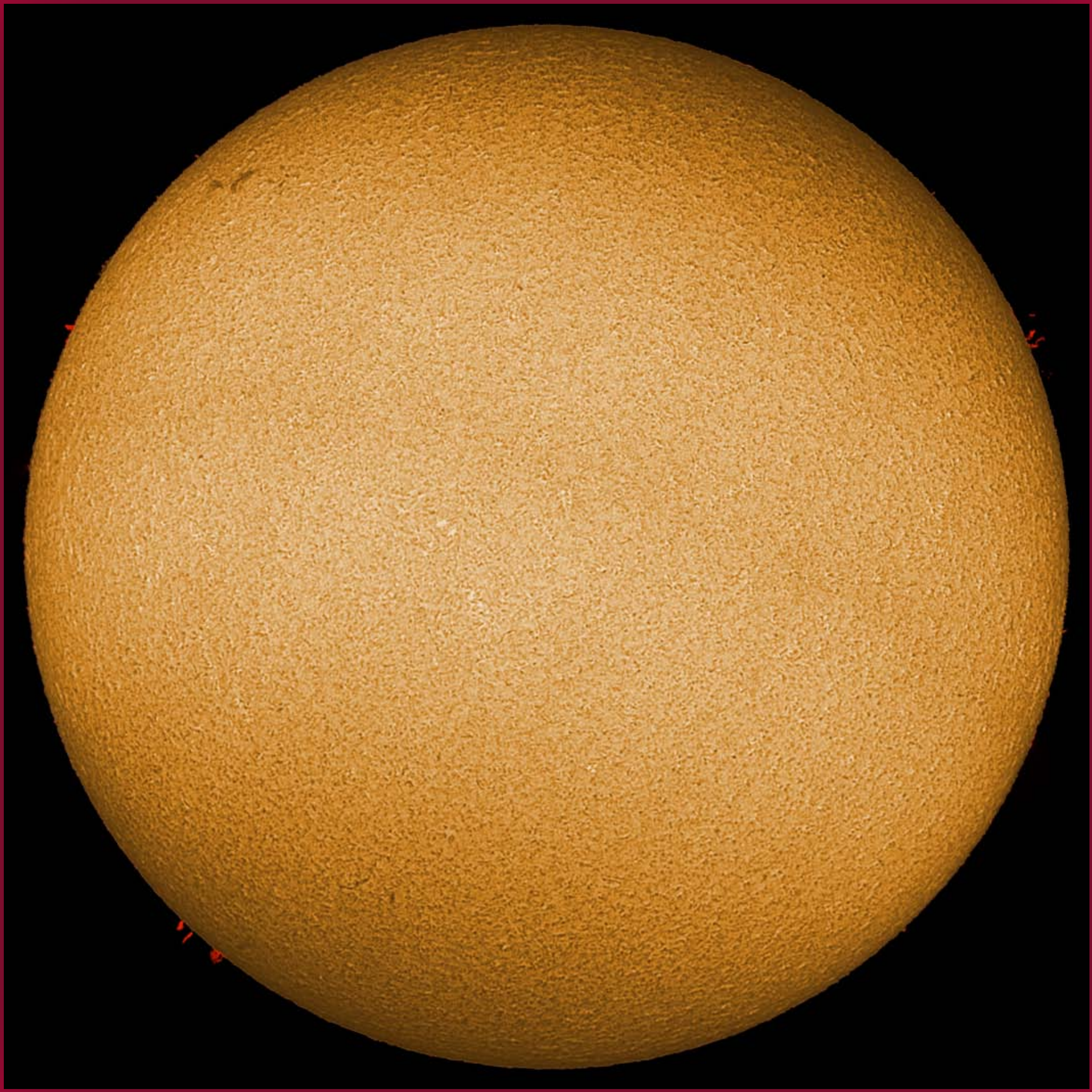
by Ted Dunphy

Great Images

by Tony Schellinck



Comet 17P/Holmes – Tony Schellinck of Halifax Centre writes, "This was a naked eye object after the great expansion though my wife was unimpressed as it did not have a tail." 2007 April 11, Canon XTi, 40 sec, ISO 1600, Port Mouton, Nova Scotia. This was one of Tony's submissions for his Wide Field Astroimaging Certificate.



Journal

Great Images

The Sun may be quiet, but Paul Campbell managed to capture our nearest star using a 60-mm double-stacked Lunt telescope and a DMK video camera. The images were then stacked in AviStack2 and Registax and processed using Photoshop.