The Journal of The Royal Astronomical Society of Canada

Journal

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1997 Meteor Spectrum Revisited

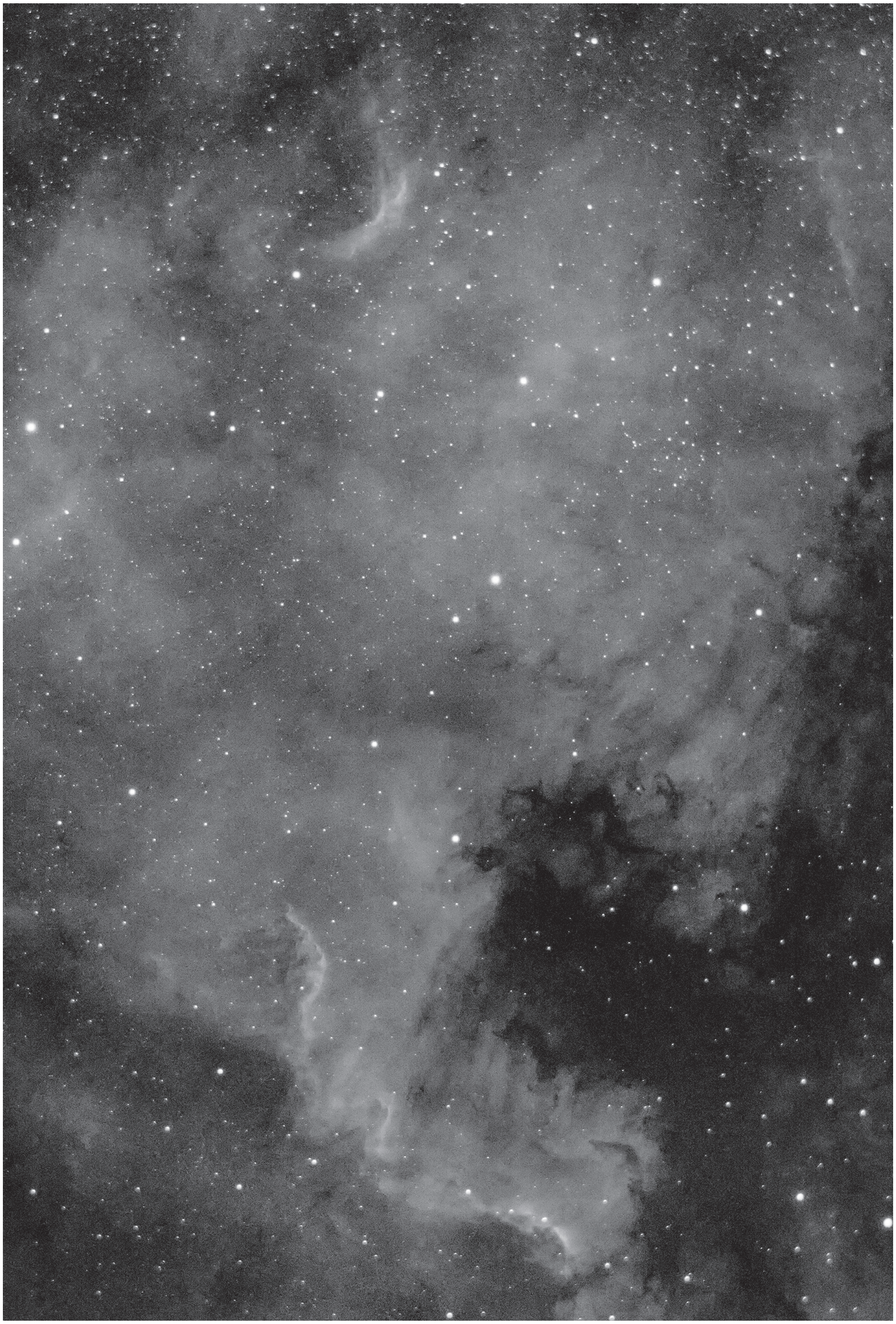
Impact of the Extent of Lighting

Life in the Cosmos Revisited

Vulpecula City

The Best of Monochrome.

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



Accomplished astrophotographer Stacey Downton imaged the North America Nebula from Birmingham, England, with an Altair 72EDF with an Altair hypercam 183M Pro Tec camera on a Sky-Watcher EQ6-R Pro. This is a single 240-second image through a hydrogen-alpha filter.

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Royal Astronomical Society of Canada
Société Royale d'Astronomie du Canada

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This amazing image of NGC 6822 was captured by Dave Dev from his backyard in the light-polluted area of Woodbridge, Ontario, just north of Toronto. Dave took this narrowband image using the SHO pallette with an ASI 1600 mono camera on an Orion 115-mm APO refractor and Astrodon filters mounted on an EQ6 mount. The image, which was roughly 8 hours per filter, was processed in PixInsight.

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

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President's Corner

by Robyn Foret, Calgary
(arforet@shaw.ca)

In the last issue I introduced to readers the structure of the RASC and the roles of our Committees. Here I will focus on our Light-Pollution Abatement Committee.

Whether it be the war on climate change, the arguments around wearing masks versus freedom to choose, or the upcoming predictable outcry against vaccination to suppress COVID-19, science and education play a critical role in influencing what people "think" or "believe" about these issues. A favourite t-shirt of mine says "Science doesn't care what you believe!" However, unfortunately, it takes considerable effort to sway people and common beliefs around over-lighting to enhance security, and the esthetics of urban areas at night are well entrenched.

When it comes to preserving the night sky, explaining to readers of the *Journal* the need to address this issue is essentially preaching to the choir. But there is a greater need to educate those outside of our realm and it's here that the RASC's Light-Pollution Abatement Committee does its work, and it's a cause all of you can help with, too.

Some of the committee's greatest work is in the development and execution of the Dark-Sky Programs and the underlying Canadian Guidelines for Outdoor Lighting (CGOL). CGOL addresses Artificial Light At Night (ALAN), making connections to crime, human activity, human health, environmental health, animal behaviour, shorelines, and cultural impact. You can find the current version of the CGOL, edited by Robert Dick, here: www.rasc.ca/dark-sky-site-guidelines

One thing the CGOL does is introduce us to scotobiology, the study of the biological need for periods of darkness. This is where light-pollution abatement starts to touch the broader population. Robert Dick quotes the Light Research Organization and WebMD where they state that "the proliferation of outdoor lighting has a significant impact on the health and behaviour of humans," and "biological clocks control our sleep patterns, alertness, mood, physical strength, blood pressure, and other aspects of our physiology." In a referenced paper entitled "Lighting for the Human Circadian Clock," it is noted that "similar biological clocks are found in plants and animals wherein darkness plays a similar role."

Here are some facts that you can share.

- A recent study of adolescents by the *Journal of the American Medical Association, Psychiatry*, suggested higher ALAN levels resulted in fewer minutes of sleep and an increase in mood disorders and anxiety disorders, including associations with bipolar disorder and major depressive disorder.

- A study conducted by the *Journal of Sleep Medicine* targeting adults aged 60+ concludes that "Outdoor artificial nighttime light exposure was significantly associated with prescription of hypnotic drugs in older adults. These findings are consistent with the hypothesis that outdoor artificial nighttime light may cause sleep disturbances."
- Studies suggest that exposure to ALAN may disrupt circadian patterns and decrease nocturnal secretion of melatonin, which may disturb estrogen regulation, leading to increased breast cancer risk. A 2017 paper published in *Environmental Health Perspectives* that followed more than 109,000 women over a 22-year period concludes that exposure to ALAN may contribute to breast cancer risk.
- The International Dark-Sky Association and the American Medical Association suggest that disrupting circadian rhythm increases our risk of obesity, diabetes, mood disorders, reproductive problems, and cancers.

Preserving our nocturnal environment isn't just about seeing the night sky, it's also about protecting humankind, so that we're all physically and mentally healthy enough to see and appreciate the night sky. ✶

News Notes / En manchette

Compiled by Jay Anderson

Galaxy clusters: It's in the details

While studying the Coma Galaxy Cluster in 1933, astronomer Fritz Zwicky discovered that the mass of all the stars in the cluster added up to only a few percent of the bulk needed to keep member galaxies from escaping the cluster's gravitational grip. He predicted that a "missing mass"—now known as dark matter—was the glue that was holding the cluster together. Dark matter does not emit, absorb, or reflect light, nor does it interact with any known particles. The presence of these elusive particles is only known through their gravitational pull on visible matter in space.

Astronomers have been chasing this ghostly substance for decades but still don't have many answers. They have devised ingenious methods to infer dark matter's presence by tracing the signs of its gravitational effects. One technique involves measuring how dark matter's gravity in a massive galaxy cluster magnifies and warps light from a distant background galaxy. This phenomenon, called gravitational lensing, causes massive clusters to be typically surrounded by a halo of distorted arcs of distant background galaxies.

Most of the influence of dark matter is associated with the cluster's central regions where most of the missing mass resides. However, an observational study of 11 massive galaxy clusters conducted by the *Hubble Space Telescope* and companion spectroscopic observations by the Very Large Telescope of the European Southern Observatory revealed many smaller embedded gravitational lenses in the cluster core. The researchers believe that the embedded lenses are produced by the gravity of dense concentrations of dark matter associated with individual cluster galaxies. Dark matter's distribution in the inner regions of individual galaxies is known to enhance the cluster's overall lensing effect.

These sub-haloes were more numerous and their lensing was on average ten times stronger than predicted by computer simulations of clusters formed according to existing theories of dark matter. The model simulation used by the study team assumed that dark matter is made up of massive, weakly interacting, collisionless particles, the nature of which is currently unknown. This unexpected discovery of gravitational sub-halos means there is a discrepancy between these observations and theoretical models of how dark matter should be distributed in galaxy clusters.

"Galaxy clusters are ideal laboratories to understand if computer simulations of the Universe reliably reproduce what we can infer about dark matter and its interplay with luminous matter," said Massimo Meneghetti of the INAF (National Institute for Astrophysics) Observatory of Astrophysics and Space Science of Bologna in Italy, the study's lead author.

"We have done a lot of careful testing in comparing the simulations and data in this study, and our finding of the mismatch persists," Meneghetti continued. "One possible origin for this discrepancy is that we may be missing some key physics in the simulations."

Priyamvada Natarajan of Yale University in New Haven, Connecticut, one of the senior theorists on the team, added: "There's a feature of the real Universe that we are simply not capturing in our current theoretical models. This could signal a gap in our current understanding of the nature of dark matter and its properties, as these exquisite data have permitted us to probe the detailed distribution of dark matter on the smallest scales."

Follow-up spectroscopic observations added to the study by measuring the velocity of the stars orbiting inside several of the cluster galaxies. "Based on our spectroscopic study, we were

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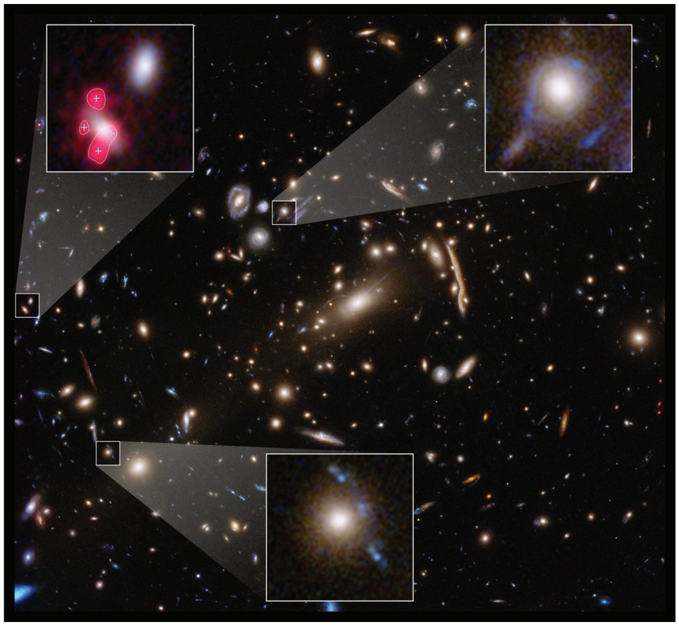

Figure 1 — This Hubble Space Telescope *image shows the massive galaxy cluster MACS J1206. Embedded within the cluster are the gravitationally distorted images of distant background galaxies, seen as arcs and smeared features, caused by the amount of dark matter in the cluster. In addition to the dark matter smoothly distributed within the cluster, astronomers found that an expectedly large amount of it is concentrated in individual cluster galaxies. Image: Hubblesite.*

In the snapshots at upper right and bottom, two distant, blue galaxies are lensed by the foreground redder cluster galaxies, forming rings and multiple images of the remote objects. The red blobs around the galaxy at upper left denote emission from clouds of hydrogen in a single distant source. The source, seen four times because of lensing, may be a faint galaxy. These blobs were detected by the Multi-Unit Spectroscopic Explorer (MUSE) at the European Southern Observatory's Very Large Telescope (VLT) in Chile and do not appear in the Hubble *images. Image: NASA, ESA, M. Postman (STScI), and the CLASH team.*

able to associate the galaxies with each cluster and estimate their distances," said team member Piero Rosati of the University of Ferrara in Italy.

"The stars' speed gave us an estimate of each individual galaxy's mass, including the amount of dark matter," added team member Pietro Bergamini of the INAF-Observatory of Astrophysics and Space Science.

Composed in part with material provided by Hubblesite and Yale University.

Messy divorce creates Type Ib and Ic supernovae

Supernovae are created in the end-of-life explosions of massive stars. Such an explosion may arise from the collapse of the star's core when fusion reactions decline to the point where they can no longer overcome gravitational forces or by the accumulation of material on a white dwarf star from a companion star that suddenly re-ignites.

There are several types of supernovae, mostly based on their spectral composition. Two of these are the types Ib and Ic, which are similar enough that they may be collectively referred to as type Ibc. In this type, the material thrown out by the explosion is deficient in hydrogen and sometimes helium, signalling that the star had lost its outer envelope before erupting. Such stars are known as stripped-envelope supernovae. The lost envelope may have been pushed away by radiation forces during the red-giant phase of the star's evolution or may have been lost to a close companion star.

Searches for close companions near past supernovae are often fruitless. The most prominent example of this is associated with the supernova remnant Cassiopeia A, a type IIb, where deep searches have found no evidence for a former companion. Cas A's light is estimated to have reached Earth about 300 years ago but there are no reliable reports of its visibility, though John Flamsteed, the first Astronomer Royal, may have spotted and catalogued it in August 1680.

In a recently published study led by the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) in Australia, researchers propose a third scenario for creating these lonely stripped-envelope stars. OzGrav researcher and lead author of the study, Dr. Ryosuke Hirai, explained: "In our scenario, the stripped-envelope star used to have a binary companion with a mass very similar to itself. Because the masses are similar, they have very similar lifetimes, meaning that the explosion of the first star will occur when the second star is close to death, too."

In the last million years of their lives, massive stars are known to become red supergiants with unstable and puffed up outer layers. So, if the first supernova of the binary star system hits the puffy red supergiant, it can easily strip off the outer layers, making it a stripped-envelope star. The stars disrupt after the supernova, so the secondary star becomes a lonely stellar widow and will appear to be single by the time it explodes one million years later.

The OzGrav scientists performed hydrodynamical simulations of a supernova colliding with a red supergiant to investigate how much mass can be stripped off through this process. They found that if the two stars are close enough, but not too close, the supernova can strip nearly 90 percent of the envelope off the companion star.

"This is enough for the second supernova of the binary system to become a stripped-envelope supernova, confirming that our proposed scenario is plausible," said Hirai. "Even if it's not sufficiently close, it can still remove a large fraction of the outer layers, which makes the already unstable envelope even more unstable, leading to other interesting phenomena like pulsations or eruptions."

If OzGrav's scenario occurs, the stripped-off envelope should be floating as a one-sided shell at about 30 to 300 light-years away from the second supernova site. Recent observations revealed that there is, indeed, a shell of material located at around 30 to 50 light-years away from Cas A.

Hirai added: "This may be indirect evidence that Cas A was originally created through our scenario, which explains why it does not have a binary companion star. Our simulations prove that our new scenario could be one of the most promising ways to explain the origin of one of the most famous supernova remnants, Cas A."

The OzGrav scientists also predict that this scenario has a much wider range of possible outcomes—for example, it can produce a similar number of partially stripped stars. In the future, it will be interesting to explore what happens to these partially stripped stars and how they could be observed.

How much does the Universe weigh?

A top goal in cosmology is to precisely measure the total amount of matter in the Universe, a daunting exercise for even the most mathematically proficient. A team led by scientists at the University of California, Riverside, has now done just that.

Reporting in the *Astrophysical Journal*, the team determined that matter makes up 31 percent, plus or minus 1.3 percent, of the total amount of matter and energy in the Universe. The remainder is made up of elusive dark energy.

"To put that amount of matter in context, if all the matter in the Universe were spread out evenly across space, it would correspond to an average mass density equal to only about six hydrogen atoms per cubic metre," said first author Mohamed Abdullah, a graduate student in the UCR Department of Physics and Astronomy. "However, since we know 80 percent of matter is actually dark matter, in reality, most of this matter consists not of hydrogen atoms but rather of a type of matter which cosmologists don't yet understand."

Baryonic matter—the stuff we see around us—makes up only six percent of the Universe.

Abdullah explained that one well-proven technique for determining the total amount of matter in the Universe is to compare the observed number and mass of galaxy clusters per unit volume with predictions from numerical simulations. Because present-day galaxy clusters have formed from matter that has collapsed over billions of years under its own gravity, the number of clusters observed at the present time is very sensitive to cosmological conditions and, in particular, the total amount of matter.

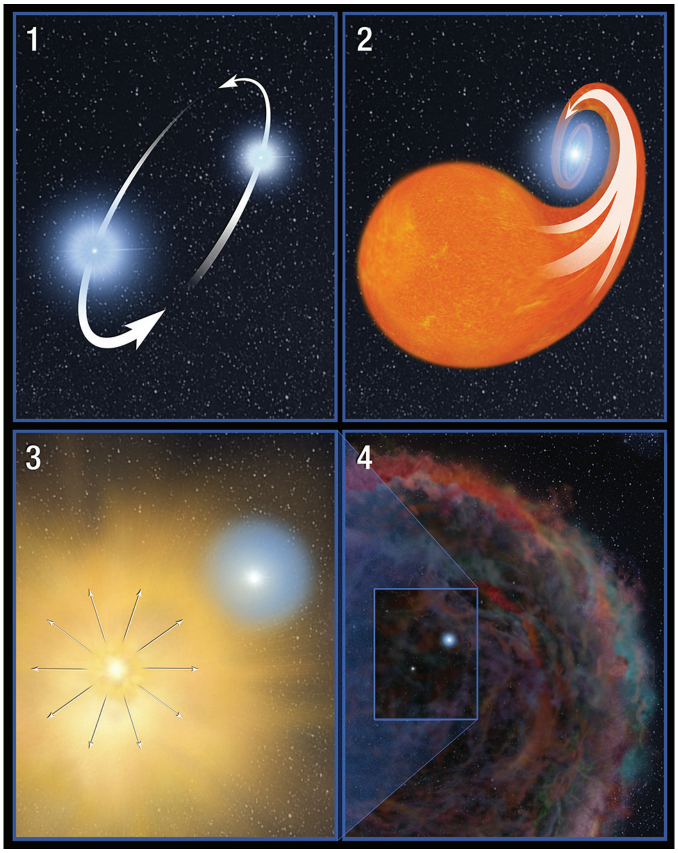

Figure 2 — This graphic illustrates the scenario for the processes that create a Type IIb stripped-envelope supernova, in which most, but not all, of the hydrogen envelope is lost prior to the primary star's explosion. The four panels show the interaction between the SN 2001ig progenitor star, which ultimately exploded, and its surviving companion. 1) Two stars orbit each other and draw closer and closer together. 2) The more-massive star evolves faster, swelling up to become a red giant. In this late phase of life, it spills most of its hydrogen envelope into the gravitational field of its companion. As the companion siphons off almost all of the doomed star's hydrogen, it creates an instability in the primary star. 3) The primary star explodes in a supernova. 4) As the supernova's glow fades, the surviving companion may become visible. Credits NASA, ESA, and A. Feild (STScI).

"A higher percentage of matter would result in more clusters," Abdullah said. "The 'Goldilocks' challenge for our team was to measure the number of clusters and then determine which answer was 'just right.' But it is difficult to measure the mass of any galaxy cluster accurately because most of the matter is dark so we can't see it with telescopes."

The critical part of the task is to determine which galaxies are members of a cluster and which are merely nearby interlopers. Inclusion of non-cluster galaxies in the calculation of overall mass leads to significantly inaccurate estimates.

To overcome this difficulty, the UCR-led team of astronomers first developed a new technique called "GalWeight," a tool to determine which members of a galaxy sample belong to a given cluster. In initial testing, GalWeight was able to correctly place 98 percent of a sample of galaxies.

The researchers then applied the tool to observations from the Sloan Digital Sky Survey (SDSS) to create "GalWCat19," a more accurate catalogue of 1800 galaxy clusters containing 34,471 galaxies. Finally, they compared the number of clusters in their new catalogue with simulations to determine the total amount of matter in the Universe.

"We have succeeded in making one of the most precise measurements ever made using the galaxy cluster technique," said co-author Gillian Wilson, a professor of physics and astronomy at UCR, in whose lab Abdullah works. "Moreover, this is the first use of the galaxy-orbit technique which has obtained a value in agreement with those obtained by teams who used non-cluster techniques, such as cosmic microwave background anisotropies, baryon acoustic oscillations, Type Ia supernovae, or gravitational lensing."

"A huge advantage of using our GalWeight galaxy orbit technique was that our team was able to determine a mass for each cluster individually rather than rely on more indirect, statistical methods," said the third coauthor, Anatoly Klypin, an expert in numerical simulations and cosmology.

By combining their measurement with those from the other teams that used different techniques, the UCR-led team was able to determine a best combined value, concluding that matter makes up 31.5±1.3 percent of the total amount of matter and energy in the Universe.

A study of comet motions hints that the Solar System has a second alignment plane

Analytical investigation of the orbits of long-period comets shows that the aphelia of the comets—the point where they are farthest from the Sun—tend to fall close to either the well-known ecliptic plane where the planets reside or a newly discovered "empty ecliptic." This has important implications for models of how comets originally formed in the Solar System.

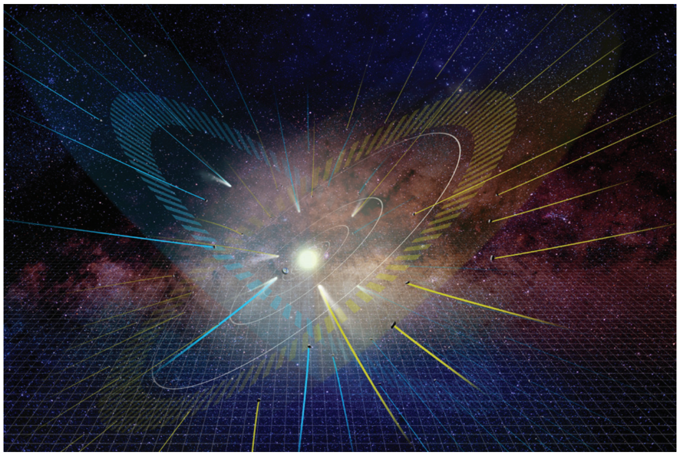

Figure 3 — Artist's impression of the distribution of long-period comets. The converging lines represent the paths of the comets. The ecliptic plane is shown in yellow and the empty ecliptic is shown in blue. The background grid represents the plane of the galactic disk. Image: NAOJ.

In the Solar System, the planets and most other bodies move in roughly the same orbital plane, known as the ecliptic. Comets, especially long-period comets taking tens-of-thousands of years to complete each orbit, are not confined to the area near the ecliptic; they are seen coming and going in various directions.

Models of Solar System formation suggest that even long-period comets originally formed near the ecliptic and were later scattered into the orbits observed today through gravitational interactions, most notably with the gas giant planets. But even with planetary scattering, a comet's aphelion, the point where it is farthest from the Sun, should remain near the ecliptic. Other, external forces are needed to explain the observed distribution. The Solar System does not exist in isolation; the gravitational field of the Milky Way also exerts a small but non-negligible influence.

Arika Higuchi, an assistant professor at the University of Occupational and Environmental Health in Japan, studied the effects of the galactic gravity on long-period comets through analytical investigation of the equations governing orbital motion. She showed that when the galactic gravity is taken into account, the aphelia of long-period comets tend to collect around two planes.

The first is the well-known ecliptic, which is inclined with respect to the disk of the Milky Way by about 60 degrees. The second ecliptic is also inclined by 60 degrees, but in the opposite direction. Higuchi calls this the "empty ecliptic" based on mathematical nomenclature and because initially it contains no objects, only later being populated with scattered comets.

Higuchi confirmed her predictions by cross-checking with numerical computations carried out in part on the PC Cluster at the Center for Computational Astrophysics of NAOJ. Comparing the analytical and computational results to the data for long-period comets listed in NASA's JPL Small Body Database showed that the distribution has two peaks, near the ecliptic and empty ecliptic as predicted.

This is a strong indication that the formation models are correct and long-period comets formed on the ecliptic. However, Higuchi cautioned: "The sharp peaks are not exactly at the ecliptic or empty ecliptic planes, but near them. An investigation of the distribution of observed small bodies has to include many factors. Detailed examination of the distribution of long-period comets will be our future work. The all-sky survey project known as the Legacy Survey of Space and Time (LSST) will provide valuable information for this study."

Composed with material provided by the National Astronomical Observatory of Japan.

Rare dual quasars inhabit cosmic giants

In our dynamically evolving Universe, galaxies occasionally experience collisions and mergers with a neighbouring galaxy. These events can be dramatic, causing the birth of new stars and the rapid feeding of the supermassive black hole that resides in each galaxy. It's understood that these enormous black holes have masses millions to billions of times larger than our Sun and exist in the centre of all massive galaxies. As material swirls around the black hole, it is heated to high temperatures, releasing so much light that it can outshine its host galaxy. Astronomers refer to this phenomenon as a quasar.

Simulations of galaxy mergers demonstrate that sometimes quasar activity occurs at the centres of both galaxies concurrently as they undergo a cosmic dance. Such a merging pair will arise as a pair of luminous "dual" quasars. While astronomers have previously found a modest number of luminous quasar pairs, they are rare. Finding them requires observations with both the resolution to separate the light from two quasars in close proximity and coverage across a wide enough area of the sky to catch these rare events by random chance.

To overcome these challenges, astronomers are taking advantage of a high-resolution and wide-area survey of the sky, using Hyper Suprime-Cam (HSC) on the Subaru Telescope, to search for dual quasars.

"To make our job easier, we started by looking at the 34,476 known quasars from the Sloan Digital Sky Survey with HSC imaging data to identify those having two (or more) distinct centres," explained lead researcher John Silverman, of the Kavli Institute for the Physics and Mathematics of the Universe. "Honestly, we didn't start out looking for dual quasars. We were examining images of these luminous quasars to determine which type of galaxies they preferred to reside in when we started to see cases with two optical sources in their centres where we only expected one."

Using automated analysis tools, the team identified 421 promising cases. However, there was still the chance that many of these were not bona fide dual quasars but rather chance projections such as due to stars in our own galaxy. Confirmation required detailed analysis of the light from the candidates to search for definitive signs of two distinct quasars. Using the Keck-I and Gemini-North telescopes on the summit of Maunakea in Hawaii, Silverman and his team identified three dual quasars, two previously unknown: each object in the pair showed the signature of gas moving at thousands of kilometres per second under the influence of a supermassive black hole. The mass of each black hole is around 100 million times the mass of our Sun. The companion is redder than its partner, perhaps indicating that it is partially hidden behind other material left over from the collision between the host galaxies.

Based on these observations, the team estimates that 0.26 percent of all quasars actually have two supermassive black holes in the quasar phase. The low fraction exemplifies their rarity and the reason so few were found in past searches. However, Shenli Tang, a graduate student at the University of Tokyo and a project member, points out, "In spite of their rarity, they represent an important stage in the evolution of

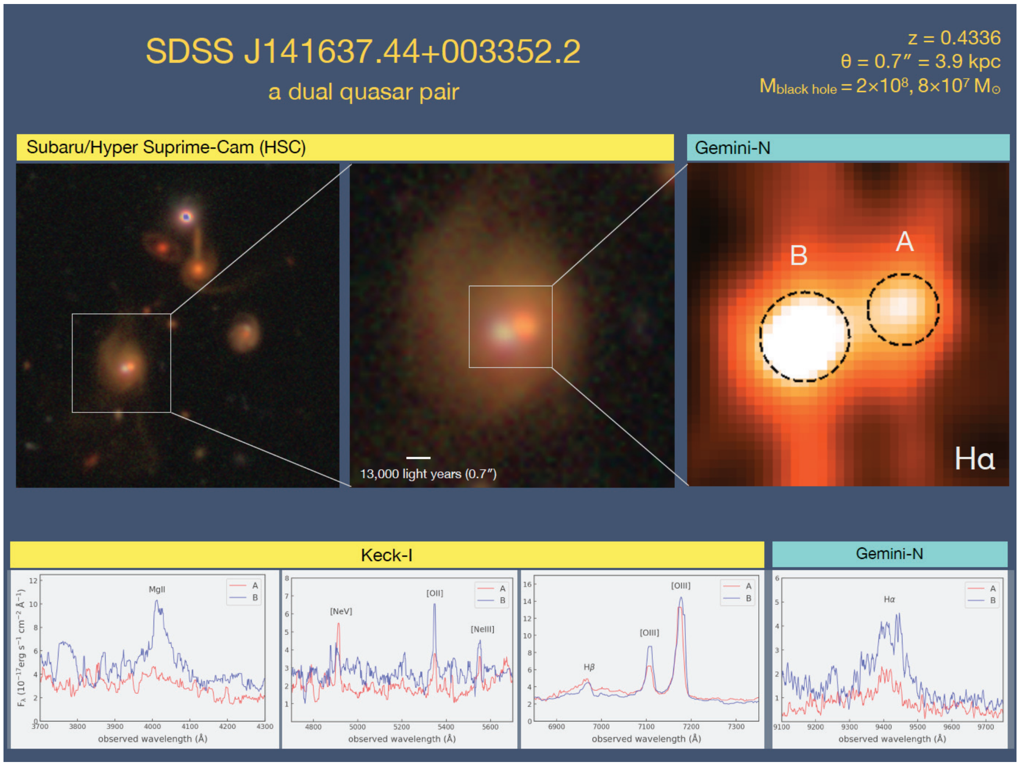

Figure 4 — SDSS J141637.44+003352.2, a dual quasar at a distance for which the light reaching us was emitted 4.6 billion years ago. The two quasars are 13,000 light-years apart on the sky, placing them near the centre of a single massive galaxy that appears to be part of a group, as shown by the neighbouring galaxies in the left panel. In the lower panels, optical spectroscopy has revealed broad emission lines associated with each of the two quasars, indicating that the gas is moving at thousands of kilometres per second in the vicinity of two distinct supermassive black holes. The two quasars are different colours, due to different amounts of dust in front of them. Image: W.M. Keck Observatory/Silverman et al.

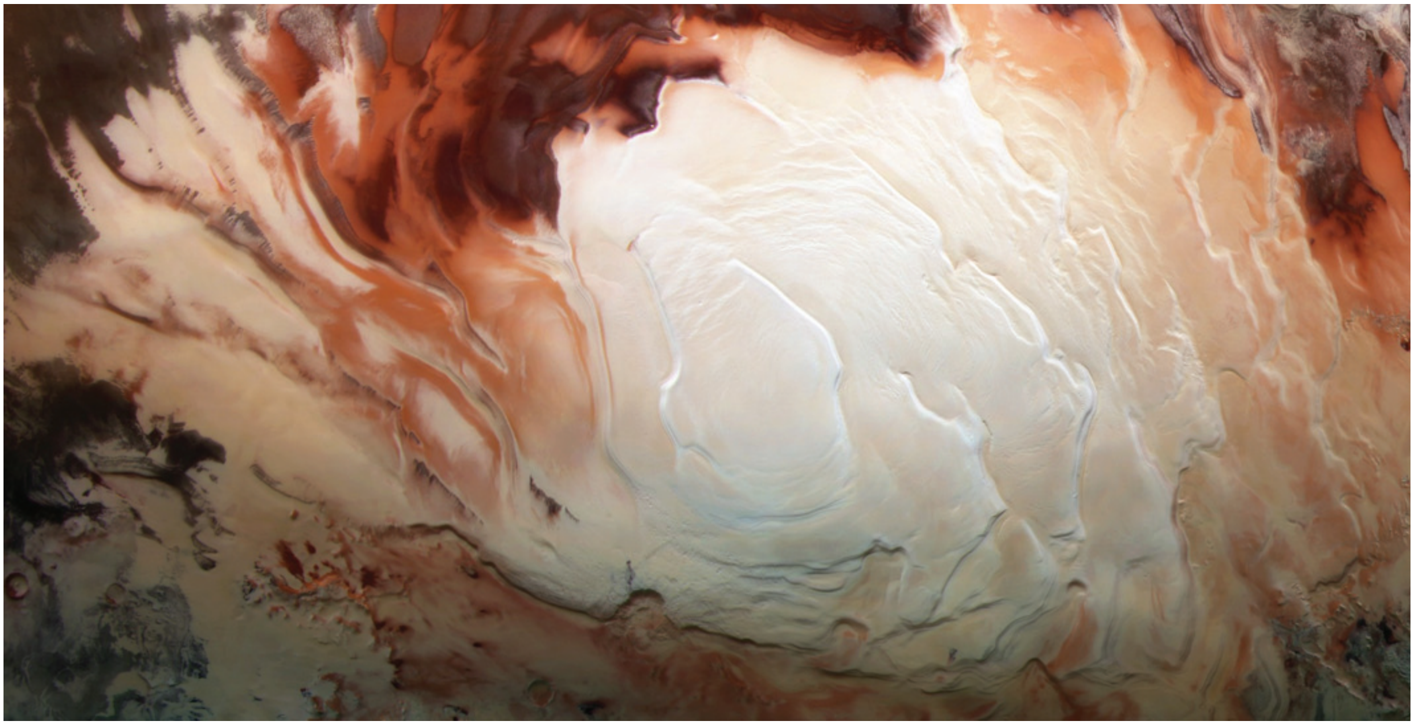

Figure 5 — A view of the Martian south pole. Image: ESA/DLR/FU Berlin/Bill Dunford.

galaxies, where the central giant is awakened, gaining mass, and potentially impacting the growth of its host galaxy." These results demonstrate the promise of wide-area imaging to detect dual quasars for the study of the growth of galaxies and their supermassive black holes. These three detections are just the beginning of the results to come with HSC on the Subaru Telescope, as the team obtains spectra of many more dual quasar candidates.

Composed with material provided by the National Astronomical Observatory of Japan.

More buried lakes on Mars

Two years ago, scientists reported the detection of a sub-surface lake near Mars's south pole, a discovery that largely escaped wider public attention. This early discovery has now been reinforced by additional radar surveys, which not only confirmed the original revelation, but added three more potential lakes to the inventory. The latest detections were placed on a more solid foundation by the use of 134 observations compared to the 29 in the 2018 report.

The research team, led by Sebastian Emanuel Lauro and Elena Pettinelli of the Dipartimento di Matematica e Fisica, Università degli studi Roma Tre in Rome, used radar data from the European Space Agency's Mars Express satellite. Radar transmissions from Mars Express are able to penetrate the surface, reflecting off buried density discontinuities below the ground. The buried lakes, ranging in size from 5 to 19 km, are revealed as areas of high reflectivity, which the researchers claim is due to liquid water buried under a kilometre of Martian ice. The same technique is used to find sub-surface glacial lakes on Earth.

Heat generated by radioactive elements is not sufficient to keep underground water in a liquid state (the temperature at the base of the Martian ice cap is estimated to be around 205 K), so some other mechanism is needed to explain the radar signatures. Very salty water would do the trick and the significant presence of perchlorates on the planet's surface make it reasonable to assume that they would also be present in subsurface lakes. Dissolved perchlorates can remain liquid to temperatures of 150 K (–123.15 °C) but the salinity of the underground lakes is unknown.

Liquid water in any form immediately brings speculation about life on the planet. Terrestrial microbes that survive in very salty conditions are known as halophiles, but the additional complication of frigid temperatures makes the presence of similar life forms on Mars much more challenging. ✷

The research findings have been published in Nature magazine.

Feature Articles / Articles de fond

1997 Meteor Spectrum Revisited

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Abstract

The spectrum of a meteor was obtained by the first author in 1997 using a thin-film holographic grating mounted on a large-format film camera. The second author has analyzed that spectrum and identified the spectral emission lines. The procedures that have been used in this project could be applied to observations made with modern electronic detectors.

Observation

The first author is an amateur astronomer who has been active for many years in trying to secure meteor spectra by a variety of means, including conventional film cameras, objective prisms, blazed precision replica transmission gratings, image-intensified video systems, and other procedures and devices. Various degrees of success have been achieved. At the time of the original observation being reported here, the recording of high-dispersion spectra required the use of large-format films and was costly. To obtain spectra of faint meteors, image intensifiers were required. Image intensifiers of high quality were expensive two decades ago, and are now difficult to obtain at a reasonable cost.

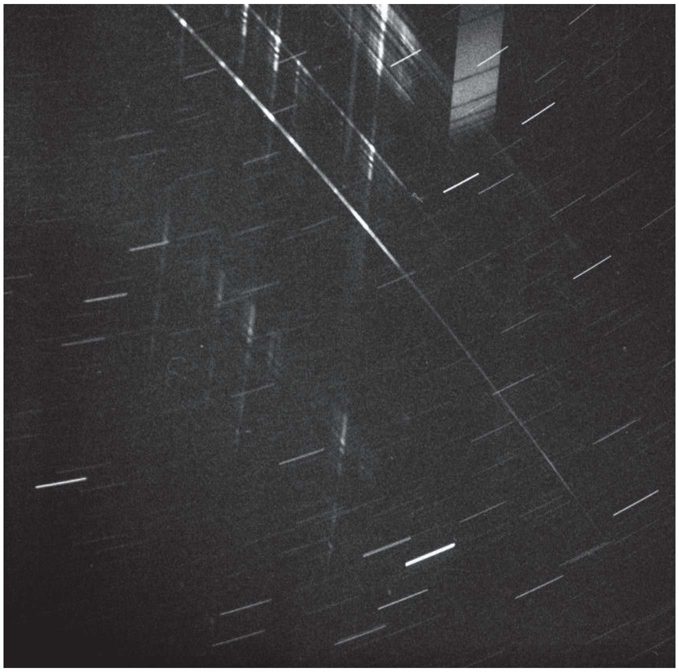

Figure 1 — The original image showing the meteor crossing the background star field diagonally from upper-left to centre and dispersed from lower-left to upper-right, and the spectrum of Vega running from near-centre to top-centre.

At present, the use of film and image intensifiers is, for most observers, largely moot thanks to the availability of a wide range of still and video cameras that make use of very sensitive electronic detectors. Near-continuous monitoring of large areas of the sky are possible, with continuous recording of the data on computers for later examination and analysis.

In the original paper (Majden 1998), the equipment used, including especially the use of inexpensive holographic gratings, was described. For the benefit of readers who may not have easy access to the original paper, following is a brief description of the equipment used to record the spectrum under discussion here: The camera was a 2¼-inch-square Hasselblad film camera fitted with an *f*/2.8 100-mm lens with a front-mounted 'Learning Technologies' holographic grating. The thin-film grating was mounted between glass sheets to keep it flat.

Using similar devices and modern electronic detectors, meteor spectroscopy is within the realm of observations that can be attempted by almost any committed amateur astronomer, and with a reasonable hope of success.

As noted in the first paper, on the *first* attempt to record a meteor spectrum, a very bright meteor passed through the field of view while the camera was pointed to an area of the sky that included the star Vega. The meteor and star spectra were recorded simultaneously. That fortuitous event made analysis of the film record slightly easier than it might otherwise have been. The original image is shown in Figure 1. A cropped portion of the original is shown in Figure 2 with the spectrum of Vega and five selected scans of the spectrum of the meteor labelled.

Analysis

The two authors met online after Majden read a paper published by Ward in the *Proceedings of the International Meteor Commission's Meeting* in Mistelbach, Austria, in 2015. Ward's paper discussed video meteor spectroscopy. Whereas others had told Majden that his 1997 meteor spectrum could not be measured due to its non-linearity, Ward offered to attempt the analysis.

The second author used a high-resolution film scanner to scan the original negative. The wavelength scale of the spectra was initially determined from the prominent Balmer line series in the fortuitously recorded spectrum of Vega, which is shown in Figure 3. The final line identifications were made by examining published meteor spectra that are available in the *International Meteor Organization Photographic Handbook, Chapter 3*. By using the most prominent spectral lines and their relative strengths, their unambiguous identifications were made, and an initial calibration followed. Once those lines were assigned in the "Visual Spectrum" spectroscopy software, the "unknown" lines could be measured and identified. Any small non-linearity in the spectra was deemed to be of no consequence in analyzing these low-dispersion spectra.

Scans were made at five locations along the meteor's spectrum. The five scans of the meteor spectrum are shown together in Figure 4, all aligned according to wavelength but shifted by arbitrary amounts in intensity so as to fit in one image. The spectrum for one of the meteor scans is shown in Figure 5 with the prominent lines identified.

The wavelength scale is given in angstroms as was commonly done at the time of the original observation. For the reader who is familiar only with metric units we note that 10 angstroms (A) = 1 nanometer.

Future Observations

The first author is working on a high-resolution film spectrograph using a surplus WWII aircraft reconnaissance *f*/2.5 305 mm lens that originally used 9 × 9-inch film. Such lenses are now rare and expensive. It will be fitted with a thin glass 600 g/mm blazed replica grating. Jiri Borovicka, Ondrejov Observatory in the Czech Republic, has suggested using 4 × 5-inch film to keep costs down. High-resolution spectra are necessary for studying the fine features in meteor spectra.

As noted above, the recording of meteor spectra is an activity which, while challenging, is possible by amateur astronomers using readily available equipment.

Acknowledgements

The first author thanks John Purdy for making the mount for the thin film grating.

Dr. David Turner, a former Editor of this *Journal* made helpful suggestions during the early stages of the project.

Dr. Douglas Hube, currently Associate Editor of this *Journal* made helpful suggestions as to content and style, and then rewrote an earlier version of this paper. ✶

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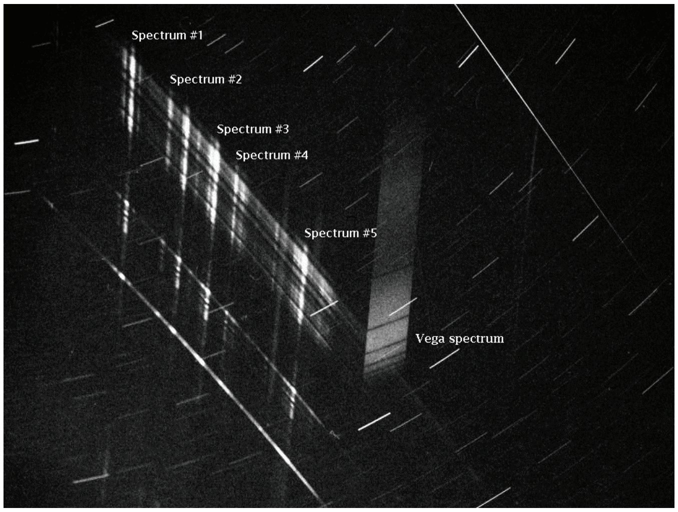

Figure 2 — Relevant portion of the original image cropped and contrast enhanced.

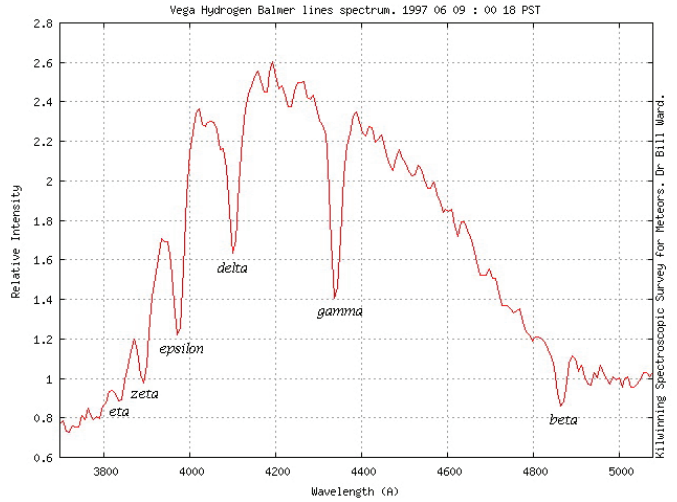

Figure 3 — Spectrum of Vega with the Balmer lines of hydrogen labelled.

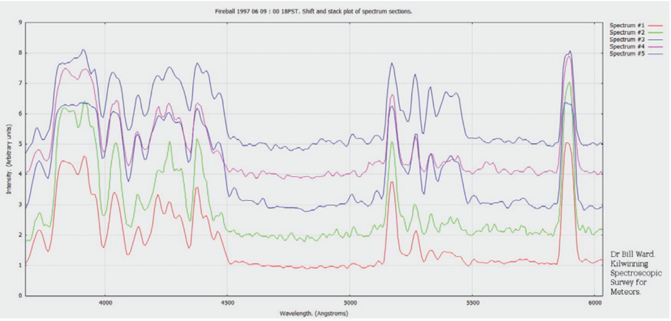

Figure 4 — The five spectral scans of the meteor superposed according to wavelength, but arbitrarily shifted in intensity.

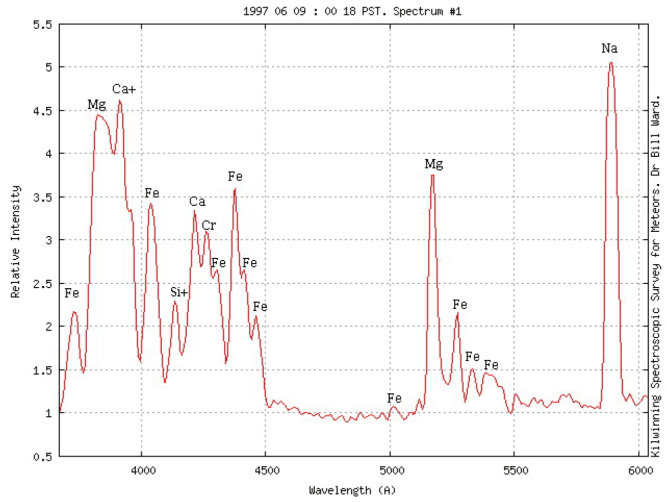

Figure 5 — Spectral scan #1 with spectral line features labelled.

The Biological Basis for the Canadian Guideline for Outdoor Lighting 3 – Impact of the Extent of Lighting

by Robert Dick, M.Eng., P.Eng., FRASC
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Abstract

A light shines as far as the eye can see—even to the edge of the observable Universe, but its brightness dims with distance. Although this dimming renders distant light innocuous, its impact close to the source can alter the ecology and reduce visibility. This paper will discuss and quantify the impact of area lighting on the health and well-being of animals and the ecology of the affected region.

Introduction

There are two questions that should be addressed when considering to what extent we should illuminate the landscape. How large an area do we need to illuminate, and how much glare from the lamp luminance can we tolerate? The first affects the ecological impact and the second affects the vision of animals and in particular humans—since only humans want, and use the light.

As naturalists of the night, amateur astronomers witness the extent of artificial (anthropogenic) light at night (ALAN). It may be a neighbour's patio light, or a streetlight that shines between buildings into their backyard. ALAN is not limited to urban areas. It is also produced by car headlights and even beacons on tall communication towers.

Figure 1 — The Entrance to a National Park. Unshielded wall packs shine into the eyes of motorists as they approach the kiosk. The luminance of the lamps overwhelms visibility in the area, and even the Stop sign. The glare masks any obstacles and hazards beyond the kiosk. The wall packs shine into bush and forest—disrupting the habitats and attracting predators and insects.

Our current society makes lights unavoidable because of our predilection for ALAN. Light fixtures are expensive to install and maintain, so there should be a reluctance to install them. However, they can offer enhancements to safety and security, and they can provide an urban aesthetic.

In the second article of this series, we differentiated between the need for luminance and illuminance (Dick 2020b). The role of luminance is to provide light to illuminate an area, or as a point source to attract attention, whereas illuminance is the light that falls on a surface that provides situation awareness, reveals hazards, or assists in navigation across the space. Although there is a need for luminance to shine far from the lamp, there does not seem to be a need for illumination that shines beyond the area of human activity, which we call the target area, and yet this is a consequence of most outdoor lighting.

Satellite imagery provides a regional perspective to the impact of ALAN. Light accompanies people as they migrate out of cities and take up residence in the less-congested countryside. This light delineates the system of rural roads and hamlets across the region. Most homes have outdoor lighting. Without shielding, these lights shine out across the roads and are visible from the neighbouring properties along the highways. These residential lights are augmented by widely spaced streetlights that mark intersections and bends in the roads.

Due to the low tax base of most rural municipalities, these roadway luminaires tend to be old, unshielded, and poorly maintained. Many were installed in the era when the mantra was "more light is better than less" and shields were either unavailable, or roadway officials did not believe they were necessary. Even today, the amount of light along a rural road

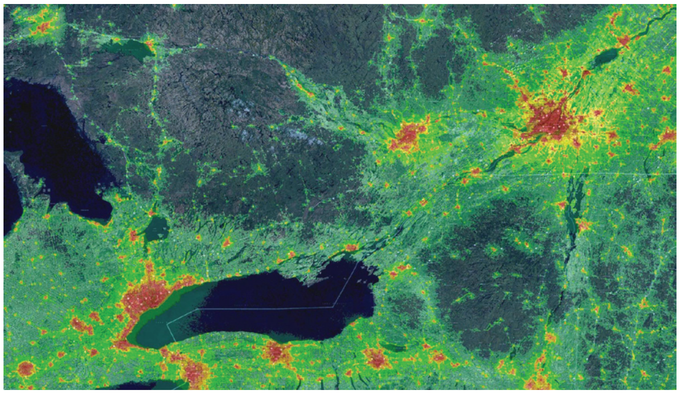

Figure 2 — Light delineates the system of rural roads across eastern Ontario. People migrating from urban to rural areas bring urban lighting standards with them. In doing so they change the landscape away from the rural environment they wish to experience. Rural activity (pedestrian and vehicular) is significantly less than what is experienced in a city, yet illumination levels may exceed urban standards. (Source: www.lightpollutionmap.info, 2019 Data Release)

is selected based on marking the right of way regardless of the glare it creates, or the amount of vehicle traffic at night.

The regional perspective in Figure 2 reveals continuous illumination along rural roadways, and accentuated by the dark forested areas between the roads. These "lines of light" sever and fragment animal habitats. Most areas coloured "dull green" will have artificial skyglow on the local horizon—illuminating the countryside and undermining the natural aesthetic and ambience of the night, and the star-filled sky. The combined effect of this illumination is to raise the ambient lighting significantly above the natural background.

It may seem obvious to prevent the spreading of "green" across the map, but to do so requires a change in our priorities and our approach to lighting.

Figure 3 — View down a rural road with an approaching car. Although modern bright headlights provide illuminance to increase visibility for the driver who cannot see the luminance of their lights, the glare is debilitating for the opposing traffic.

Ecological Extent Of Light

Nocturnal wildlife is affected by both the luminance and illuminance of light (Dick 2020b). Therefore, if ALAN is deemed necessary for human activity in an area (i.e. it is a priority), is there a rational extent we can impose on the light to minimize its impact on the ecosystem while still enabling human activity?

There are several approaches to lighting that depend on whether it is for illumination or luminance. We begin with illuminance.

If predators can see their prey, then the prey is vulnerable. Many animals take advantage of anonymity for safety and hide in the darkness, but nocturnal foraging animals must be mobile, which forces them to move out from the shadows under the trees and bushes.

The extent of their foraging range is a function of how far they are able to travel during the night. This is reflected by their body mass (Swihart 1988). Smaller animals (low mass) tend to have short legs and travel shorter distances in a given period of time. The visible extent of the illuminated landscape presents visible barriers across their foraging range requiring costly detours that affect their use of energy and their survival from predation.

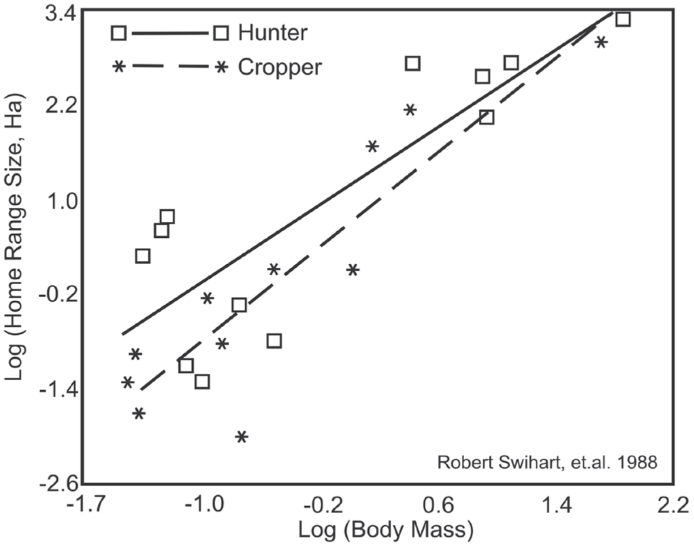

Figure 4 — Foraging range versus body mass. Foraging animals need a range sufficiently large enough to provide enough food for their survival. Larger animals require more food, but larger body size, and hence longer limbs, enables them to exploit a more expansive area. Smaller animals may not be fast enough to circumnavigate an illuminated area within a single night. If the illuminated area is too large, then its normal foraging area will become fragmented and more restrictive. This forces animals to abandon the area for a larger uncontaminated range.

Animals learn when an area is not safe, and they relocate. However, most habitats are already in ecological balance. Changing the number of animals and the mix of species within a habitat will cause that ecosystem to re-balance—resulting in a new set of winners and losers. But regardless, change is inevitable.

The new balance may take many seasons to be established—beginning at the low end of the animal food chain that most people are not aware of. It is only after the change has affected the larger animals that people begin to take notice. The media place the blame on "habitat disruption" due to the expansion of urban areas and in the growth in the rural population, and perhaps water and noise pollution. Rarely has ALAN been raised as a contributor to this disruption so, until recently, ALAN continued unreported and uncorrected.

The luminance of an unshielded light fixture will also impact wildlife. Most mammals have similar eyesight to humans. So, glare that reduces human vision will affect animals as well. Unshielded lights undermine their dark adaptation and reduce their ability to see into the shadows.

Figure 5 — Unshielded light from Commercial Facility. Although the purpose of outdoor lighting is to improve safety, many industrial sites reduce lighting costs by using inexpensive unshielded luminaires. In this case, roughly 25% of the light energy shines off the property. Not only does the lack of shielding produce glare across the site, it impacts the surrounding landscape and visibility along adjacent roads. With proper shields, this wasted light could be "harvested" to improve site visibility and safety. (Credit Roland Dechesne)

Even relatively dim lights can undermine animal survival. Birds use the stars to navigate through the night (Emlen 1975). So, their vision is sensitive enough to use at least the brighter celestial objects. They recognize the patterns of stars and their orientation to compensate for the passage of time, and their direction of flight. Unshielded light can confuse the recognition of the celestial patterns. Patterns of "point sources" quickly change as birds fly over isolated urban lighting. And, artificial sky glow will confuse extended features like the Milky Way and the polarization of the skylight. These can lead to navigation errors that waste energy during long migrations or will delay the animal's arrival at their destination.

The bane of Canadian summers is the mosquito. Their olfactory sense allows them to follow smells upwind, but light will attract them from greater distances. The luminance of an unshielded lamp is greater than the low albedo of most clothing, so the main attractor is the lamp, not the people. Once close to their "blood meal" they may home in by smell.

Figure 6 — Spider web under an outdoor light along a pedestrian way in the Muskoka District north of Toronto. Each luminaire in the string of lights had a web.

The attraction of unshielded lights will concentrate insects that will increase the success of predators. Examples are spider webs built near outdoor lighting. So, it is important to shield light fixtures to minimize the visibility of the lamp at a distance.

Light fixtures along the shorelines of waterways will affect both aquatic life (Dick 2020b), and the safety of late-night boaters. Not only does the luminance of the lamp create glare but the light reflecting off a wavy water surface will obscure floating hazards.

Shoreline lighting also affects the aquatic ecology (Watersheds Canada 2019). The low-angle emission across the water is well below the critical angle for the reflection off a smooth water surface (45°), but wave action causes greater angles that let light penetrate the water column. This extends twilight illumination into the night, and raises illumination levels at greater depths than normal.

Figure 7 — Shoreline Glare along Waterway. Most outdoor lighting is left on through the night—yet serves no practical purpose because the people are indoors or asleep. Glare from these lights reflects off the water and prevents boaters' visibility of hazards, and can confuse navigation by masking shoreline features and navigation buoys. Although this low emission angle is below the critical angle for the reflection off the water's surface, wave action causes light to penetrate the water column to affect aquatic life.

Optics of Shielding

There are three reasons for shielding luminaires: to reduce debilitating glare, to limit the extent of the illumination and to preserve the aesthetics of the natural landscape.

An argument that is used to not shield light fixtures is, "Shielding will limit the extent of the illumination, thereby requiring more lights." However, the illumination far from

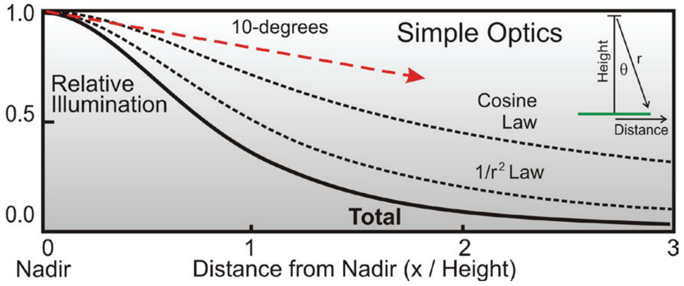

Figure 8 — Falloff of illumination with distance. Two geometric effects cause a decrease in illumination with distance from the luminaire. The surface of the expanding bubble of illumination increases with the radius^2—thereby diluting the luminance over a larger area. And the angle at which the light hits the ground becomes more shallow with distance. This is referred to as the cosine law and the distribution is called Lambertian. Combining these causes a rapid falloff in illumination with distance from the luminaire. These effects can be reduced with optics that project more light into the periphery.

Figure 9 — Aesthetic Lighting at Rural Home. This image was taken at 3 a.m., when the homeowners were absent. The 750 W lamps over-illuminate the entrance and obscure hazards and wildlife along the road. The light attracts vandals and thieves by putting the property's outdoor furniture and equipment on display. The better it looks to the owners, the better it looks to "ne'er-do-wells," and they won't need flashlights to do their nasty deeds.

the light source is not helpful in the face of the glare from the unshielded light. Figure 9 shows that a fixture with simple or no optics has a limited range of use, and the light that shines beyond this range contributes only glare, which can actually reduce visibility.

Emitted light shines into an expanding shell whose surface increases with the square of the radius. Therefore, ground illuminance (lux or lumens/m^2) produced by the light fixture decreases with the square of the distance, so that doubling the distance from the light reduces the illuminance by a factor of four.

Also, the angle at which the light hits the ground will become shallower with distance, so the incident light becomes diluted over the larger area in the periphery—further reducing the illuminance on the ground. Combining these effects shows that illumination beyond about 1.5-mounting heights is less than 1/10 that at the nadir, making it look relatively dim. Industry guidelines for roads and pathways recommend limits to this non-uniformity from 3:1 to 6:1 (average/minimum), which depend on the speed and traffic that the road or pedestrian path are expected to carry (IESNA, 2000). The equivalent "maximum/minimum" uniformity can be over 10:1, so the periphery will appear too dim with respect to the brightest areas.

If the illumination level is the only metric in the lighting designer's toolbox, then increasing the lamp luminance might satisfy the low peripheral illumination. However, this increases the glare, which further reduces the effectiveness of the illumination. Reducing the glare from the lamp with shielding is the only effective solution.

Carefully designed optics can expand the illuminated area by projecting more light into the periphery. However, this can also increase the amount of light that is projected close to the horizon—in the glare zone—within 10° below the horizontal. This low-angle light becomes very sensitive to the mounting and alignment of the fixture. Consider the headlights of an approaching car. Modern headlights have optical systems that focus the light below the horizon to limit the glare for on-coming vehicles, but if not aligned properly, or if the grade of the road is not flat, these systems produce debilitating glare for other drivers.

Some luminaires should not be shielded. If the light serves to mark the place of an intersection or hazard, then it should

Figure 10 — Comparison of the luminance of the Moon to an LED streetlight. The Moon illuminates the countryside to a maximum of about 0.1 lux (scotopic vision) with a luminance of only 4,000 cd/m^2 (4,000 nits). The small emitters in a LED fixture must illuminate a very large surface to levels suitable for our photopic vision (>3-lux) requiring a luminance of 100,000 to over a million nits.

be visible from a distance (i.e. aircraft avoidance beacons). However, for most marker lights, the brightness need only be greater than surrounding lights. When other fixtures are shielded, marker lights require far less luminance. In ecologically protected areas, very low luminance marker lights can be used because management has control over the shielding of the other installed lighting.

However, there is currently no control over the luminance of residential and commercial lighting in urban areas. Marker luminance in built areas will be situation dependent. Only a few rural municipalities "request" that light fixtures not shine onto roadways specifically because of its hazardous glare (United Counties of Leeds and Grenville, Ontario).

Natural light sources near the horizon can be debilitating. For example, Venus (1 cd/m^2) is a brilliant spectacle above the tree line against the fading twilight. The brightest nocturnal object is the full Moon at 4,500 cd/m^2. However, Venus and the Moon tend to be obscured by trees as they approach the horizon where they might be within a pedestrian's field of view.

The relatively low altitude of a marker light will appear in front of dark trees or bushes and close to the observer's field of view—exasperating visibility for pedestrians. Therefore, a luminaire with the luminance of Venus, and especially the Moon, will appear very bright and distracting.

This leads to the conclusion that even some natural light levels can be disruptive. However, natural lighting is transient, whereas ALAN is permanent. Later in this series of papers we will be addressing ways to reduce this impact as well.

Existing Shield Solutions

The luminance of ALAN undermines visibility and the ecology. Metrics have been developed to quantify the problem, but metrics alone are not a "solution." Optics and shields should be required to contain the glare to within the target area and prevent light trespasses beyond its borders.

Fixtures are classified by, among other things, the amount of shielding. There are three ranges of shielding: no shielding, partial shielding, and fully shielded. Globe lights and most dusk-to-dawn fixtures have no shielding. They emit light over almost 4π-steradians. Older fixtures have partial shielding called Cut-Off (CO) and Semi-Cut-Off (SCO). Fully shielded luminaires include Full Cut-Off (FCO) and Sharp Cut-Off (ShCO) fixtures. Only the FCO and the ShCO fixtures do not shine light directly into the sky.

The difference between the FCO and ShCO fixtures is the amount of light allowed to shine within the "glare zone" 10° below the horizon. Light shining close to the horizon is visible almost "as far as the eye can see," which is particularly important for motorists and pedestrians because it produces glare close to the centre of their field of view. FCO fixtures limit this light to 10% of the total light output and ShCO to 1%.

Figure 11 — Luminaires with different glare characteristics. The cut-off limits apply to the light that shines above the horizon and contributes directly to artificial sky glow. (a) The typical dust-to-dawn luminaire has very limited shielding. They are designed to scatter light at angles except directly upward. Less than 25% of the light illuminates the nadir. (b) Full Cut-Off fixtures can be identified by their "flat and horizontal window." The recessed lamp prevents up-light and limits the emission within 10 degrees below the horizon to 10% of the total light output. (c) The "drop glass" cobra fixture is called a "Semi Cut-Off" —allowing up to 5% up light. A shallower lens, called a "Cut-Off", allows 2.5% up light.

BUG Rating

The optics of light fixtures can be designed to tailor the emission of light into specific directions and vertical zones. This provides another tool in the designer's toolbox. Simple shields are not perfect due to diffraction in the optics and light scatter from external shields, so a practical specification for shielding must tolerate these effects. The BUG Rating classifies the degree of shielding. BUG stands for Back-light, Up-light and Glare. This helps users to select luminaires that, minimize the amount of glare for a given application.

The BUG Rating refines the light distribution and consolidates this information into a relatively simple format

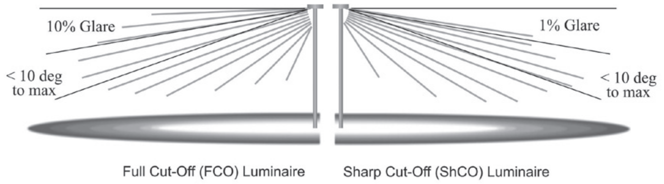

Figure 12 — Comparison of Full Cut-Off and Sharp Cut-Off fixtures. The difference between these classifications is the amount of light that shines within the Glare Zone because it creates glare well beyond the practical illuminated area. FCO has been the "standard" for over two decades. Low-impact fixtures use ShCO that limit this glare to only the illuminated area. Therefore, ShCO fixtures create virtually no glare beyond the target area.

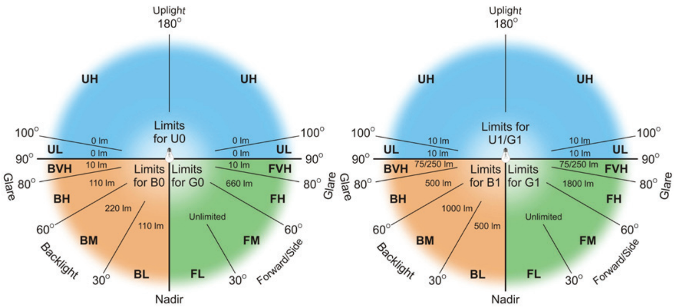

Figure 13 — Diagram defining lighting zones in "BUG" photometric system. Most Full Cut-Off luminaires (except when parts of the luminaire extend below the aperture of the luminaire) have no "up-light," so UH and UL are usually zero. The left image shows the lumen limits for B0, U0, and G0. The right image is for B1, U1, and G1. Notice that G1 has some up light and much more light at higher angles. (Ref: IES TM-15-07)

(IES 2011). The luminance pattern of the fixture is characterized by the azimuth and elevation angle of the emitted light (see Figure 13).

To limit the extent of the illuminated area, and the apparent luminance of the lamp, the light should only shine into the lower sectors (BL and FM). However, it is sometimes desirable to illuminate into the periphery. Therefore, the amount of light in the high-elevation sectors becomes important (BH and FH). Note that back light produces light trespass and glare into buildings behind the luminaire. If the luminaire is mounted on a wall, this back-light will make the wall appear very bright—contributing to glare visible beyond the target area.

The amount of light in each sector is used to classify the overall BUG rating of a luminaire. The limits for each sector are shown in Figure 13 for B=U=G=0 and B=U=G=1. In determining the BUG rating, the lumens emitted in each zone must be less than the limiting values—irrespective of the total lumen output of the luminaire.

Depending on the luminance of the light fixture and the amount of light emitted in the glare zone (within 10° below the horizon), the Glare component can range from G0 to G4. For example, a FCO 1000 lumen luminaire is G1 (1,000 lumens x 10% = 100 lumens) but a 1000 lumen Sharp Cut-Off luminaire is G=0 (1,000 lumens x 1% = 10 lumens). For more general applications, the BUG rating might be: B0-1, U0, G0-1. A limited amount of light in the glare zone is permitted for G0 because it is virtually impossible to produce a practical light that has zero light within 10° of the horizon—due to light scatter in the optics and their protective window.

Summary

Since luminance is required to illuminate an area for human activity, it will be impossible to eliminate the contamination of this area. The best that can be done is to minimize the extent of the contamination beyond the target area.

Luminaires with CO and SCO shielding, with their up light and horizontal emission, will illuminate the sky and create bright "false stars" above the horizon, which can confuse the navigation of animals and affect their night vision. Such luminaires also emit significant light that illuminates a wide area—affecting the foraging range of many animals. However, it must be recognized that even the popular FCO, and even ShCO luminaires will cause some degree of distant contamination. Therefore, in addition to limiting the extent of the ground illuminance, reducing the lamp luminance will also reduce the glare and should be minimized below a "practical" ecological threshold (Dick 2020b).

How does the luminance of Venus compare to that of urban and roadway lighting? The industry guideline for the apparent luminance of an illuminated road surface is about 0.5–1.0 cd/m^2 (IES 2000). However, traffic lights are over 1 million times brighter in order to outshine streetlights and automobile headlights. This undermines any practical ecological threshold for an urban lighting guideline. Indeed, the lack of control over urban traffic and automobile lights impacts visibility limits along roadways. The high-luminance lighting along roadways has no parallel in nature. Therefore, a lighting guideline that limits luminance to preserve the ecological integrity of a space may not be applicable to some urban areas. However, it may provide an alternative perspective for urban (residential) lighting that can be more environmentally sound and "sustainable."

We have reviewed the impact of brightness (Dick 2020b). Shielding is a second "tool" to limit the impact of ALAN. However, these limits may not be sufficient, so we must bring to bear controls on other light attributes. The next paper considers the colour, or more specifically, the spectrum of the emitted light. ✶

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Life in the Cosmos Revisited

by Klaus Brasch, National Member

Two possibilities exist: either we are alone in the Universe or we are not. Both are equally terrifying."
 – Arthur C. Clarke

"We are the cosmos made conscious and life is the means by which the universe understands itself."
 – Brian Cox

Abstract

The quest for life beyond Earth has become a major driving force in current astronomical research and space exploration. Whether this involves looking for fossil or extant evidence of microbial life on Mars or potential life on outer Solar System water bodies, biosignatures from exoplanets, or SETI, the underlying questions are the same: "Is life common or rare in the Universe?" and perhaps even more compelling: "Are we alone?" Since, for the first time in human history, we may actually get answers to these questions, this article reviews some of the key issues and considerations involved.

Introduction

"Are we alone in the Universe?" This ever-tantalizing question has been posed by philosophers for centuries and well before the scientific fundamentals of astronomy were fully elucidated. In ancient Greece, for example, the idea of the plurality of life-bearing worlds was first proposed by Anaximander (610–546 BCE), who held that the Universe is infinite, a notion also adopted by the atomists, Leucippus, Democritus, and Epicurus (Darling 2016). Plato and Aristotle, however, countered that our Earth is unique, a dogma that became enshrined in the Christian world under the geocentric model of the cosmos according to Claudius Ptolemy (Salviander, 2013) (Figure 1).

In contrast, medieval Muslim scholar Fakhr ad-Din-ar-Razi (676–733), in dealing with the concept of the physical world in his *Matalib*, rejects the Aristotelian notion of the Earth's centrality, and argues that there are "a thousand, thousand worlds beyond this world such that each one of those worlds be bigger and more massive than this world as well as having the like of what this world has" (Weintraub 2014). It's important to note, however, that "world" did not necessarily imply a planet to ancient thinkers as it does today, but more like another realm or even parallel Universe (Darling 2016).

With onset of the Renaissance, the Aristotelian-Ptolemaic doctrine was challenged, most notably by Giordano Bruno in his 1584 treatise *De l'infinito universo et mondi* (Concerning the infinite universe and worlds), wherein he proposed innumerable celestial bodies and earths harbouring life (Sullivan and Carney 2007). The ensuing Copernican revolution cast the first observational doubt on Earth's centrality and provided at least indirect support for the possibility that other life-bearing worlds might exist. This gained further traction during the scientific revolution and age of enlightenment, most notably in Bernard Le Bovier de Fontenelle's *Entretiens sur la pluralité des mondes* (Conversations on the Plurality of Worlds, 1686) (Figure 2). By the 18th and 19th centuries, the idea had become mainstream, with backing by such luminaries as John Adams, William Herschel, Immanuel Kant, Karl Friedrich Gauss, Pietro Angelo Secchi, among others (Darling 2016). This perspective was also rooted in the precept that God would not create anything without purpose, which gave rise to concepts of "natural philosophy," namely that there is a design underlying the cosmos and life (Sullivan and Carney 2007).

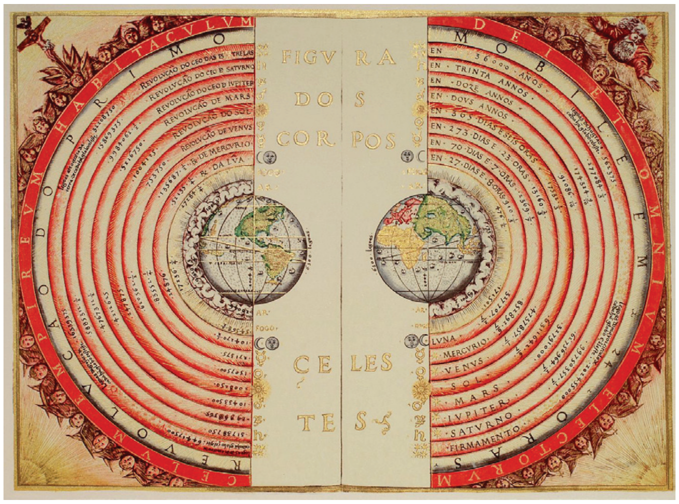
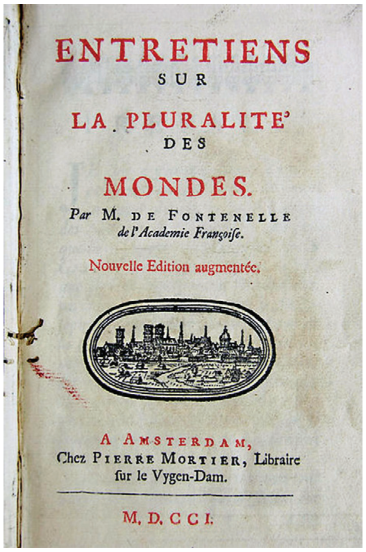


Figure 1 — Illustration of the Ptolemaic geocentric system by Portuguese cosmographer and cartographer Bartolomeu Velho, 1568 (Bibliothèque Nationale, Paris)(Public Domain)

The main popularizer of pluralism in the 19th century was Camille Flammarion. His 1862 treatise, *La Pluralité des mondes habités* (The Plurality of Inhabited Worlds), reinforced in the public mind that extraterrestrials might inhabit other worlds, and helped fuel Percival Lowell's contention that the putative "canals" on Mars were the work of an advanced



ENTRETIENS
SUR
LA PLURALITE'
DES
MONDES.
Par M. DE FONTENELLE
de l'Académie Françoiſe.
Nouvelle Edition augmentée.

A AMSTERDAM,
Chez PIERRE MORTIER, Libraire
ſur le Vygen-Dam.
M. D. C C I.

Figure 2 — Conversations on the pluralities of Worlds, 1686 by de Fontenelle (Public domain)

civilization (Brasch 2018b). The 20th century redefined the concept of life in the Universe along scientific terms rather than theology and philosophy. The antiquity of the Earth and life's origin were addressed experimentally for the first time, the structure of DNA and genetic basis of all life was clarified and, by mid-century, efforts to seek and/or communicate with potential alien civilizations were initiated (Shklovskii and Sagan 1966). Since then, humans have walked on the Moon, interplanetary probes and landers have revealed much about our Solar System and the possibility of finding simple life on Mars and several outer moons, astrobiology has become a serious scientific enterprise and, most relevant, several thousand exoplanetary systems have been discovered.

Where Are We Now?

A working hypothesis today is that life is universal and will gain a foothold on any stable celestial body located in some form of "habitable zone" (Figure 3); zones defined as "the orbital region around a star in which an Earth-like planet can possess liquid water on its surface and possibly support life," and perhaps giant planets like Jupiter with rocky moons where subsurface water can exist in liquid form for extended periods of time (Lissauer 2020). A case can also be made that alien life is probably not dissimilar in chemical characteristics to terrestrial life, namely carbon-water based. As suggested by McKay (2007) "Although speculations of alien life capable of using silicon and ammonia (as carbon and water alternatives) are intriguing,…" "…speculations on alternative chemistries for life are premature." While that Earth-centric perspective does not preclude alternative biochemistries, there are several good reasons why carbon and water are the most likely components of life elsewhere.

The Case for Carbon and Water

As many have noted (see e.g. Ball 2007; Bennet and Shostak 2017; Jones 2003) carbon is the fourth most abundant element in the Universe by mass, after hydrogen, helium, and oxygen, particularly in stars, including the Sun, as well as comets and the atmospheres of many if not most planets. It can also bond with up to four other atoms and thereby form profusely diverse compounds and generate very large (macro) molecules like proteins and nucleic acids (Figure 4).

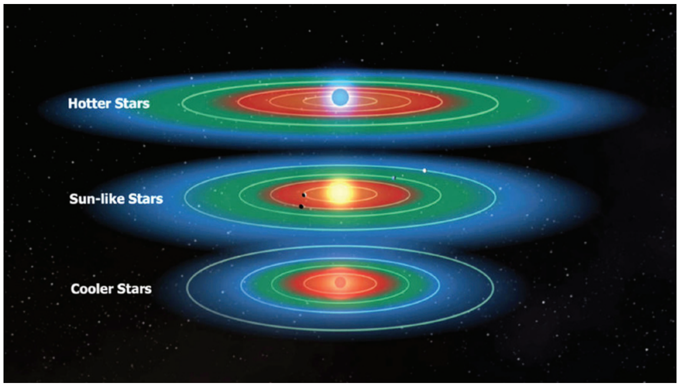


Figure 3 — Illustrations of potential habitable zones around various types of stars (NASA)

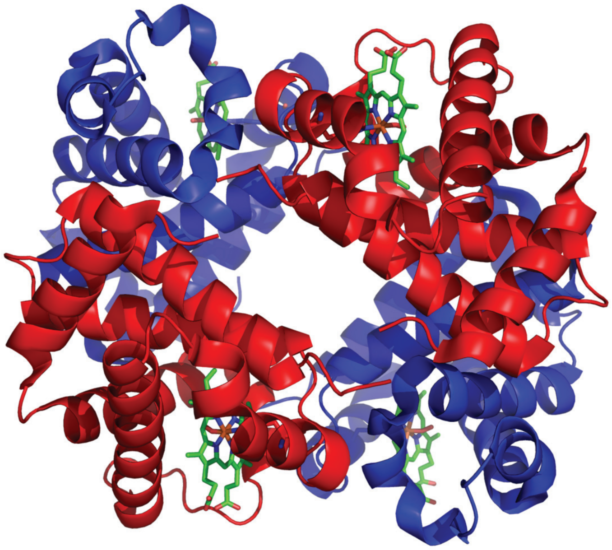


Figure 4 — Schematic illustration of the human Hemoglobin molecule, the all-important oxygen-carrying protein in red blood cells. It consists of four subunit chains and iron-containing heme groups shown in green (Wiki media)

Along similar lines, water (be that in solid, liquid, or gaseous form) is present in celestial objects as diverse as planets, moons, stars, star-forming clouds, and even beyond our Milky Way, in the stellar cradles of other galaxies (Pilbratt 2017). Liquid water also serves as the ideal medium for the amazingly complex biochemistry of life and does so over a relatively wide temperature range (0–100 °C). Notably as well, for most of its presence ~ 3.5 Gy (billion years), life on Earth thrived in aqueous settings and only ascended to land about 450 million years ago (Ball 2007).

It seems reasonable, therefore, that in looking for life in the Solar System and beyond, focusing on carbon-water-based organisms is the most likely route to success. That does not of course preclude *a priori* other possibilities (see e.g. Trefil and Summers 2019), but as yet we have no knowledge of them.

Defining Life and Its Origin

Despite numerous attempts, a satisfactory definition of life continues to elude us. As Trefil and Summers (2019) point out "The central problem is that life on Earth is tremendously complex and diverse. In addition, there appears to be a yawning gulf between living and non-living things, a gulf that must be described and accounted for in any definition of life." Historically life has been described in near-mystical terms as a kind of "force" or "vitalism" that distinguishes it from non-living matter, but also in terms of properties like: ordered structure, growth and development, reproduction, energy utilization, response to external environment, evolutionary change, etc. (Cleland and Chyba 2007). These characteristics apply to most organisms, but are not a comprehensive definition of life. Hence these authors suggest "…living organisms operate according to the same laws of chemistry that everything else does, they just tend to be more complex"; and "For our purposes, it will be useful…to resolve the issue [through] definitions of life based on a list of properties and processes, and definitions based on the science of thermodynamics."

Attempts have also been made to redefine life more broadly using information theory, environmental factors, and in terms that might apply to forms other than terrestrial life. For instance, we think of ourselves as distinct individuals and yet we host as many microbes in our guts as we have "self" cells. Such symbiotic microbiomes are inextricably linked with our development, metabolism, physiology, health, and survival. So, rather than defining life only as, say, simple, complex, or intelligent organisms, we should do so in terms of much broader interactive processes (Cepelewicz 2020). Moreover, what if we develop or encounter artificial life, or life not as we know it? A better definition might be based on: 1. Dissipation or a thermodynamically irreversible process; 2. Homeostasis or a system that always returns to equilibrium; 3. Autocatalysis or a self-catalytic system; and 4. A system capable of learning (Bartlett and Wong 2020). Keeping in mind that artificial intelligence is just around the corner and genetic engineering is at hand, what are humans going to be like a century from now? How about a far more advanced alien civilization? In the words of Arthur C. Clarke "The truth, as always, will be far stranger."

The origin of life also remains an unresolved issue. There are three basic possibilities: 1. It arose abiologically from organic pre-cursors on the young Earth in aqueous ponds or oceanic hydrothermal vents; 2. It originated elsewhere in the Solar System or our galaxy and reached Earth through transfer or migration, also known as panspermia; 3. A combination of both (Joshi 2008; Brasch 2018a).

Most scientists today favour the abiological origin of life on Earth since there is considerable, though by no means definitive, experimental evidence to support that. For a comprehensive summary see: Abiogenesis (2020), which can be defined as the natural process by which life has arisen from non-living matter, specifically simple organic compounds, be these synthesized chemically on Earth or seeded via impactors in the early Solar System. While details remain unclear, the prevailing hypothesis is that the transition from non-living to living entities was not a single event, but an evolutionary process of increasing complexity involving molecular self-replication, self-assembly, autocatalysis, and the emergence of cell membranes (Figure 5).

Fossil and other geologic evidence place the earliest signs of life on Earth between 3.8–3.5 Gy before the present (Bennet and Shostak 2017). That presents a potential dilemma, since it is widely accepted that formation of the Solar System dates to about 4.5 Gy ago. During its formation in the solar nebula and gradual cooling, our planet went through a stage of accretion and heavy bombardment lasting several hundred thousand years. Known as the Hadean or pre-fossil eon, it ended around 4 Gy ago. Since the first undisputed fossil evidence of bacterial life dates to 3.5 and possibly as far back as 3.7 Gy ago (Fig. 6), that seems a remarkably short time for fully formed cellular organisms to evolve from pre-biotic chemistry (Brasch 2018a; Kaufman 2017; Zubrin 2001).

The Case for Panspermia

Although the idea dates to antiquity, panspermia or "seeds everywhere" was first framed in potentially testable terms by Arrhenius (1908) and later by Hoyle and Wickramasinghe, 1978). More recently, it has been proposed as a transfer mechanism of viable microbes between Mars and Earth (Mileikowsky et al. 2000) and within the Milky Way Galaxy (Ginsburg et al. 2018).

The case for interplanetary panspermia is persuasive since we know that Martian meteorites have landed on Earth and probably vice versa. A celebrated example is ALH 84001 (Figure 7) discovered in the Allan Hills region of Antarctica in 1984 (Martian Meteorite 2020). Estimated to be 4.1 Gy old, it differs from other Martian meteorites as an igneous rock dominantly composed of orthopyroxene. It drew extensive attention in 1996 when McKay et al. (1996) reported that, in addition to PAHs or polycyclic aromatic hydrocarbons, it also contains structures similar to terrestrial nanobacteria fossils. The fossil claim has been widely questioned, as most likely mineral formations or preparatory artifacts. More recent studies indicate that ALH 84001 also contains 4 Gy-old nitrogen-bearing organics, suggesting that early Mars might

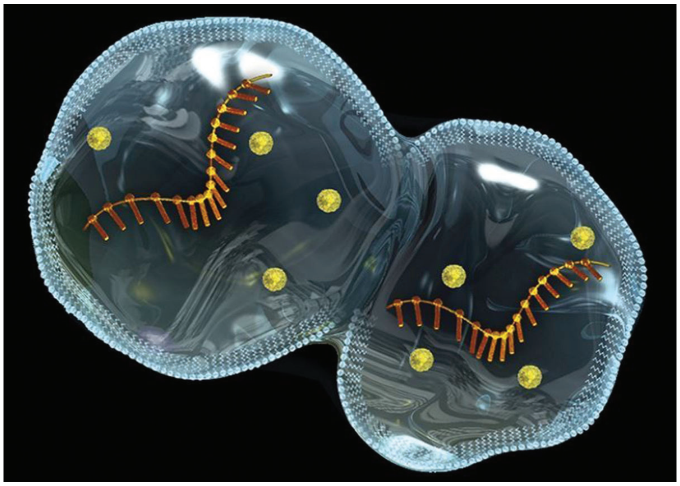


Figure 5 — Artistic rendition of a protocell undergoing division. The lipid bilayer membrane encloses a strand of RNA (the first genetic material) and rudimentary protein synthesizing machinery. (Henning Dalhoff Science Library)

Figure 6 — Living stromatolite colonies in Shark Bay, Australia. Fossils of such colonies date as far back as 3.5 Gy (Public domain)

have had abiotic or biotic nitrogen fixation and a less oxidizing environment than today (Koike et al. 2020).

Along similar lines, reports of possible mineralized biosignatures have been reported in another Martian meteorite ALK-77005 (Gyollai et al. 2019). Clearly, the jury is still out on many of these possible Martian biosignatures. While these and other examples of material transfer between Solar System bodies support the theory of panspermia, they don't as yet prove it.

NASA scientists hope to shed direct light on this question in future space missions by developing instruments to search for extraterrestrial genomes (SETG). State-of-the-art instruments aboard a Mars lander, for example, could look for traces of DNA or RNA and compare sequences with known terrestrial microbe data bases (Kaufman 2017).

An even more far-reaching suggestion is that panspermia might operate across interstellar distances and disperse microbial life within the galaxy. This idea was seriously advocated by Hoyle and Wickramasinghe (1978), proposing that life did not originate on Earth and that infectious diseases were due to invasive viruses from space, a notion entirely untenable on genetic and other grounds. In part because of that, interstellar panspermia was largely dismissed by most scientists at the time but has since regained more serious consideration (Ginsburg et al. 2018; Scharf 2012; Zubrin 2001).

Figure 7 — Martian meteorite AHL 84001 (NASA)

The argument goes something like this: 1. Despite extensive research, no evidence exists as yet for viable microorganisms on Earth simpler than fully evolved bacteria, which date back in fossil form to no less than 3.5 Gy, only about 300 million years after the end of the heavy bombardment phase of the planet where life would have been impossible (Zubrin 2001); 2. The advent of 'Oumuamua, the first confirmed but certainly not the only interstellar object, indicates that exchanges of material between stellar systems is not only possible but quite probable over time (Ginsburg et al. 2018); 3. The Oort Cloud (Figure 8), a proposed cloud of predominantly icy planetesimals surrounding the Sun, is thought to extend to distances ranging from 2,000 to 200,000 AU (0.03 to 3.2 light-years).

Collectively, the foregoing considerations have raised at least the theoretical possibility that, in addition to cometary and other primordial Oort cloud materials, microorganisms might be exchanged between stellar systems during close encounters. In a recent paper, Zubrin (2020) proposes a model to calculate the frequency of random stellar encounters and the levels of material exchanges between interacting Oort clouds during such events. It is not known, of course, whether all stars are circled by such a debris cloud, though it seems likely they would as remnants of their respective protoplanetary disks (Gilster 2019). Based on this model, Zubrin speculates "If we estimate that each Oort Cloud object disrupted has an average mass of 1 billion tons, then an encounter [with a star] at 20,000 AU would appear to have the potential to import about 25 trillion tons of mass from another Solar System into our own." While only a tiny fraction of this might hit the Earth, the potential for transfer of biological material is clear.

Enticing though this idea is, it faces many obstacles. First, even if life exists on an Earth-like planet and is catapulted into space through asteroidal or cometary impacts, or gravita-

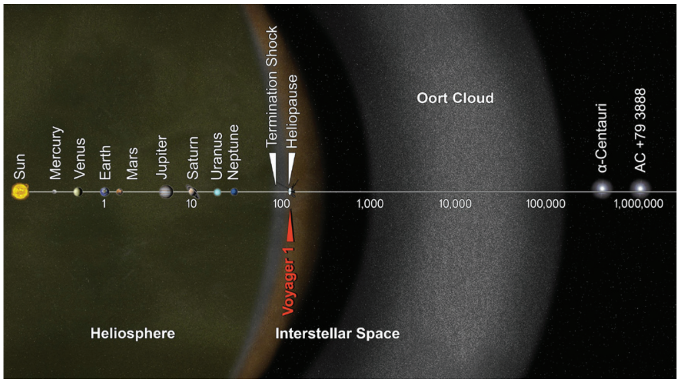


Figure 8 — Illustration of major features and distances (in log scale) of the Solar System including the putative Oort Cloud (NASA)

tional perturbations through stellar encounters, can it survive Oort cloud conditions to allow such transfer? (Gilster 2019). The only way this seems likely is through bacterial endospores, embedded in sizeable rocks and under deep freeze (Brasch 2018a). Second, given this scenario, what is the probability that such embedded spores do survive, possibly for very long periods, and successfully infect a suitable host planet in another stellar system? Thus, while panspermia seems an attractive option for spreading life between planets in the Solar System, and possibly among other star systems, it remains highly speculative and totally sidesteps the question as to how and where life originated.

Life as We Don't Know It?

Since we only have terrestrial life as example so far, nor is there any absolute reason why possible alien life must conform to our biochemistry, some researchers have advocated broadening our horizons in the search for life elsewhere. Jones (2003), for example, states "Rather than making the exploration-restricting assumption that all life requires carbon, water and terrestrial biochemistry, we should make the exploration-friendly assumption that indigenous, environmentally adapted, alien life forms might flourish using unearthly biochemistry in many places in the Solar System."

There are several potential candidate worlds for alien biochemistry in the Solar System, notably the outer moons Callisto, Enceladus, Europa, Ganymede, and Titan, all of which are known as water worlds because they harbour subsurface oceans (Figure 9). Europa and Enceladus are particularly enticing targets since they are covered by relatively thin layers of surface ice. Moreover, organic molecules have been detected in the icy emission plumes of Enceladus. Other contenders include several more outer moons, minor planets, and Pluto. Among these worlds, Titan and Pluto are surely the most tantalizing candidates for unearthly biochemistry.

In many ways, Titan is the most Earth-like body in our Solar System, if we swap methane chemistry for water chemistry (Impey 2011) (Figure 10). Saturn's largest moon has a thick atmosphere rich in carbon compounds and is chemically very active. However, due to its distance from the Sun, Titan is much colder than Earth with surface temperature around 94 K (–179 ˚C, or –290 ˚F). In addition to being covered with lakes of liquid methane and ethane, Titan is likely to contain a subsurface of liquid water beneath a solid sheet of ice. Because of the extreme cold and lack of carbon dioxide (CO_2) in the atmosphere, scientists see Titan less as a habitat for extraterrestrial life, than a cauldron for pre-biotic chemistry similar to conditions that prevailed prior to the appearance of life on Earth (Life on Titan 2020; Trefil and Summers 2019). Nevertheless, scientists at the University of Hawaii have been funded by NASA to further investigate the habitability of Titan and biosignatures that might be detectable by future spacecraft (SOEST 2018) (Figure 11).

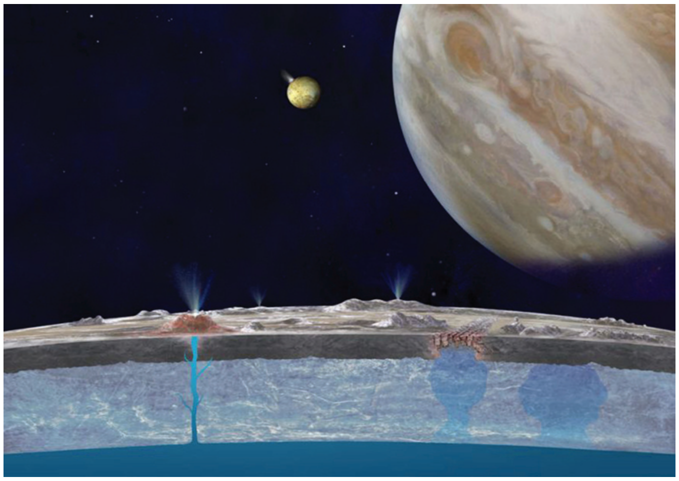


Figure 9 — Artist rendition of subsurface ocean on Jupiter's moon Europa (NASA)

Unlike Titan, Pluto does not have as thick an atmosphere, but its surface, interior, and chemistry are equally intriguing. For a full overview see Pluto (2019). Much to everyone's surprise, the *New Horizons* flyby in 2015 revealed this dwarf planet (about 1/6th the width of the Earth) to have a tenuous atmosphere of mostly nitrogen and traces of methane and CO_2, a surface with prominent ice mountains, valleys, plains, and craters, and temperatures in the range –375 to –400 ˚F (–226 to –240 ˚C). The most prominent plains appear to consist of frozen nitrogen gas and show structures suggesting convection (blobs of material circulating up and down). In short, rather than being a passive, totally frozen world, Pluto turns out to be a remarkably dynamic and geologically active planet (Figure 12).

The chemical richness of Pluto's atmosphere and surface have naturally prompted questions as to whether some form

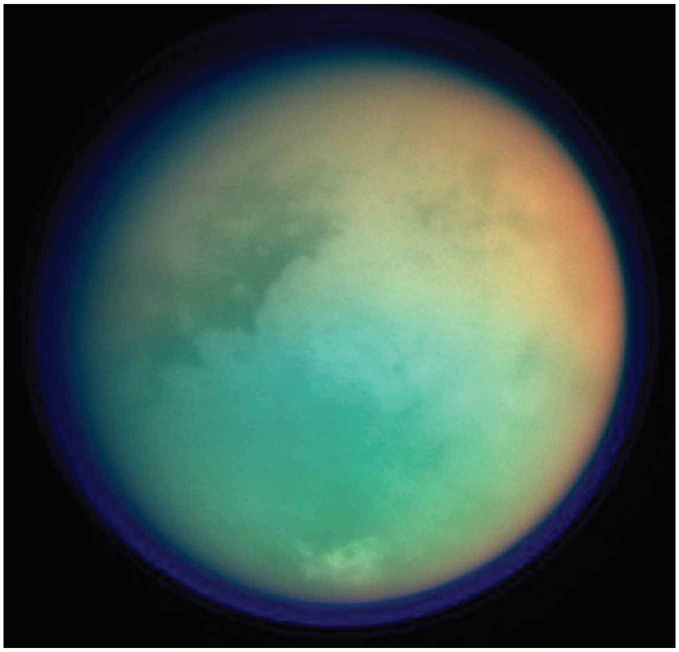


Figure 10 — Multi-spectral Cassini Mission *image of Saturn's largest moon Titan (NASA)*

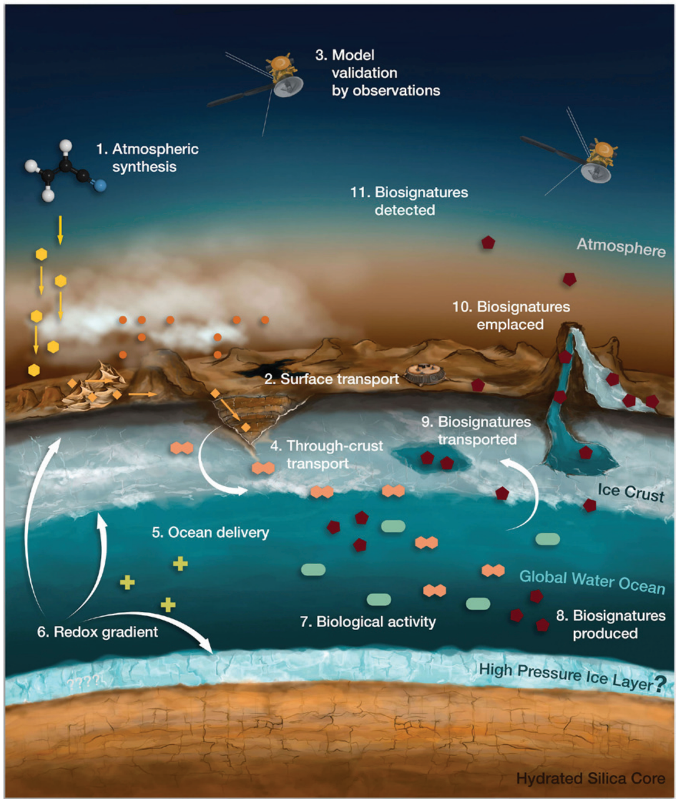


Figure 11 — Location of potential biosignatures on Titan. Credit: A. Karagiotas and T. Shalamberidze (NASA)

of prebiotic chemistry has or is occurring there, and what that might tell us about the formation of planetary bodies in the early Solar System and whether such carbon-based compounds were also provided to eventual life-bearing planets like Earth (Cruikshank et al. 2019). *New Horizons* has shown that Pluto's dark surface features, tinted yellow to red and dark brown, match those of laboratory-generated residues known as tholins, which consist of complex, macromolecular organic solids. Some of these residues likely formed in Pluto's atmosphere, while others appear near surface fractures possibly originating subsurface. Since there is also evidence of subsurface water on Pluto (Figure 13**),** that might be part of a cycling process for organic residues. That would be of prebiotic interest, since laboratory studies with purines and pyrimidines frozen in H_2O-NH_3 produced many of the bases involved in DNA and RNA molecules (Materese et al. 2017).

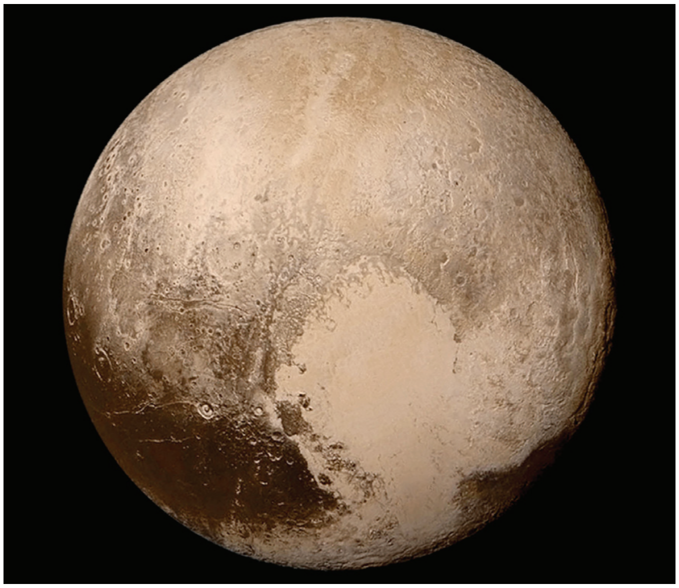


Figure 12 — New Horizons image of Pluto showing yellow-brownish surface features (NASA)

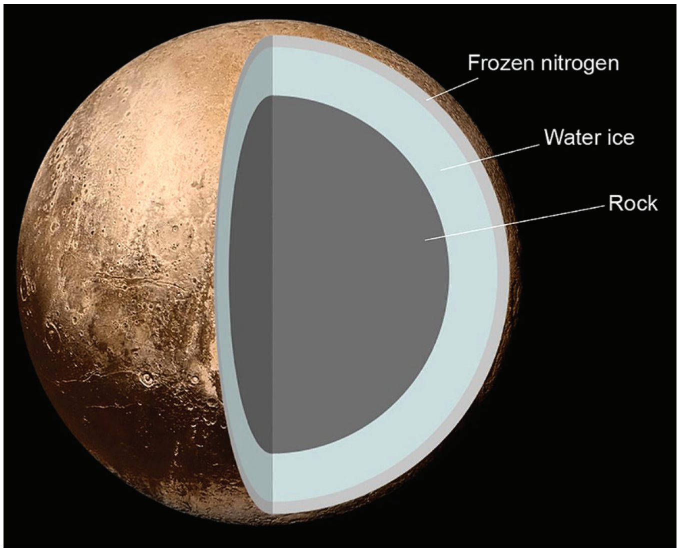


Figure 13 — Presumptive interior geology of Pluto (NASA)

SETI

Regardless of how and where life came about, much of the intellectual driving force behind our quest to seek it elsewhere is to find out if our planet is unique and whether or not we have company in the cosmos. In the words of Carl Sagan, "The Universe is a pretty big place. If it's just us, it seems like an awful waste of space." That certainly underlies much of the reasoning for SETI, the Search for Extraterrestrial Intelligence (www.seti.org), and raises the fundamental question as to whether intelligent life, and in particular CETI or Communication with Extraterrestrial Intelligence, is common or rare in the Universe. On that score, opinions vary considerably, see: Cordova, H. (2020). Some key considerations are the following:

Although Earth has hosted simple life for over 3.5 Gy, or as soon as it cooled enough, complex multi-cellular animals only appeared about 600 million years ago, mammals 200 million years, primates 55 million years, and we attained CETI status less than a century ago. So even if Earth is a Goldilocks planet for life, it's been a very long journey indeed to reach that stage.

Biological evolution is a complex, ever-changing and unpredictable process, driven by genetic variations, environmental factors, competition, and survival of the fittest at any given point in time. The question has often been asked as to whether there is any direction in this otherwise chaotic flow and whether, given enough time, higher intelligence is inevitable. (Bennet and Shostak 2017; Impey 2011; Will 2020). No one knows of course, but at least two possibilities have been suggested. One argues that since evolutionary direction seems so chancy, the advent of technological intelligence on Earth was an enormously improbable event. Alternately it can be argued that various evolutionary mechanisms have led to increases in intelligence for a wide range of animal species, including the use of simple technologies like rocks and sticks as tools. Consequently, higher intelligence and technology might be natural end points.

Many biologists are not optimistic about the inevitability of higher intelligence (Davies 2019) and see no directionality in the evolutionary process. However, it is also becoming clear that classical Darwinism is not the sole evolutionary driving force, and that additional factors may be at play. According to Davies there are "several mechanisms whereby characteristics acquired during the lifetime of an organism seem to be passed on to their offspring, a process known as epigenetic inheritance. This is in stark contrast to standard Darwinism, according to which mutations in offspring arise from purely random errors unconnected to the circumstances of the parent" and "If epigenetic inheritance plays a significant role in the evolution of brains, it is possible to imagine a sort of accelerating IQ phenomenon."

As has been pointed out (see below), our Solar System has some seemingly unusual attributes termed "Goldilocks," whereby the Earth has been in near-perfect position to harbour life for billions of years, long enough for CETI to evolve. However, judging by the exoplanetary systems discovered to date, ours seems rather unusual and perhaps unique (Ward and Brownlee 2004; Weiss 2018). That of course opens a floodgate of even more questions.

In 1961, when astronomer Frank Drake and other SETI pioneers devised this now famous equation $N = R_* f_p n_e f_l f_i f_c L$ designed to guestimate the number (N) of possible CETI civilizations in our galaxy, most key factors were largely unknown. For example, not a single exoplanet had actually been discovered nor was the average rate of star formation known. Today astronomers have a far better idea about that and other aspects relating to SETI. What still remains totally unknown, however, are the last three terms, namely f_i, f_c, and L, the fraction of planets developing intelligent life, the fraction of those that develop technology to releasing detectable signals, and the average life span of a CETI civilization, respectively (Oberhaus 2020).

Although estimates of those three terms of the Drake equation remain largely guesswork, Westby and Conselice (2020) have attempted to narrow the possibilities down using the latest astrophysical data. They begin with two hypotheses: One, termed "strong," assumes that an Earth-like planet (our only model so far) will produce CETI when it reaches between 4.5–5.5 Gy; the other, termed "weak," assumes that such a planet produces CETI after 5 Gy but not before. Since the average age of stars in our galaxy is around 10 Gy, this offers a larger pool of CETI that could still exist today (Oberhaus 2020). Based on the strong hypothesis, they estimate that there should be no less than 36 civilizations in our galaxy, and up to 3000 under the weak hypothesis. They go on to change assumptions and estimate how far from us any CETI might be. Ultimately much of that depends on final term "L" of the Drake equation or the average lifetime of an intelligent civilization. On that point, SETI pioneer and radio astronomer Alan Bridle opines "The main message from the Drake equation has always been that the biggest uncertainty is what we do not know about ourselves."

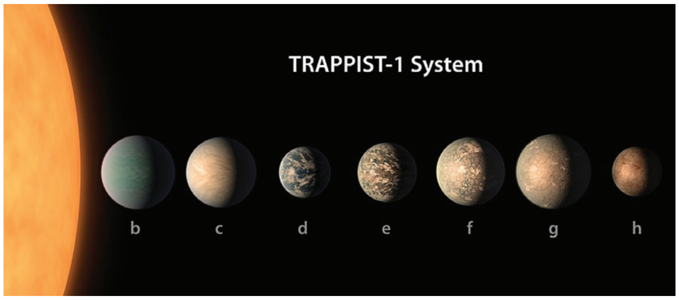


Figure 14 — Artist's rendition of the seven terrestrial-class planets in the TRAPPIST-1 system. Distances are not to scale. (NASA)

Is Earth Unique?

In their controversial 2004 book, *Rare Earth*, Ward and Brownlee argue that our Solar System, Sun, and Earth, comprise an unusual combination that allowed advanced life, including us, to evolve, but is probably exceedingly rare. They list a number of astronomical, biological, and geological reasons why this may be so and surmise that, while simple life forms may be quite common in the cosmos, complex, let alone CETI, life is not. At the time of *Rare Earth* publication, only 100 exoplanets had been discovered, whereas today well over 4000 are known with many more to come. How does that impact their conclusions, and does it change the picture significantly?

Simply put, the Rare Earth hypothesis goes something like this. The Earth has long resided in an ideal habitable zone, since it orbits a fairly stable star, and has a strong magnetic field to deflect solar wind and prevent stripping the ozone layer that protects life from deadly UV radiation. Earth also has a relatively large Moon compared to other planets, which helps minimize axial wobbling. It also has large oceans and land masses and is subject to active tectonics, which churn its surface and stimulate evolution. Yet, despite this apparent near-ideal situation, humans entered the scene just a few million years ago and reached CETI status only recently. In sum, the case is made that a combination of all these favourable factors on a single planet is so unlikely that the Earth and, by inference, we, may well be unique.

Is there any support, direct or indirect, for this hypothesis today in the wake of many more exoplanetary systems detected by the *Kepler Mission*, *Spitzer Space Telescope*, and others? Equally germane, have any planetary systems been found similar to ours and do any hold potential Earth-like planets? The answers so far are still equivocal. One of the most exciting discoveries is the TRAPPIST-1 system (Transiting Planets and Planetesimals Small Telescope) (TRAPPIST-1 2020). About 40 ly from us, the host star is known as an ultra-cool red dwarf, somewhat greater in diameter than Jupiter and has 7 terrestrial-class planets (Figure 14). Though Earth-size, these planets are probably tidally locked and subject to high levels of UV radiation and tidal heating, which would make the development of life there difficult. Still, given the likelihood of water on at least three of these worlds, the possibility of life there cannot be ruled out (Trefil and Summers 2019).

Even if biosignatures are eventually detected in the TRAPPIST-1 system, like many of the 400 multi-planet systems discovered so far, it bears little resemblance to the Solar System. For example, a recent analysis (Weiss 2018) shows that, unlike ours, planets in most of the other systems tend to be of similar size and mass (like peas in a pod) and have regular orbital spacings. Some of our planets also exhibit regular spacing except for Uranus and Neptune, but are definitely not similar in size. While reasons for this are unclear, and the Solar System does not conform to most others so far discovered, does that imply we are unique? The answer is clearly no, for a number of reasons.

First and foremost, of the estimated 200–300 billion stars in the Milky Way, we have studied but a fraction for planetary systems and are unlikely to ever get a truly representative sample size. Second, from all we have learned of the natural world, flukes or "one-of-a-kind" are not the norm, nor do they survive for millions of years. Third, the evolutionary process tends to replay similar themes once it chances upon a successful attribute, for example the molluscan and vertebrate eyes, wings among insects, birds, and mammals, parallel evolution of marsupial and placental mammals, etc. These are due to parallel, convergent, or homologous adaptations to different and ever-changing environments and ecosystems. Might the evolution of larger brains and increasing intelligence over time have similar adaptive value?

In sum, as pointed out by Chris Impey (Impey 2011), the Rare Earth hypothesis is logically flawed because it is circular. "Many of the attributes of our planet's atmosphere and geology that make it noteworthy arose *because* there is life here," and "Evolution might proceed quite differently on Earth's distant cousins." As example, we only have to look at the Earth before and after the Cretaceous-Tertiary event of 66 million years ago, which wiped out over 75 percent of all species on Earth including famously the dinosaurs (Cretaceous-Paleogene 2020). Due to a combination of factors, asteroid impact, massive vulcanism, and the resultant global climate change, the course of evolution was drastically altered and, among other things, led to the dominant emergence of mammals, including us.

Figure15 — "Dinosauroid" Sculpture by D. Russell and R. Seguin, 1982 Canadian Museum of Nature

Had that not happened, would we be here? We'll never know of course, but could advanced intelligence have arisen anyway via a reptilian route? Famed paleontologist Dale Russell suggested it might have along the *Troodontid* line of dinosaurs. He even provided a model of a hypothetical "Dinosauroid" as to what could have emerged (Figure 15). So, in spite of many unknowns, including alien life forms that might exist under strikingly different planetary conditions (Trefil and Summers 2019), we have really only scratched the proverbial surface in these regards. That is likely to change considerably in the near future, however, with no less than three missions to Mars in 2020 (see Space.com (2020). These include NASA's *Perseverance Rover*, which will hunt for signs of ancient life on the Red Planet and collect soil samples for future return to Earth. The United Emirates' *Hope Mars Mission* will orbit the planet to study its atmosphere, weather, and climate. Lastly, China's ambitious *Tianwen-1* mission includes both orbiter and lander, with ground-penetrating radar that could detect subsurface water. So, perhaps for the first time in human history, we seem actually on the cusp of finding out whether life is universal and whether or not we are alone. ✶

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Starlab and the Beginnings of Space Astronomy in Canada

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Abstract

As the field of space-based astronomy opened up in the 1970s, Canadian astronomers began to think about how they could use these new tools to advance their research. While discussions were stimulated when work began on the *Hubble Space Telescope*, a proposal was made in the late 1970s to orbit an ultraviolet survey telescope, the *Canadian Space Telescope.* The CST was put aside starting in 1980 in favour of a proposal for Canadians to join U.S. and Australian astronomers in placing a similar instrument along with a spectrograph on board *Starlab*, which would fly in the Space Shuttle payload bay and later on a space platform that would be deployed and retrieved by the Shuttle. The *Starlab* project came to an end in 1984 without ever leaving the drawing board when Canada withdrew. This paper examines Canada's early work in space astronomy and the problems all three partners in *Starlab* faced in their attempt to bring the concept to fruition.

Background

Today, telescopes and other astronomical instruments based in space make crucial contributions to our knowledge of the Universe, complementing the work done by instruments based on the ground. Ultraviolet, infrared, X-ray, and gamma-ray observations must be made using space-based instruments because the Earth's atmosphere blocks most wavelengths of light. This article traces the first steps made by Canadian astronomers in this field, notably two proposed space observatories that never made it off the drawing board, the *Canadian Space Telescope* in the late 1970s and *Starlab* in the early 1980s.

Space-based astronomy began shortly after the end of World War II when U.S. scientists first conducted astronomical observations using equipment mounted atop V-2 rockets and began to think about putting telescopes into space. For many years, astronomical observations have been made using sounding rockets on short flights to the fringes of the atmosphere and balloons that fly at high altitudes for hours or days. Soon after the first artificial satellite was launched in 1957, the U.S. and the Soviet Union launched the first probes to the Moon before going on to start exploring the Solar System. U.S. and European scientists began launching small space telescopes operating in various wavelengths in the 1960s. Eight orbiting solar observatories were launched from 1962 to 1975. The first U.S. *Orbiting Astronomical Observatory* (OAO) failed shortly after its launch in 1966, but the second and fourth OAO satellites, launched in 1968 and 1972, were successful. In 1972, the first European space telescope, *TD-1*, carried out an ultraviolet, X-ray and gamma-ray sky survey, followed three years later by *Cos-B*'s work in gamma-ray wavelengths. Similar small space telescopes soon followed.[1]

In 1972, the National Aeronautics and Space Administration (NASA) in the United States began building the Space Shuttle, which could carry astronauts into low Earth orbit, launch other spacecraft, or conduct scientific missions using large instruments mounted inside its payload bay. Soon NASA agreed with the European Space Agency (ESA) to build the *Spacelab* laboratory to fly in the Shuttle's payload bay. Also in the 1970s, American astronomers lobbied to build what became the *Hubble Space Telescope* (HST), which formally began as a NASA program in 1977[2]. The ESA partnered with NASA on HST and other spacecraft, and also supported its own space astronomy program. NASA launched its first of a series of *High Energy Astronomy Obervatory* (HEAO) spacecraft in 1977, and 1978 NASA and ESA launched the *International Utraviolet Explorer* (IUE) satellite.

Canada's space program had its roots in defence research focusing on the upper atmosphere because of its importance to radio communications. Canada's first satellites, *Alouette* and *ISIS*, explored the ionosphere in the 1960s and the early1970s. Government oversight of Canadian space exploration programs was spread amongst various departments and agencies, including the National Research Council of Canada (NRC), until the Canadian Space Agency began operations in 1989[3]. In 1974, the Ministry of State for Science and Technology issued the Canadian Policy for Space, which followed on previous directions by specifying that Canada's space program should emphasize space applications such as communications and remote sensing at the expense of science. The policy also called for policies that encouraged the creation of satellites and space systems by Canadian industry.

At the time that policy was issued, the Canadian government made its first move toward participation in human spaceflight when the NRC opened talks with NASA about building the remote manipulator system for the Space Shuttle, and the talks led to a formal agreement in 1975 that led to Canadian industry building what became known as the Canadarm. NASA issued its first invitation to the Canadian government to fly astronauts on the shuttle in 1979, but the invitation was not taken up until 1983[4].

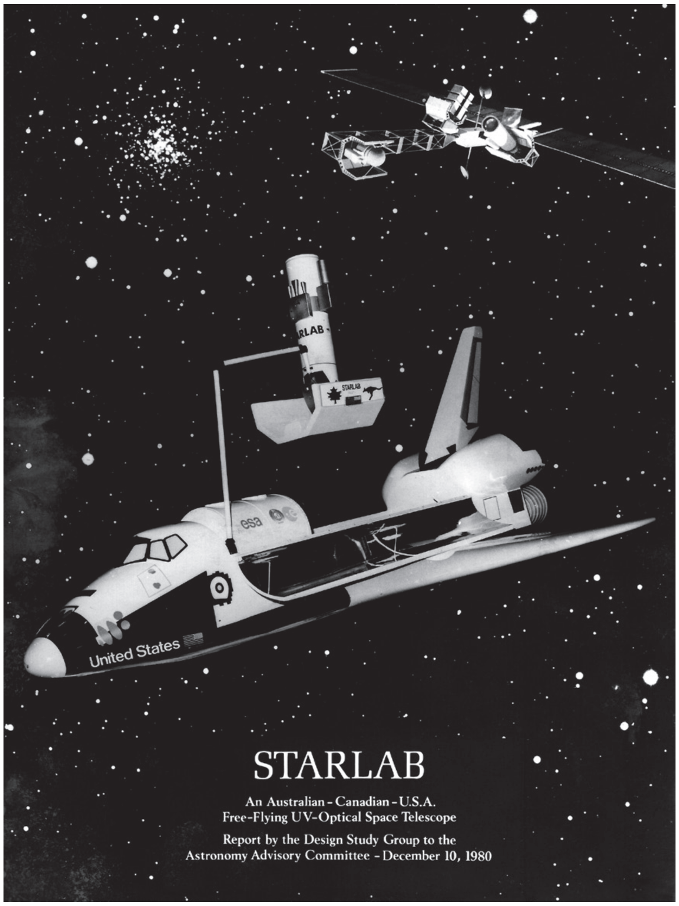
Astronomy programs sponsored by the Canadian government making use of radio astronomy and optical astronomy instruments around Canada and beyond were spread amongst various government departments until 1970, when they were consolidated under the NRC, which is where these programs have remained to the present day. The Canadian government first took notice of space-based astronomy in April 1974 when the NRC Associate Committee on Astronomy issued a report, *The Future of Ground and Space Based Astronomy in Canada.* The report predicted that a Canadian space astronomy program would pay off in terms of international recognition of Canadian science, the creation of more trained engineers, scientists, and technicians, and the stimulation of industrial activity. In common with previous studies of Canadian space efforts, the report pressed strongly for the creation of a Canadian space agency to co-ordinate space research. The report argued that the existing department-based setup for Canadian space research meant policymakers neglected basic research such as that done by astronomers. The associate committee suggested that sounding rockets, aircraft, and balloons with scientific payloads should continue, augmented by "small Canadian scientific satellites from the Chuchill Rocket Range with *Scout* rockets." But its strongest recommendation involved the Space Shuttle, which it argued would "revolutionize space astronomy." The report said, "A long term goal for Canada should be the participation in the U.S. Space Shuttle programme, possibly with a Canadian-built shuttle laboratory for scientific experimentation in space." [5]

When an ad hoc committee on Canadian scientific participation in the Space Shuttle reported to the NRC three years later in 1977, it noted that many Canadian scientists were involved in the work of what became HST, and a small number in science being planned for the ESA's *Spacelab* modules on board the Shuttle. A working group on space astronomy involved in that process stated that Canadians had not taken an active part in space astronomy due to a lack of funding and coordination. But a survey of Canadian astronomers showed strong interest in gaining access to facilities based aboard satellites and the Shuttle. Interestingly, given the difficult history of HST's main mirror that then still lay in the future, the working group suggested that "Canada might provide the primary mirror for the Telescope," an idea that wasn't pursued[6]. Although Canada did not become a formal partner in HST, it caused Canadian astronomers to think seriously about space astronomy and their role in it. As James Hesser, an astronomer at the Dominion Astrophysical Observatory (DAO), put it in 1983, "many people have been wondering how Canadian astronomers will continue to compete effectively in forefront research in the [H]ST era without having guaranteed access to an orbiting telescope."[7]

Canadian Space Telescope

In the fall of 1977, Bruce Campbell and Gordon Walker of the University of B.C. Geophysics and Astronomy Department began work on a feasibility study for a *Canadian Space Telescope* (CST). Walker said the concept was inspired by the success of the first look at the sky in X-ray wavelengths by the *Uhuru* satellite launched in 1970. He recalled that, "the prediction was in the X-ray region there would be very little, and yet Sco X-1 and all these other remarkable sources popped up." By launching a satellite to survey the sky in ultraviolet wavelengths, Walker and Campbell hoped to make groundbreaking discoveries similar to those the X-ray astronomers were making. In December, the proposal appeared in *Cassiopeia*, the newsletter of the Canadian Astronomical Society/Société Canadienne d'Astronomie (CASCA). There, Campbell and Walker proposed "orbiting a small-aperture, wide-field telescope for ultraviolet and visible astronomy" for "intermediate resolution mapping and photometry," and sought responses from interested astronomers. This telescope would have a field of view between 0.5 and 2 degrees, much wider than HST's narrow field of view, and would seek to delineate the "faint outer regions of galaxies," seach for distant galactic clusters, and see "a cosmological far ultraviolet background." Like HST, this 20- to 100-cm aperture $f/2$ telescope would utilize then-new charge coupled devices (CCDs) to gather light.[8]

By April 1978, Campbell and Walker had developed a 17-page proposal for the CST, which would be equipped with a one-metre off-axis Schmidt reflecting telescope using two CCD cameras, one for wide-angle imagery and another for higher resolution imagery. The optics for the CST could be produced by the optical shop at the DAO near Victoria, with the CCD arrays being produced by Bell Northern Research of Ottawa, which became one of Canada's top high technology companies in the latter part of the 20th century. The telescope could be attached to a "space bus" either built in Canada by one of the growing Canadian space firms of the time such as Spar Aerospace, or a Multimission Modular Spacecraft then under development at NASA's Goddard Space Flight Center. The two UBC astronomers proposed that the CST be launched and deployed by the Space Shuttle into a "high altitude orbit," possibly as high as geosynchronous orbit, to permit uninterupted exposure times of several hours. Much of the proposal dealt with scientific objectives for the CST, many of them related to cosmology and refining the distances between galaxies, along with studies of distant galaxies and nearby planets in our Solar System. The proposal called for a preliminary design study, and urged that it take place as soon as possible. "If CST is not launched before the 1990s, advances in astronomy could substantially alter observational priorities."[9] The CST won "strong endorsement" from a working group of Canadian astronomers in February 1980, but the growing cost of the proposal, which was exceeding C$200 million, was seen as being beyond the level of funding available from Canadian sources.[10]



STARLAB

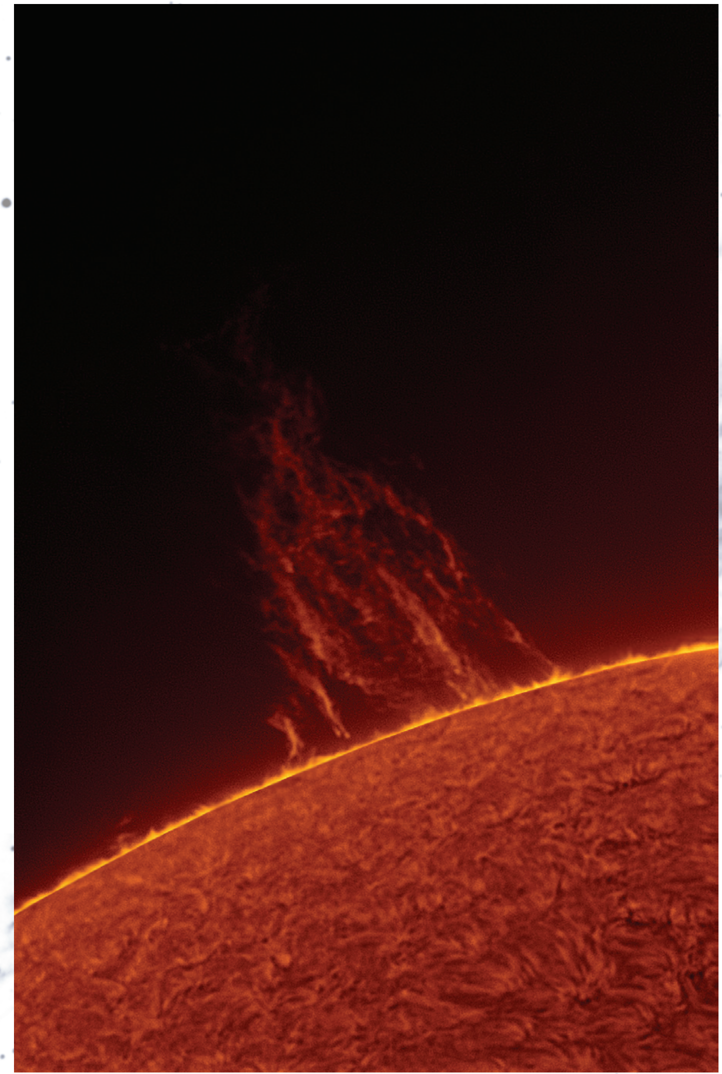
An Australian - Canadian - U.S.A.
Free-Flying UV-Optical Space Telescope

Report by the Design Study Group to the
Astronomy Advisory Committee - December 10, 1980

Figure 1 — This report cover shows two Starlab Concepts - one flying in the payload bay of the Space Shuttle and another as a free flyer deployed by the Space Shuttle. Courtesy Gordon Walker

Continued on page 270

Debra Ceravolo was able to capture a beautiful Perseid meteor streaking against the sky over Anarchist Mountain, southern B.C. She used a Canon 6D at ƒ/1.8 with 14-mm lens, 25-second exposure at ISO 800.



Our star hasn't been so active lately during solar minimum, though maximum (Solar Cycle 25) looks to have begun. Gary Palmer was able to catch this solar prominence on October 2 from his home in mid-Wales in the U.K. Gary used a StellaMira 85-mm ED2 Triplet Daystar Quark with an ASI 174M and a SharpCap.

Pen & Pixel

Ron Brecher imaged the dark nebulae Barnard 142 (top) and 143, together known as Barnard's E. Luminance was acquired using a Sky-Watcher Esprit 150 ƒ/7 refractor and QHY 16200-A camera with Optolong UV/IR filter on a Paramount MX (unguided) from his SkyShed in Guelph, Ontario. Chrominance was taken using a Takahashi FSQ-106 ED IV @ ƒ/3.6 and QHY367C one-shot colour camera with Optolong UV/IR filter. All pre-processing and processing was done in PixInsight. Luminance: 36 x 5m for a total of three hours. Chrominance: 20 x 3m for a total of 1 hour.

Martin Gisborne captured our lovely companion using a Nikon D850 DSLR connected to a William Optics Zenithstar 80 II ED apochromatic refractor with an Orion 2x Shorty Plus Barlow. This is a single image from a burst of 14 raw frames taken at ISO 400 at 1/80th-second exposure. The telescope was mounted on a Stellarvue M1 alt-az head on a Manfrotto 475 tripod.

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Starlab Background

When NASA was first advancing the idea of a Space Shuttle in 1969 following the triumph of the early Apollo lunar missions, it saw the Shuttle as a means of delivering astronauts and payloads between the Earth and crewed space stations in orbit. The administration of President Richard Nixon sought to cut space spending at a time when costs associated with the Vietnam War and growing domestic programs were putting pressure on the budget of the U.S. government. Although it gave the green light for the shuttle in 1972, the Nixon administration turned down the idea of a permanent Space Station. During the 1970s when the Space Shuttle was being developed and built, many ideas and concepts were advanced to extend the Shuttle's reach beyond low Earth orbit, where it was to operate.

The ESA *Spacelab* program, which included pressurized laboratories and pallets that would carry equipment exposed to space, all within the Shuttle payload bay, was a means of extending the abilities of the Shuttle in the absence of a Space Station. Various NASA centres and private aerospace contractors sought to keep the idea of a crewed Space Station alive in the 1970s and early 1980s by proposing vehicles and platforms that could carry instruments and astronauts that could be deployed for lengthy missions and later picked up by Shuttle craft. One of them was Marshall Space Flight Center's Science and Applications Space Platform (SASP), which also was known as the space platform and the power module.[11]

NASA scientists and engineers began in 1974 to work on a program called *Starlab*, which proposed placing a one-metre telescope mounted on a pair of *Spacelab* pallets in the Shuttle payload bay during multiple Shuttle missions of up to a month in duration. *Starlab* was planned to be a one-metre aperture $f/15$ telescope facility operating in visible and ultraviolet wavelengths with a field of view 100 times greater than the Wide Field Camera on HST, and capable of accomodating a variety of instruments supplied by investigators. Images and data would be recorded on photographic film or digital detectors. With its wide-field and survey capabilities, it was seen as an essential means of complementing HST. By the beginning of 1979, NASA had completed a Phase A feasibility study, and Phase B system and subsystem design studies were well under way. A competition to build the telescope facility was planned to be run through NASA's Goddard Space Flight Center, but NASA's plans in early 1979 did not specifically include international participation. Consideration was also being given to flying *Starlab* on a space platform such as SASP. Scientists saw potential in using the space platform, many of them preferring its use without astronauts, whose movements in a spacecraft could smear images and whose life-support systems could contaminate astronomical instruments.[12]

In 1980, astronomers from Canada and Australia began conversations with their American colleagues about *Starlab*. Australian astronomy, with its location in the Southern Hemisphere, was already well established with major facilities for optical and radio astronomy. Up to that time, Australia had only launched one satellite, *WRESAT*, from Australia atop a surplus U.S. Redstone rocket in 1967. Like Canada, the Australian government resisted calls to create its own space agency. Australian astronomers had started in space astronomy in the 1960s with X-ray instruments on sounding rockets and balloons, and in the 1970s began to think about using telescopes in orbit. Astronomers at the Australian National University's (ANU) Mount Stromlo Observatory headed by its director, Don Mathewson, had been developing photon-counting detectors, which were among several kinds of electronic detectors coming into use in telescopes alongside CCDs at the time to replace photographic film.[13]

It is important to note that the field of electronic detectors for space telescopes was still in its early days in the 1980s, even in the United States, and this posed a challenge to scientists and engineers in all three countries participating in *Starlab*. HST, the most ambitious space telescope that was being built in that era, had to overcome many managerial, technical, and financial challenges before it was launched years behind schedule, and one of them involved detectors, especially for its first-generation instruments that were on board when it was launched in 1990. In looking back at *Starlab*, Hesser noted that despite the presence of knowledgeable physicists and experienced space contractors from Canada taking part in *Starlab*, officials at the NRC "harboured some justified skepticism about" their ability to carry off their ambitious plans for *Starlab*.[14]

The *Starlab* Program

By June 1980, representatives from Canada and Australia took part in a *Starlab* Facility Definition Team Meeting at Goddard. That meeting followed delays to the Shuttle program and NASA budget changes that caused *Starlab* to change from a NASA project to one supported by NASA and international partners. At the time, there was hope that *Starlab* could fly up to three times each year for a decade or more under the highly ambitious Shuttle launch schedule NASA had projected at the time. Canada's interest in *Starlab* was demonstrated by the presence of four Canadians at the meeting, including Gordon Walker and James Hesser, along with Gerry Atkinson of the NRC. Walker told the meeting that the CST concept was effectively finished due to a lack of funding support, and noted that Canadian participation in *Starlab* would require "major industrial involvement," a fact underlined by the participation of the fourth Canadian, engineer Lloyd Secord, whose firm DSMA Atcon Ltd. was also helping develop the Shuttle robotic arm[15]. Australian representatives came to the meeting armed with information about Mount Stromlo's highly advanced Large Format Photon Counting Detector. Excited by the great potential this detector offered the instruments planned for *Starlab*, ANU convened the Australian Space Industry Symposium that year to measure industrial interest in participating in *Starlab*. More than 100 firms expressed interest, and 15 invested in research and development related to the space observatory worth the equivalent of A$1 million.[16]

While Canadian astronomers showed "great enthusiasm" for *Starlab* in a survey that year, clouds were already gathering around the concept. Some astronomers felt that the projected mission lengths, by then shortened to between a week and a fortnight, "bordered on being insufficient to to justify the costs." And at a meeting of representatives from all three countries in September

Figure 2 — Photo of Starlab scientists in the Starlab Joint Science Working Group from the United States, Canada, and Australia meeting at Mount Stromlo Observatory in Australia in November 1983. Courtesy Gordon Walker and John Glaspey

at Goddard, previously quoted costs for *Starlab* were proving to be too low to meet requirements for high image quality. On a more positive note, that meeting was also told that NASA was evaluating Marshall's free-flying SASP for missions of up to six months in duration. The scientific priorities of Canadian astronomers included establishing the expansion rate of the Universe, surveys of galaxies with active nuclei and of the Universe in general, stellar astrophysics, and studies of galactic objects to complement observations made by radio telescopes.[17]

About 80 Canadian astronomers took part in workshops on *Starlab* late in the year at the DAO and the David Dunlap Observatory near Toronto under the auspices of the NRC's Canada Centre for Space Science (CCSS). The workshops showed that Canadians put higher emphasis on imagery for surveys over spectroscopy, which was a higher priority for Australian astronomers. Optical concepts for the telescope were shifting to discussion of off-axis designs instead of a Ritchey-Chrétien design.[18]

The first meeting of *Starlab*'s Joint Science Working Group (JSWG) brought together Canadian, Australian, and American scientists at ANU in Canberra in February 1981. The Space Shuttle program finally got off the ground later that year with its first two flights. The months that followed included a series of "ups and downs" for Canada's involvement in the program, starting with questions being raised about whether the CCSS could approve funding even for preliminary design studies. After astronomers appealed to NRC President Larkin Kerwin, and potential industrial partners in *Starlab* lobbied the Canadian government, the NRC agreed that Canada could take part in the initial exploratory studies for *Starlab*, "although it was emphasized that this approval convey[ed] no commitment to entering into the advanced design and construction stages."[19]

By the time 30 scientists and engineers gathered at the University of Victoria and UBC in February 1982 for the second JSWG meeting, discussions were turning to missions flying on space platforms. Participants at the meeting were told that payloads other than *Starlab* were being planned for the space platform that would put greater mass, power, communications, and pointing demands on the platform than *Starlab* would, an encouraging development for astronomers. NASA hoped that the space platform would make its first flight in 1988 and be available for *Starlab* flights starting around 1990. Another major topic at the meeting was detectors, including photon-counting arrays, and MAMA (multi-anode multichannel array) detectors, a type which was later used in HST instruments. Australian astronomers presented layout proposals for an instrument package, including an imager and a spectrograph, which was similar to an instrument that was put in orbit in 1978 on the *International Ultraviolet Explorer*. Walker noted that IUE's results were limited because of the challenges at the time involved in creating effective detectors for ultraviolet observations, and these difficulties also affected the development of detectors for *Starlab*.[20]

Australian astronomers reported that they were seeking A$3.25 million for a preliminary design study, while Canadian astronomers had access to C$200,000.00 in exploratory funds. Canadian supporters of *Starlab* always had to pay attention to the fact that building the Canadian Long Baseline Array (CLBA), a major radio telescope proposal, remained the top priority for Canadian astronomers at the time. At that juncture, Canadian astronomers involved with *Starlab* believed that NASA support for astrophysics at the time was growing, and support for the space platform was "assured."[21]

The Australian government's research budget brought down in 1982 put its major spending priority on a radio telescope program similar to Canada's CLBA covering the Southern Hemisphere of the sky. The Australian government turned down a request of A$28 million for *Starlab* but agreed to supply A$3.25 million for early studies to keep the program alive.[22] Donald C. Morton, a Canadian astronomer who was director at the Anglo-Australian Telescope in Australia at the time, found his Australian colleagues keen on *Starlab*. But Morton, who had previously worked in the U.S. on astronomy programs with sounding rockets and OAO-3, did not conceal his own view that "*Starlab* was much too ambitious for an initial space project."[23]

By the third JSWG meeting that September in Canberra, Roy VanKoughnett of NRC had been named Project Manager and Walker as Project Scientist for *Starlab* and chair of JSWG in place of American experts. NASA proposed at the meeting that the first one or two flights of *Starlab* take place in the payload bay of the Shuttle, prior to flights on the space platform.[24] *Starlab* was also gaining public profile in Canada with an article in the Toronto *Globe and Mail*.[25]

The following year, the three participating countries signed a Memorandum of Understanding covering *Starlab* that called for two "shakedown" missions in the Shuttle payload bay, followed by two six-month missions on the space platform at the end of the decade. The memorandum did not oblige the three countries to proceed with *Starlab*. Canada soon needed to decide whether to spend C$4 million on design studies, leading to C$50 million in costs to Canada for the first missions. *Starlab* supporters hoped to win funding for the project by arguing that it was a space science project, while the higher priority CLBA was an astronomy project. At that point, Canada had responsibility for building the *Starlab* telescope with optics to be developed at DAO, along with integration of the telescope with the instrument package that would be built in Australia. NASA would supply the ride aboard the Shuttle and the Space Platform. Canadian astronomers remained more interested in imaging work with *Starlab* and considered the spectrograph, which was favoured by the Australians, to be "somewhat controversial." The photon-counting arrays from Mount Stromlo remained the leading contender for both imaging and spectroscopy instruments. At that point, it appeared that *Starlab* would not be built with a capability for Solar System astronomy unless it could be done without increasing the cost of the telescope.[26]

The Space Station

When Ronald Reagan became President of the United States in 1981, he was not committed to a Space Station, especially with the major economic challenges his administration faced in its first two years. But his first NASA administrator, James Beggs, put together a team at NASA Headquarters that aimed to win the President's support for the station. A 1982 NASA Headquarters study of approaches to the Space Station resulted in decisions that killed the evolutionary approach to a station embodied in Marshall's space platform concept, which was also supposed to carry *Starlab*.[27]

By the fall of 1982, planning for *Starlab* began to focus on the early missions due to fly in the Shuttle payload bay. Ed Weiler of NASA reported that the agency "cannot guarantee" that a space platorm would be ready for 1991, and spoke of a Space Station complemented by robotic experiment platforms. The following spring, plans called for the initial Shuttle missions for *Starlab* to be followed by longer missions "in association with a vehicle yet to be determined."[28]

At the fifth JSWG meeting in Canberra in November 1983, plans moved in another direction. *Starlab*'s Project Management Committee announced its decision that it had "dropped" plans to fly *Starlab* in the Shuttle payload bay. Since the Marshall SASP space platform was no longer under active development, project management hoped to fly *Starlab* for six-month missions on a Fairchild *Leasecraft*, a robotic space platform being developed by Fairchild Industries for various commercial applications, and "which is expected to be available in the mid to late 1980s if a NASA phase 2 contract is signed." In the meantime, the *Leasecraft* would be adopted "as a strawman for design and planning." The committee also announced that NASA would set up a data archive facility for *Starlab*. This meeting was also notable for the concerns expressed about the "slow pace" of work on a prototype detector for *Starlab* and on spending for detector development, and the recommendation from the JSWG that "the project be prepared to plan for two fallback options" if certain technical specifications for detectors could not be met.[29]

Beggs and his Space Station team worked through 1983 to win the President's approval for a Space Station. On 1984 January 25, Reagan announced in his State of the Union Address to the U.S. Congress that he was directing NASA "to develop a permanently manned Space Station and to do it within a decade." He gave few details but promised that NASA would be inviting other countries to participate in the program.[30] Seeing that the Canadian government would likely be involved in this Space Station program, the leading Canadian scientists involved in *Starlab* sent a telex to the government on February 23 appealing for *Starlab* to be part of Canada's space program alongside the recently announced Space Station. "We are convinced that not only would the quality of Canadian science benefit from *Starlab* but there would be an important expansion of Canadian space industry capabilities."

On March 19, Science Minister Donald Johnston announced a Space Plan that included $2.4 million for a study of Canadian participation in the Space Station, but no provision for *Starlab*. That same day, CCSS Director Ian McDiarmid told NASA and the Australian government that there would no money for *Starlab*, and therefore Canada's involvement in *Starlab* was effectively over. "So ends the dream of Canadian participation in a major astronomical observatory in space," Walker wrote the next day.[31] At a final meeting in December 1984 of the three participating countries in *Starlab*, McDiarmid was told that since no partner to replace Canada could be found, NASA and Australia decided to "shelve *STARLAB* indefinitely." Australian and U.S. astronomers looked at working with other partners on a UV telescope facility, including the ESA as part of its Columbus project. At the time, Columbus encompassed a laboratory attached to the U.S. Space Station and a free-flying platform similar to SASP, although in the end Columbus became a module attached to the *International Space Station*.[33]

After *Starlab*

In Australia, *Starlab* is remembered as something of a catalyst for the country's space industry. Many of the staff at Mount Stromlo left ANU and formed a space contractor, Auspace Pty Ltd. The new company and ANU worked on developing an instrument similar to that planned for *Starlab* for the NASA/ESA *Far Ultraviolet Spectroscopic Explorer* (FUSE) satellite, although in the end the Australian government chose not to participate in FUSE due to budget limitations. ANU and Auspace went on to build a small space telescope operating in the ultraviolet called *Endeavour*, which flew inside two Getaway Special canisters in the Shuttle's payload bay in the STS-42 mission in 1992 and the STS-67 mission in 1995. Auspace also built equipment for other space applications. Australian space historian Kerrie Dougherty wrote that the work on *Starlab* and the decision to establish a domestic Australian communications satellite system "encouraged a dramatic revival of Australian interest in space in the 1980s," but the interest did not result in lasting accomplishments.[34]

While NASA used the Space Shuttle to deploy three of the four Great Observatories—HST, the *Compton Gamma Ray Observa-*

tory and the *Chandra X-ray Telescope*—the Shuttle never deployed a space platform with large telescopes on board as contemplated for *Starlab*. A suite of ultraviolet space telescopes flew in the Shuttle payload bay on two missions in the 1990s. The *Astro Observatory*, which included the Hopkins Ultraviolet Telescope, the Ultraviolet Imaging Telescope, and the Wisconsin Utraviolet Photo-Polarimeter Experiment, flew on mission STS-35 on board *Columbia* in December1990 and STS-67 on *Endeavour* in March 1995. The telescopes were mounted on *Spacelab* pallets as planned for the first *Starlab* missions, and many of the American investigators involved in these flights had also been involved in *Starlab*. The nine-day flight of *Astro-1* was affected by problems pointing the instruments and failures of data display units, but the 16-day mission of *Astro-2* went in the books as a major success.[35] A space platform such as SASP, the Fairchild *Leasecraft*, or the Columbus *Free Flyer* was never built during the Shuttle era, although two satellites, both carrying materials-science payloads, were left in space by Shuttle craft and picked up on subsequent flights.[36]

By the time the *Hubble Space Telescope* was launched in 1990, NASA and the Space Telescope Science Institute (STScI) had established new policies making HST data more widely available than had been the case with previous space telescopes or with ground-based telescopes up to that time. While many data were considered proprietary for a year to observers who were granted time on HST, more HST data became available immediately upon transmission to Earth in the years after HST began operations, facilitated by the shift to digital storage of data and the rise of the internet in the 1990s. Moreover, the STScI and the ESA created easily accessible archives of HST and other data, inspiring the creation of other astronomical data archives. Experts at the Canadian Astronomy Data Centre at the DAO played an active part in helping NASA, ESA, and STScI archive data from HST. Astronomers from Canada and Australia quickly became active in seeking, receiving, and using observing time on HST and other NASA and ESA space telescopes, which allowed them to keep up with astronomers from the U.S. and elsewhere in this new field of astronomy without having their own space telescopes.[37]

Like their Australian counterparts, Canadian astronomers were interested in taking a direct role in FUSE, which was designed to make observations in ultraviolet wavelengths using high resolution spectroscopy. With strong support from Canadian astronomers, the Canadian Space Agency, which came into operation in 1989, arranged with Canadian contractors to build fine-guidance sensors for FUSE, which was launched in 1999 and operated until 2007. Hesser explained that Canada's involvement in FUSE, which was led by John Hutchings of the DAO, led to Canada contributing two instruments and a fine-guidance sensor to the *James Webb Space Telescope*, the successor telescope to HST, which is due to be launched in 2021. Canada has also been involved in the European Space Agency's *Herschel Space Observatory* and *Planck Space Observatory*, both of which operated from 2009 to 2013. Canadian astronomy instruments have also flown on Sweden's *Odin* satellite, which was launched in 2001, and India's ASTROSAT, which was launched in 2015.[38]

During the time of CST and *Starlab*, Canadian scientists interested in space astronomy in the NRC and CASCA formed a committee known today as the Joint Committee on Space Astronomy. The joint committee arose from the NRC Associate Committee on Astronomy of the 1970s and the committees and working groups in NRC and CASCA that were associated with it. According to Hesser, the joint committee helped establish the Canadian Astronomy Data Centre, and it helped allocate NRC funding that made possible technical advances in recording radio-astronomy observations and Canada's involvement in creating hardware for FUSE, JWST, and other space telescopes.[39]

A Canadian space telescope was launched from Russia on 2003 June 30, in the form of a 54-kg microsatellite called MOST, for *Microvariability and Oscillations of STars*. MOST, which cost less than C$10 million, won funding in 1998 under the CSA's Small Payloads Program. The idea originated with Slavek Rucinski, and carried to fruition by UBC astronomers, notably Jaymie Matthews, who became principal investigator, and Gordon Walker. Built by Dynacon Enterprises of Mississauga, MOST carried a 15-cm Maksutov telescope that monitored variations in light emitted by stars, and operated until 2019. In 2013, another Canadian space telescope, NEOSSAT, the *Near Earth Object Surveillance Satellite*, was launched from India with the mission of searching for asteroids that might pass near Earth, and for satellites and space debris in Earth orbit. Like MOST, NEOSSAT is a microsatellite with a 15-cm telescope on board.[40]

The idea behind the CST in the 1970s could be said to have gone full circle in the 21st century with the still-active proposal for the *Cosmological Advanced Survey Telescope for Optical and ultraviolet Research* (CASTOR). The concept for CASTOR, which for a time was called the *Canadian Space Telescope*, arose in 2006 and became part of CASCA's 2010 Long Range Plan before winning a study contract from CSA in 2011. CSA is still studying the concept of CASTOR, whose principal investigator is Patrick Côté of DAO. The concept behind CASTOR—conducting a survey with wide-angle images of the sky in ultraviolet using a one-metre telescope in cooperation with international partners—is similar to the ideas behind the original CST and *Starlab*. But with the benefit of roughly 40 years of technical advances and experience in space astronomy, CASTOR would be a much more capable facility than CST and *Starlab*.[41]

Conclusion

The demise of *Starlab* was laid at the door of NRC in Canada. According to Canadian historian Richard Jarrell, the project was cancelled by the Canadian government in 1984 due to a "lack of funds."[42] Hesser recalled later that NASA's cost estimates for *Starlab* were shown to be unrealistically low, and technology problems with the telescope's detectors were still open at that time.[43] Indeed, all three participating countries would have faced ballooning costs for *Starlab* had it continued. "As far as I was concerned, ultimately the project collapsed under its own weight." Walker said. "The addition of the spectrograph by the Australians greatly amplified the cost."[44]

Some of the assumptions behind U.S. involvement in *Starlab* were shown to be wanting during the early 1980s. When the Space Shuttle program began in 1972, NASA projected up to 60 flights a year with very short turnaround times between flights for each orbiter. As time went on, this projection fell, and in reality the year 1985 saw the highest number of Shuttle flights, only nine. The great cost and time involved in turning around Shuttles contributed to major increases in costs compared to the hopes of the 1970s. Mounting costs for the Shuttle and other programs, including HST, contributed to NASA's decision to vastly reduce its role in *Starlab* in 1980. Had *Starlab* continued beyond 1984, the loss of the *Challenger* shuttle in January 1986 would no doubt have added to the questions surrounding NASA's involvement in the program. Costs for space telescopes, including HST and the U.S. share of *Starlab*, increased greatly in the early 1980s, and HST had pride of place for funding at the time.[45]

This study suggests that all three partners in *Starlab* were moving toward cancellation. Morton recalled that the challenges facing the Australians building the detectors for the spectrograph appeared to require financial support from the Canadian side, which went against normal arrangements for international space projects, where each participating country covers its own costs.[46] The reluctance of the Australian government to fund space programs in the 1980s, at a time when a space industry in Australia was clearly making its presence known, strongly suggests that Australia would not have continued to support *Starlab* if Canada had continued in the project.

Looking back on his own experience with *Starlab*, Walker said the time he put on the proposal took away from other scientific work he could have done at the time. But he learned many things that helped him in his later career, notably when he began to work with MOST on stellar rotation.[47] At roughly the same time as *Starlab*, Walker and Campbell were also working on a promising technique that used the spectrum of hydrogen fluoride gas together with the spectrum of a star to precisely measure its doppler shift and hence its movement, a critical advance that led to early discoveries of planets orbiting other stars starting in the 1990s. This discovery helped enhance Walker's career even long after he retired from UBC. But Campbell left the field of astronomy in 1991, after years of effort to obtain a permanent job as an astronomer, and his public criticism of the level of government support for astronomy in Canada.[48]

While the Canadian government has supported many astronomy programs, including international projects like FUSE and JWST, funding levels for basic research and for space exploration in Canada are far lower than in the United States, even when adjusting for population. That message was driven home in the mid-1980s when the federal government declined to fund the CLBA, the highest priority project for Canadian astronomers in the early 1980s, and followed that up with a round of cutbacks at the NRC in 1986.[49] It could be argued that the success of Canadian astronomers in space astronomy has benefitted more from the generous funding levels afforded by NASA for HST and other space observatories than from funding from the Canadian government. Canadian astronomers were able to build on their work developing CST and *Starlab* to take part in international space telescope projects sponsored by NASA and ESA, and our own modest efforts like MOST. ✶

Endnotes

1 A general survey of the early years of space astronomy is contained in David Leverington, *New Cosmic Horizons: Space Astronomy from the V2 to the Hubble Space Telescope* (Cambridge: Cambridge University Press, 2000). The *Apollo 16* astronauts took a telescope to the Moon with them in 1972, and NASA's *Skylab* Space Station in 1973 and 1974 included a telescope that made extensive observations of the Sun.

2 For more on the development of the Shuttle program, see T.A. Heppenheimer, *The Space Shuttle Decision: NASA's Search for a Reusable Space Vehicle* (Washington, D.C.: NASA History Office, 1999). For more on the development of HST, see Robert W. Smith, *The Space Telescope: A study of NASA, science, technology and politics* (Cambridge: Cambridge University Press, 1993). The program was known as the *Space Telescope* from its inception in 1977 until 1983, when it was named in honour of American astronomer Edwin P. Hubble. In this paper it will be referred to by its post-1983 name.

3 For more on early Canadian space efforts, see Andrew Godefroy, *The Canadian Space Program: From Black Brant to the International Space Station* (Chichester UK: Springer Praxis, 2017).

4 Godefroy, *The Canadian Space Program*, pp. 118-120, 149, 156-157; W.M. (Mac) Evans, "The Canadian Space Programme – Past, Present, and Future - A history of the development of space policy in Canada," in B. Battrick & L. Conroy. eds., *Proceedings of the Concluding Workshop The Extended ESA History Project* (ESA SP-609). 13-14 April, 2005, ESA Headquarters, Paris, France., pp.133-150.

5 NRC Associate Committee on Astronomy, *The Future of Ground and Space Based Astronomy in Canada* (Ottawa 1974) pp. VII–5-VII–8. Quotations, p. VII–7. U.S. and Canadian sounding rockets had been launched from Churchill, Manitoba, starting at the time of the International Geophysical Year in 1957–58.

6 Working Group on Space Astronomy, *A Report Submitted to the Ad Hoc Committee on Canadian Scientific Experiments for the Space Shuttle/Spacelab Programme* (Ottawa, 1977) and the ad hoc committee's Report Submitted to the Space Science Coordination Office, NRC (Ottawa, 1977); and Jarrell, Richard A. *The Cold Light of Dawn: A History of Canadian Astronomy.* (Toronto: University of Toronto Press, 1988) pp.173–4. The mirror suggestion for HST is on page 6 of the working group report. For more on the spherical aberration that afflicted HST's main mirror, see Christopher Gainor, *Not Yet Imagined: A Study of Hubble Space Telescope Operations* (Washington, D.C.: National Aeronautics and Space Administration, 2020) pp. 26–32, 53–75.

7 James E. Hesser, "Starlab: An International Observatory in Earth Orbit," *JRASC, Vol. 77, No. 6* (December 1983), pp. 310–335. Hesser later served as director of the DAO from 1986 to 2014 and took a prominent role in many international astronomy programs.

8 "Report to the NRC Associate Committee on Astronaony for its 1977 November 18 Meeting from the Sub-Committee on Astronomy in Space," Annex F of "Minutes of the Fourteenth Meeting of the Associate Committee on Astronomy," Montreal, 1977 November 18, National Research Council of Canada; Gordon Walker, oral history interview by Chris Gainor, 2019 April 25; Bruce Campbell and Gordon Walker, "A Canadian Space Telescope Proposal," *Cassiopeia*, Canadian Astronomical Society (Winter Solstice 2017) No. 17, pp. 13–15.

9 Bruce Campbell and Gordon Walker, "A Proposal for A Canadian Space Telescope," 1978. NASA Goddard designed a Multimission Modular Spacecraft that could be used as the basis for satellites with various purposes, but it never left the drawing board. Geosynchronous orbits are roughly 36,000 km above the Earth.

10 The Canadian STARLAB Working Group, "STARLAB: An Initial Scientific Appraisal of the Proposed Canada/Australia/United States Space Telescope," prepared for The Canada Centre for Space Science, May 1981. The cost figures quoted in this article are in the money of the time and are not adjusted for inflation.

11 See Howard E. McCurdy, *The Space Station Decision: Incremental Politics and Technological Choice* (Baltimore: Johns Hopkins University Press) pp. 75–77; Theodore R. Simpson, *The Space Station: An Idea Whose Time Has Come* (New York: IEEE Press, 1985) p. 128; Andrew J. Dunar and Stephen P. Waring, *Power to Explore: A History of Marshall Space Flight Center 1960–1990* (Washington: NASA SP-4313) pp. 545–547.

12 NASA Goddard Space Flight Center, "Starlab UV-Optical Telescope Facility: A Summary Report," NASA GSFC, January 1979. See also Edward J. Weiler, oral history interview by Chris Gainor, 2020 August 19.

13 Kerrie Dougherty, *Australia in Space* (Hindmarsh, SA: ATF Press, 2017) pp. 116–121. Photon-counting detectors were coming into use in a number of observatories, including the ESA's Faint Object Camera on HST. The Australian Space Agency was finally formed in 2018.

14 James Hesser, note to author, 2020 July 26. The second- and third-generation instruments launched to HST starting in 1997 relied on much improved detectors. See Gainor, *Not Yet Imagined*.

15 "STARLAB – Facility Definition Team Meeting No. 17, 1980 June 5–6, Goddard Space Flight Center," record of meeting. The American contractor Ball Aerospace, which has built many robotic spacecraft and instruments for HST, was also involved in *Starlab*.

16 Dougherty, *Australia in Space*, pp. 121, 141.

17 Canadian STARLAB Working Group, "Initial Scientific Appraisal," May 1981. The working group was made up of James E. Hesser of the DAO (Chair), Gordon Walker of UBC, Bill Harris of McMaster, G.J. Michaud of the Université de Montréal, Gary Welch of St. Mary's University, and Gerry Atkinson of the Canada Centre for Space Science. David Crampton of the DAO soon joined the group.

18 J.E. Hesser, "Some Results of the 1980 Canadian Starlab Workshops," *Cassiopeia, Winter Solstice 1980*, No. 30, pp. 16–19.

19 "Starlab Status Report," *Cassiopeia*, Autumnal Equinox 1981, No. 32, pp. 4–7.

20 Walker, OHI with Gainor, 2019. MAMA detectors were used on the the Space Telescope Imaging Spectrograph (STIS) and the Advanced Camera for Surveys on HST.

21 "The Starlab Joint Science Working Group: Second Meeting, February 22-26, 1982," *Cassiopeia, Vernal Equinox 1982, No. 34*, 24–28. See also Christopher Aikman, David Crampton, James E. Hesser, "The Second STARLAB Joint Science Working Group Meeting," *JRASC, Vol. 76, No. 3* (June 1982), pp. 209–210.

22 Peter Hunt, "Few winners in Australian budget," *Nature*, Vol. 298 Issue 5877 (1982 August 26) pp. 781–782.

23 Donald C. Morton, email to author, "Re: Questions about Starlab," 2020 July 10; Walker, OHI with Gainor, 2019. Morton was director at the Anglo-Australian Telescope from 1976 to 1986, before returning to Canada.

24 Jim Hesser, "STARLAB Joint Science Working Group Meeting, Canberra, Australia, 20–24 September 1982," *Cassiopeia, Autunmal Equinox 1982*, No. 36, pp. 48–49.

25 Wallace Immen, "Canada considers building space telescope, helping to make space platform," *The Globe and Mail*, 1982 April 12, p. 11.

26 Chris Pritchet, "STARLAB Meeting – June 29, 1983," *Cassiopeia, Summer Solstice 1983*, No. 39, pp. 30–32. At that time, Walker was Project Scientist, VanKoughnett was Project Manager, Telescope Project Scientist was John Glaspey of the U de M, Telescope Project Manager was Tom Darlington of the CCSS, and Canadian members of the JSWG were Greg Fahlman of UBC, Glaspey, Hesser, and Stefan Mochnacki of the University of Toronto.

27 Dunar and Waring, *Power to Explore*, pp. 543–549; Hans Mark, *The Space Station: A Personal Journey* (Durham: Duke University Press, 1987) 136–140; McCurdy, *The Space Station Decision*, pp. 80–85.

28 NASA, Marshall L. McCall and Michael A. Dopita, "Minutes of the Third Meeting of the Starlab Joint Science Working Group," 1982 Sept. 20–24, Canberra; NASA Goddard, "Minutes of the Fourth Meeting of the Starlab Joint Science Working Group," 1983 April 25–29, Greenbelt, MD.

29 Gordon Walker and Marshall L. McCall, "Minutes of the Fifth Meeting of the Starlab Joint Science Working Group," 1983 November 14–18, Canberra (Draft 3) pp. 8, 15, 17, 22.; NASA Goddard Space Flight Center, "Starlab Ground System Guidelines Document: Final." January 1984, p. ii. The Fairchild *Leasecraft* never left the drawing board. For more on this space platform, see S. Neil Hosenball, "A Study of Factors Related to Commercial Space Platform Services," (Boulder: The University of Colorado Center for Space Law and Policy, August 1986).

30 See John M. Logsdon, *Ronald Reagan and the Space Frontier* (Palgrave Macmillan, 2019) pp. 145–167.

31 Gordon Walker, "Canada Withdraws From Starlab," *Cassiopeia, Vernal Equinox 1984*, No. 42, pp.11–12.

32 James E. Hesser, "Starlab News Flash," *Cassiopeia, Winter Solstice 1984,* No. 45, p. 49.

33 Ian R. Tuohy, "Starlab: An Ultraviolet/Optical Space Telescope," *Astrophysics and Space Science*, 188 (1986) pp. 71-77. For more on the early history of Columbus, see J. Krige, A. Russo, and L. Sebesta, *A History of the European Space Agency 1958–1987*, *Volume II, The story of ESA, 1973 to 1987* (European Space Agency, 2000) pp. 620–622, 633–638, 643–648.

34 Dougherty, *Australia in Space*, pp. 121–122, 141–142, 167. The first Australian communications satellites were built by Hughes in the U.S. with some Australian components.

35 NASA Press Kit, "Space Shuttle Mission STS-35" (Washington, D.C.: NASA Headquarters, December 1990); NASA Press Kit, "Space Shuttle Mission STS-67" (Washington, D.C.: NASA Headquarters, March 1995). See also William P. Blair, "Astro-2: A Shuttle Mission Made in Heaven," https://blair.pha.jhu.edu/astro2.html?fbclid=IwAR2BO6mlM8DJci0YXepCtk6TJMJ4erM3aWg3ArBAx-xL26VHLruq5UXAB48 Accessed 2020 May 29.

36 The Long Duration Exposure Facility was put in orbit in 1985 and retrieved by another shuttle in 1990. *The European Retrievable Carrier*, EURECA, was left in orbit in 1992 and retrieved the following year.

37 See Gainor, *Not Yet Imagined*, pp. 287–328 for a discussion of how HST has changed astronomy around the world. HST time allocation by country is listed on pp. 349–350.

38 Dr. James Hesser, oral history interview by Chris Gainor, June 6, 2005; Headlines @ Hopkins, "FUSE Moves Closer to Launch," 1998 August 28, http://pages.jh.edu/~news_info/news/home98/aug98/fuse.html Accessed 2020 July 7; Dougherty, *Australia in Space*, 142. Roberto Abraham, et al., Joint Committee on Space Astronomy, "Space Astronomy in Canada," White Paper, CASCA 2010 Long Range Plan. Hutchings led Canada's involvement in ASTROSAT, which centres on the *Ultraviolet Imaging Telescope* instrument.

39 Hesser, note to author, 2020 July 26.

40 Randy Attwood, "MOST: Canada's First Space Telescope, Part I." *JRASC, Vol. 96, No. 6* (December 2002), pp. 232–235; Randy Attwood, "MOST: Canada's First Space Telescope, Part 2." *JRASC, Vol. 7, No. 1* (February 1997) pp. 7–10; Barry Shanko, "The Humble Space Telescope," *Astronomy Now*, April 2005, pp. 11–12; Chris Gainor, "NEOSSat: The Micro-Surveillance Satellite," *Space Quarterly (Canadian edition)*, December 2011, pp. 14–15.

41 Chris Gainor, "CASTOR," *JRASC, Vol. 106, No. 3* (June 2012) pp. 117–8; Hesser note to author, 2020 July 26. See also www.castormission.org

42 Jarrell, *Cold Light of Dawn*, p. 174. Jarrell wrote that the Conservative government of Brian Mulroney cancelled *Starlab* in March 1984. The Liberal Party under Prime Minister Pierre Elliott Trudeau was still in office at that time, and the Mulroney government, which did not take office until the following September, cut back astronomy programs in 1985 and 1986. In his 2019 OHI interview with the author, Walker said *Starlab* was halted by NRC President Larkin Kerwin and was not considered at the ministerial level.

43 Hesser, OHI by Gainor, 2005.

44 Walker, OHI by Gainor, 2019.

45 T.R. Heppenheimer, *Development of the Space Shuttle 1972–1981*, *History of the Space Shuttle, Vol. 2* (Washington: Smithsonian Institution Press, 2010) pp. 383–387.

46 Morton, email to author.

47 Walker OHI by Gainor, 2019.

48 Jacob Berkowitz, "Lost world: How Canada missed its moment of glory," *The Globe and Mail*, 2009 September 25.

49 E.R. Seaquist, "Report of the CLBA Planning Committee," *Cassiopeia, Summer Solstice 1986, No. 51*, pp.11–12; Colin Scarfe, "Editorial," *Cassiopeia, Winter Solstice 1986, No. 53*, p. 2.

Astronomical Art & Artifact

Attracting Uncommon Notice: the Society's 1892 Report on Webb's *Celestial Objects for Common Telescopes*

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Abstract

Throughout the first century of the RASC's existence, the Rev'd Prebendary Webb's *Celestial Objects for Common Telescopes* was the dominant observing guide for amateurs in the English-speaking world. Of the various editions issued from 1859–1962, the last and its minor updates remained in print for twice as long as the currency of the previous editions combined. It was immensely influential, sympathetically reflecting, and moulding observing tastes. Prominent on the first page of the "Advertisement to the Fifth Edition" (reprinted in subsequent editions) was the thanks of the editor, the Rev'd T.H.E.C. Espin, to the Special Committee of the Astronomical and Physical Society of Toronto (=RASC) for their suggested improvements. The RASC was the only astronomical group singled out for such praise. More astronomers worldwide may have learned of the RASC through this means than any other in the days of the book's popularity. Rev'd Espin didn't specify the Society's suggestions, but fortunately the Committee's hitherto unpublished report survives, and its text is reproduced here, along with commentary.

Two clerical astronomers, and a very influential book

The Rev'd Thomas William Webb (1806–1885, Figure 1), the quintessential Victorian country vicar in his local context, was a revered figure in the English language orb of amateur astronomy (on Webb see the contributions in Robinson & Robinson 2006; Baum 2004). The son of a clergyman, he had read mathematics at Oxford before becoming ordained, a typical course of study (often combined with classics) for many Anglican clerics of the middle and upper classes. An active contributor to some of the best known British scientific periodicals catering to amateurs (he also published in the professional journals), Webb was a dedicated observer whose *Celestial Objects for Common Telescopes* was considered the standard guide to amateur observational astronomy for over a century (Lightman 2006, 217–218; Ranyard 1886, 200–201).

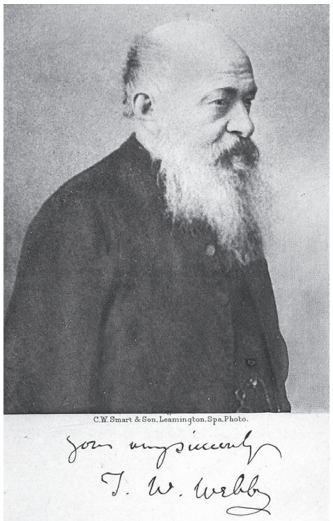


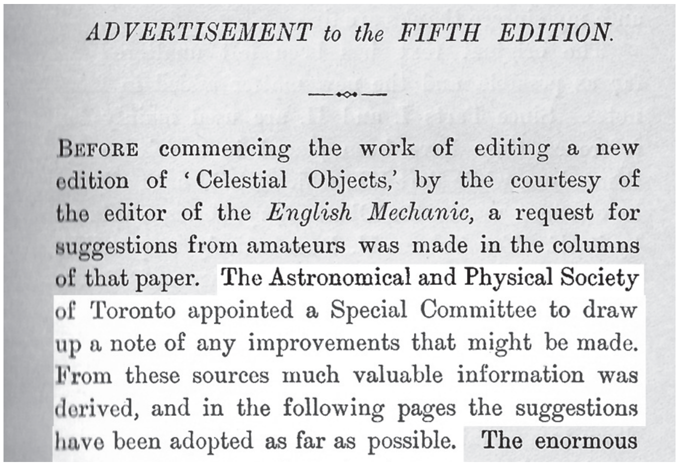
Figure 1 — The Rev'd Thomas William Webb (1806-1885), frontispiece to the fifth edition of his Celestial Objects for Common Telescopes *(1893). Reproduced courtesy of the Specula astronomica minima.*

It went through five, or by some counts seven editions (1859, 1868, 1873, 1881, 1893–1894; the editions of 1917, and 1962 largely repeated the matter of the fifth edition).[1] Webb's fame in astronomical circles was largely due to that book. Allan Chapman went so far as to attribute the present prevalent style of amateur astronomy to its influence: "Modern amateur astronomy, as a pursuit for serious observers whose principal motivation was pleasure, [or] fascination…as opposed to fundamental research, began in a Herefordshire vicarage in the 1850s" (Chapman 2017, 225).[2]

The single-volume compendium of the first edition was offered as a less challenging approach to observing than Admiral Smyth's larger *Cycle of Celestial Objects* of 1844 (Smyth 1844), which was meant for "first rate telescopes" (i.e. larger, more-capable instruments such as Smyth's own 6-inch O.G. class refractor; Webb 1859, viii). What was the "common telescope"? According to Webb in 1859, it was a refractor up to 3.75-inches in aperture, or a reflector "of somewhat larger diameter" (Webb 1859, 1–2, note). In the second edition this had become a refractor of 3 to 4 inches (1868, 1), and in the fourth edition one with an objective of 3 to 5 inches (1881, 1).

Webb's writing was clear, and included untranslated classical citations, as well as references to previous and contemporary observations, and theories on the nature of the phenomena. One of his obituarists referred to "the unpretending precision of...style" characterizing the work (Ranyard, 1886, 200; Lightman 2006, 224 emphasizes the simplicity of his language). For long stretches *Celestial Objects* doesn't read overly much like a text out of a bottle drawn from the sea across a chasm of cultural time, in contrast to the effect on modern readers of much discursive Victorian astronomical literature (e.g. by authors such as Sir John Herschel, or Agnes Mary Clerke). The feature that most reminds us we are encountering an episode of cultural astronomy different from our own is the references to concerns of natural theology, but they are relatively sparse in a text of over five hundred pages in the fifth edition (there are 13 instances: I: pp. v, viii, xvii, 18, 51, 86, 182, 198; II: 1, 5, 69, 170, 216).

The sections on Solar System objects are less concise and more narrative in nature than those dealing with stellar and deep-sky objects (double stars, nebulae, and clusters, presented



ADVERTISEMENT *to the* FIFTH EDITION.

BEFORE commencing the work of editing a new edition of 'Celestial Objects,' by the courtesy of the editor of the *English Mechanic*, a request for suggestions from amateurs was made in the columns of that paper. The Astronomical and Physical Society of Toronto appointed a Special Committee to draw up a note of any improvements that might be made. From these sources much valuable information was derived, and in the following pages the suggestions have been adopted as far as possible. The enormous

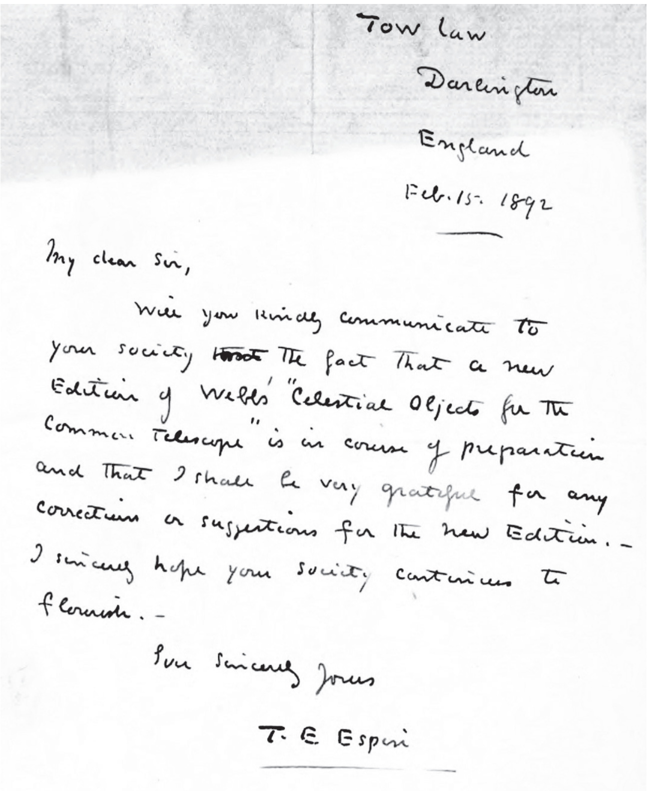
Figure 2 — "Advertisement to the Fifth Edition" of Celestial Objects for Common Telescopes *(1893, ix) prominently thanking the A&PST (RASC)–visual emphasis added. Reproduced courtesy of the Specula astronomica minima.*

under their respective constellations in alphabetical arrangement). And, for those interested, Graph 1 shows the proportion of Solar System to deep-sky matter by normalized page count in the various editions. No doubt expressing changes in amateurs' observing practices, in the first edition (1859) the proportion was 3:2 in favour of Solar System observation, but by the fifth edition (1893–1894, and its "successors") this had switched to 3:2 in favour of stellar and deep-sky targets.

In the 1870s, Webb called upon a much younger clerical colleague, the Rev'd Thomas Henry Espinal Compton Espin (1858–1934), the future Perpetual Curate of Tow Law, to assist him in gathering materials for a new edition of *Celestial Objects* (on Espin see Brown 1974; Tow Law Local History Group 1992; Williams 2014, 671–672). Espin was eventually named one of Webb's executors, and his chosen successor to edit the fifth edition of the book. Espin was among the most accomplished and productive observers of his day, with a very well-equipped observatory featuring large George Calver reflectors with primaries of 17.25 and 24 inches; his Wolsingham Observatory even boasted its own publication program (chiefly the *Wolsingham Observatory Circulars*). Webb chose wisely.

In the leading English language medium for the exchange of information (and sparring) between amateurs, *The English Mechanic & World of Science* (*EM&WS*), Espin placed the following notice:

> "Will you kindly allow me, through the medium of your columns, to say that a new edition of 'Celestial Objects for the Common Telescope' is in course of preparation, and that I shall welcome any suggestions and additions as far as space will allow. I am leaving home for some weeks, and may not be able to immediately acknowledge any communication sent to me. T.E. Espin. Tow Law, Darlington, Feb. 10" (Espin 1892).



Tow Law
Darlington
England
Feb. 15. 1892

My dear Sir,

Will you kindly communicate to your society ~~that~~ the fact that a new Edition of Webb's "Celestial Objects for the Common Telescope" is in course of preparation and that I shall be very grateful for any corrections or suggestions for the new Edition.— I sincerely hope your society continues to flourish.—

Yours Sincerely
T. E. Espin

Figure 3 — The Rev'd T.E. Espin's letter (1892 February 15) to the A&PST (RASC), requesting their suggestions for improving the next edition of Webb's Celestial Objects for Common Telescopes. *Reproduced courtesy of the RASC Archives.*

And it is at this point that the Astronomical and Physical Society of Toronto (A&PST, as the RASC was then called) enters the story.

In Espin's "Advertisement to the Fifth Edition" of *Celestial Objects* (Figure 2), he remarks that:

> "Before commencing the work of editing a new edition of 'Celestial Objects,' by the courtesy of the editor of the *English Mechanic*, a request for suggestions from amateurs was made in the columns of that paper. The Astronomical and Physical Society of Toronto appointed a Special Committee to draw up a note of any improvements that might be made. From these sources much valuable information was derived, and in the following pages the suggestions have been adopted as far as possible" (Webb 1893, ix).

The wording implies that it was Espin's call placed in the *EM&WS* that spurred the Toronto Society to strike a committee in response. Our Archives reveal that's not quite what happened. The A&PST (RASC) received a direct request from Espin, dated a few days after the appeal in the *EM&WS* (Figure 3). His letter reads:

> "TOW Law Darlington England Feb. 15. 1892
>
> My dear Sir, Will you kindly communicate to your society ~~that~~ the fact that a new Edition of Webb's 'Celestial

> Objects for the Common Telescope' in in course of preparation and that I shall be very grateful for any corrections or suggestions for the new Edition.–
>
> I sincerely hope your Society continues to flourish.–
>
> I am[?] Sincerely Yours
>
> T.E. Espin" (RASC Archives, 1890s Correspondence).

The request in the letter is essentially identical to that Espin placed in the *EM&WS*.

The A&PST (RASC) didn't wait long to act on Espin's invitation. A committee was struck for the purpose at a meeting of the Society on 1892 March 8:

> "In a communication the Rev. T. E. Espin, F.R.A.S., of Tow Law, England, announced the fact that a new edition of Webb's Celestial Objects for the Common Telescope was in course of preparation, and said he would be grateful for any corrections or suggestions that might be made. A Committee, composed of Messrs. A. Elvins, G. E. Lumsden, and A. F. Miller was appointed to take charge of the matter, it being thought that any assistance in the power of the Society, should be rendered" (A&PST 1893, 11).

It would be surprising if the A&PST (RASC) was the only group of amateurs to receive a letter of invitation to contribute suggestions, additions, and corrections for incorporation in the fifth edition of *Celestial Objects*. What is surprising is that Espin singled out the A&PST (RASC) for its contribution in the book, a recognition accorded to no other organized group of amateurs. Perhaps the A&PST (RASC) was the only amateur organization to reply, although in light of the commanding position of Webb's handbook among amateurs, it would be equally surprising if that were the case.

Espin expressed his gratitude to the A&PST (RASC) in a letter of 1893 January 6: "The suggestions of the Society in connection with the new Edition of C.O. [=*Celestial Objects*] have been helpful, & I hope to be able to adopt most of them" (RASC Archives, 1890s Correspondence).

The Report

The report itself is somewhat underwhelming. It is lacking in specificity and doesn't engage closely with the preceding fourth edition of the text. The suggestions are limited to generalities. The principal recommendations were two. In the first place, the A&PST's committee requested more on spectroscopy and celestial photography but kept consonant with the general tenor of the book, given the growing importance of these subjects in astronomy. Secondly, the Committee recommended adding a series of plates representing some noteworthy objects "as seen in common telescopes." Comparing the text of the fifth edition to that of the fourth, there is a barely discernible change amounting to much. There is a barely discernible increase in matter related to both spectroscopy and celestial photography, but hardly enough to guide a beginner on his or her first steps to using a basic star spectroscope, or simplest camera. And the suggestion for a modest selection of plates illustrating the appearance of celestial bodies as seen through "common telescopes" was not adopted. The A&PST's suggestions don't seem to have had much effect. What was there for which Espin owed them thanks?

It may be that the value Espin saw in the A&PST (RASC) report lay in its very generality, lack of specificity, and voice. In contrast to what the British Astronomical Association quickly became, a group dedicated to contributing high-quality data to astronomical science through skilled observing, the contemporary A&PST (RASC) was a group dedicated to becoming better informed about astronomy through stargazing, a more passive and less directed type of observation. If so, the voice of the A&PST (RASC) was representative of the numerous amateurs across the English-speaking world who doubtless constituted the bulk of the audience for *Celestial Objects*. The A&PST's few suggestions for the new edition, and the group's praise for the earlier editions of the book then counted for much.

Espin did the A&PST (RASC) a good turn, by dramatically increasing the international profile of the Canadian amateurs. He did this by mentioning the Society in a positive light in a prominent place in the most respected observing guide of the late Victorian and subsequent periods. More amateur astronomers worldwide may have learned of the RASC through this means than through any other in the days of the book's popularity. It seems the A&PST (RASC) was very gratified by this gift. At the fourth annual meeting of the Society on 1894 January 9:

> "Mr. Pursey laid on the table…a presentation and advance copy of the first volume of the new edition of Webb's 'Celestial Objects for Common Telescopes,' published by, and received from, Messrs. Longmans, Green & Co., of London. In addition to the compliment thus paid by the publishers, Rev. T. E. Espin, F.R.A.S., the editor of the new edition, in his preface, credited the Society with having suggested valuable features to be introduced into the book, which is invaluable to the amateur astronomer" (A&PST 1894, 144).

At that that same meeting the Rev'd Espin was elected a Corresponding Fellow (a form of honorary membership):

> "The Reverend T. E. Espin, F.R.A.S., of Tow Law, Darlington, a frequent correspondent, said, 'Your communication in which you inform me that The Astronomical and Physical Society of Toronto intend to do me the honour of making me a Corresponding Member, has just reached me. In accepting, may I ask you to convey to the members of the Society my sincere thanks and

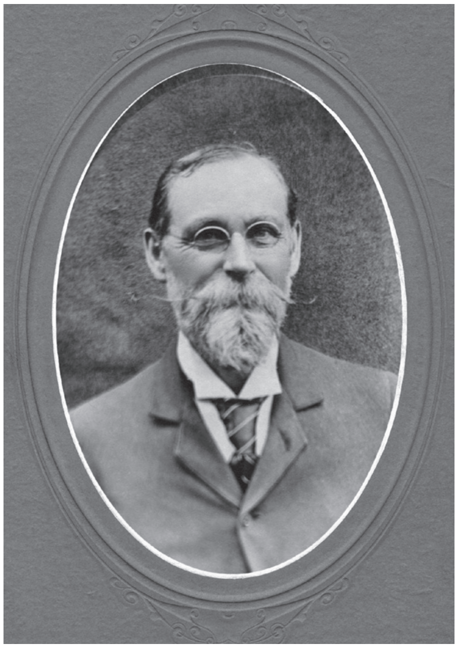
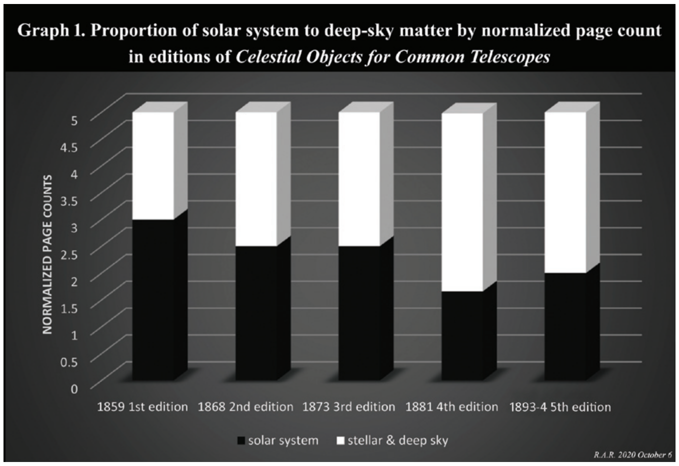


Figure 4 — Portrait (1901) of George E. Lumsden (1847–1903), leading A&PST (RASC) member, Corresponding Secretary, and Chair of the Society's Committee to suggest improvements to Celestial Objects for Common Telescopes. *Reproduced courtesy of the RASC Archives.*

wishes that what I shall soon hope to call *our* Society may be as flourishing in the future as in the past. I have watched with great interest its progress and the increasing value to Science of its publications'" (A&PST 1894, 142).

The Report of the Committee of the A&PST (RASC) is found below. The Chair of the Committee, George E. Lumsden (1847–1903), was an Assistant Provincial Secretary in the Ontario Civil Service (equivalent rank to a present Deputy Minister; Figure 4). At the time of the report on *Celestial Objects* he was the Society's Corresponding Secretary (1890–1899); he would serve as President of the Society (1900–1901) (Broughton 1994, 3).



Graph 1 — Proportion of Solar System to stellar & deep-sky matter by normalized page count in the editions of Webb's Celestial Objects for Common Telescopes *(1859–1894). The data for the fifth edition (1893–1894) is valid for the latter editions of 1917, and 1962. The changing proportion of Solar System to stellar & deep-sky content may reflect changes in the observational interests of amateurs. Copyright Specula astronomica minima.*

"WEBB'S CELESTIAL OBJECTS FOR COMMON TELESCOPES."

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To the President of the Astronomical and Physical Society of Toronto.

Your Committee to which was referred the Reverend Mr. Espin's letter inviting corrections and suggestions to be used in revising Webb's Celestial Objects for Common Telescopes, begs leave to report as follows:--

1) That while the last edition of the late Canon Webb's delightful and useful manual, in many respects, leaves but little to be desired, your Committee learns with pleasure of the intention of the publishers to reprint the book, as it will afford an opportunity to introduce matter which, in the opinion of your Committee, would enhance its practical value to the general student as well as to the amateur observer. Your Committee refers to the subjects of Spectroscopy and Celestial Photography, with respect to which, at least, an elementary knowledge is daily becoming more and more desirable and concerning which something in harmony with the general character of the book could be said without adding materially to its size or cost. Your Committee would suggest that a proposition to this effect be submitted for the consideration of the editor.

2) That your Committee would recommend that the attention of the editor be drawn to the advisability, on behalf of his readers, of inserting, on thin paper, a series of plates representing some noteworthy objects such as sunspots, planets, nebulae, and familiar double, triple, and multiple stars and stellar clusters, as seen in common telescopes.

3) That your Committee has been unable to obtain any corrections to be transmitted to Mr. Espin.

4) That your Committee considered various other matters of detail, such as including in the new edition a few charts of the more notable constellations; re-casting certain constellation lists in Webb so that they shall correspond more nearly with Proctor's Smaller Star Atlas, which is understood to be intended as a companion to The Celestial Objects; altering the shape of the book so as to make it longer and thinner; changing the form of certain contents of the book so as to provide more room without adding to its bulk, etc., but on these points your Committee felt a delicacy in volunteering its views, especially as it knew the best interests of amateurs could not be in better hands than those of Mr. Espin.[3]

All of which is respectfully submitted.

(Signed) G.E. Lumsden,
Chairman.

[Lumsden et al., 1892]

Acknowledgements

This research has made use of NASA's Astrophysics Data System. ✶

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Endnotes

1 Lightman 2006, 220–221, usefully provides print runs and sales for the first five editions, drawn from the *Archives of the House of Longman, 1794–1914* (1978).

2 Chapman's full quote includes "the Glory of God" as one of the principal motivations for amateur observing; while doubtless true for many or even most Victorian amateurs, my impression is that natural theology motivates far fewer amateurs in current scientifically literate societies—with the possible exception of wide swaths of the amateur astronomical community in the United States.

3 At the seventeenth meeting of theA&PST (RASC) on 1892 September 26 it was noted that "Difficulty having arisen in identifying upon maps, etc., markings upon the planet Mars, owing to the existence of several official lists of names of continents, seas, etc., differing each from the other, the Corresponding Secretary was instructed to communicate with the Reverend T. E. Espin, F.R.A.S., the editor of the new edition of Webb, in the hope that he would cause to be arranged for observers a table of names that would be satisfactory;" A&PST 1893, 63. This recommendation doesn't appear in the Society's report as transmitted to Espin, and it's not known if it was one of the "various other matters of detail…your Committee felt a delicacy in volunteering its views," or whether Lumsden (the Chair of the Committee, and Corresponding Secretary) did indeed subsequently communicate the recommendation to Espin.

Skyward

How to See More than Half the Solar System at Once

by David Levy, Kingston & Montréal Centres

Have you ever wondered if you could see more than half the Solar System at once? An opportunity to do so does not come about often, but it does happen from time to time. A couple of summers ago, Venus, Mars, Jupiter, and Saturn were all in the evening sky and could be spotted at once. During the summer of 2020, a couple of hours after sunset, Mars, Jupiter, and Saturn were all in the sky and could be seen at the same time.

The procession began in the evening, with Jupiter and Saturn easily visible at about the same time in the east. Jupiter is brighter than all the stars on a summer night, and through a telescope, the rings of Saturn are exquisite. Jupiter and Saturn appear to get close in the sky every twelve years, or about once every Jupiter orbit of the Sun. They were close together in 1960, 1972, 1984, 1996, 2008, and now. Saturn and Jupiter were not far apart when I first looked at Jupiter through a telescope on 1960 September 1. Galileo himself could have felt no greater thrill than I did when I used my first telescope, Echo, and saw the wonderful planet, surrounded by four bright moons and decorated with gas bands in its upper atmosphere. Dad and Mom were with me and they enjoyed that unforgettable view as well. You too can replicate that experience on the next clear night. In December, the pair can still be seen in the west shortly after sunset, with Mars rising at its highest around roughly 8 p.m.

Toward the east, Mars reached its peak brightness in October, but it's still fairly bright. Through a good telescope you should be able to see a polar cap, and dark markings on its surface like the prominent Syrtis Major or the very large Mare Acidalium.

Mars has two tiny moons, Phobos and Deimos. I have seen Phobos, one night many years ago, using a large 36-inch diameter reflector. Two spacecraft are now on their way to Mars. One carries a rover and a helicopter intended to search for evidence of past life on this planet.

Around dawn, Venus rises in the northeast. Although it is the brightest planet (and the brightest object in the sky after the Sun and the Moon), Venus offers virtually nothing to see through its dense clouds, even using a good telescope. However, on rare occasions it gets occulted by the Moon. The attached picture is of one such event I saw.

Of course, the Moon joins this pantheon of planets. Because the Moon is a real place that we have visited, not just an object

Figure 1 — The Moon about to occult Venus in the spring of 2006.

Figure 2 — Our Jarnac Observatory. Its main "Shaar" structure, Shoemaker-Levy dome, and Canada building all appear.

in the sky, it is a treat in any telescope. Walk across the craters, climb its mountains, and skate along its enormous maria, or plains. The Moon is always wonderful.

It is not a trick to see so much of the Solar System at once. Late on the night of 2020 August 12, while observing the Perseid meteors, I viewed Jupiter low in the west, and Saturn just a bit higher in the sky. Mars was high in the south. Further east shone the waning crescent Moon. Finally, Venus was low in the east.

You do not need a telescope to see all this. Just open your eyes and behold the wonder of our tiny neighbourhood in the cosmos.

The Long Summer of 2020

When Earth crossed the summer solstice on 2020 June 21, we were all mired in the midst of the most serious pandemic in more than a century. Summer is the most important season for me for one reason: it was many years ago, during the summer of 1960, that I fell in love with the night sky. This past summer just concluded had a start filled with disappointment.

On 1960 June 21, I was riding my bicycle to school when its front wheel struck a curb, knocked me off, and I broke my arm. My cousin, Roy Kaufman, gave me a book about the planets as a get-well present. I read and re-read that book all summer, and by September I was enjoying my first look through a telescope, at the planet Jupiter. The view of the planet with its bands of colour, combined with its four big moons, was one I have never forgotten. To this day Jupiter remains my favourite planet. As I never tire of looking at this world, I was able to view Jupiter this summer also.

The summer of 2020 began with a huge handicap, but something appeared in the sky that quickly altered my perception. That something was Comet NEOWISE. Not since Comet McNaught in 2007 has such a bright comet graced our sky. I first saw NEOWISE on the morning of July 5. The full Moon was setting in the west, and the sky was brightening rapidly in the east. With a pair of good binoculars, I found Capella, then carefully moved them toward the eastern horizon. Suddenly, the beautiful comet made its appearance with a bright glowing head and a brilliant tail. As the comet faded slightly over the next few days, its tail grew longer.

Comet NEOWISE might have been a highlight of this summer season, but there were other highpoints. Over the course of the summer, I enjoyed sixteen "AN" or all-night observing sessions, nights under the sky that went on from dusk to dawn. Most of these were interrupted by lengthy periods of rest during which I would watch some television, but the final one was not. Session 21755AN2 began when my friend David Rossetter and I observed for several hours at the dark site run by the Tucson Amateur Astronomers Association. Once back home, I enjoyed more hours searching for comets until dawn spelled an end.

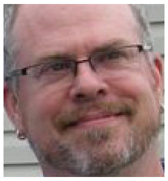
Searching for comets is something I have enjoyed for many years. It is an activity of which I never tire, even though I have not found a new comet since October 2006. After all, the search is what is so important to me. It is refreshing, it is fun, and it recharges my soul and my spirit.

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.*

Binary Universe

Thin Moon Chasing



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

When at the Carr Astronomical Observatory on Friday, September 18, we observed a very young Moon, around 1.6 days after the new-Moon phase. Spotting the thin crescent was easy to the unaided eye but the view was *boiling* in binoculars (due to bad seeing). It was bittersweet as I had missed a chance earlier this year to view a younger Moon.

I have been trying to break my youngest Moon record for some time. My career number right now is 27 hours old as viewed on March 2010 and I've been trying to get below 24.

To help me in extreme Moon pursuits, I've hunted for an app or a website to show the age of the Moon and the duration into the lunation cycle with some detail. *SkySafari* reports our nearest neighbour's age in days to one decimal. My beloved *SkyTools* is the same. They both show phase in percentage. Their data are not sufficiently detailed and I'm not good dividing by 12 or 24 off the top of my head.

Finding a Tool

Back in June, I reached out to Moon aficionado Dave Chapman, and he shared information on the phase angle (or illuminated fraction) and the selenographic co-longitude (longitude of the terminator). I was already familiar with the latter in the *Observer's Handbook*. David said the *Moon Atlas* app on his Apple mobile device shows both the illuminated percentage and the co-longitude.

During a recent Zoom Moon party, I was able to ask my question in the chat. The presenter recommended *Virtual Moon Atlas*. Of course, it's the remarkable powerful application I referred you to in December 2015 *Journal*.

Unsatisfied, I had another go with the artificially intelligent Google search robot, and I landed at the Android Authority site. I skimmed an article comparing a handful of Moon apps and it was there that I spotted *Daff Moon*. I downloaded it from the Google Play store

https://play.google.com/store/apps/details?id=com.dafftin.android.moon_phase

I quickly discovered I was using an amazing astronomy app.

Moon Data

Information on our satellite in Daff is voluminous.

The main screen (see figure 1) shows the Moon as it would appear to your eye or in binoculars with lots of technical details. By default, it renders for your current location, date, and time.

The controls to the left and right of the clock allow you to advance or retreat by days or hours and tapping in the middle allows you to jump to a specific period.

The little arc below the Moon alludes to where it is in the sky, bracketed by the rise and set times. If the arc bends upward, it is visible; otherwise, it is below the horizon. This is supported by the altitude and azimuth numbers.

Supermoon and tide watchers can keep an eye on the distance.

The phase is shown with a percentage number to one decimal place. And lastly, the datum I was most interested in—the exact age, down to the second! Awesome. An app in my pocket with granular Moon age information.

The app rotates the Moon to reflect the proper orientation above your horizon.

If you crave still more information, the "i" button reveals "upper" and "lower transit" times, predictions for the upcoming major phases, right ascension and declination, and the apparent diameter.

Out of interest, I rolled back to that Friday session (Figure 2). It correctly rendered Luna as a thin crescent.

I checked the Moon age and confirmed what I knew. I was nine hours past my life list record.

But there's lots more to know, learn, and do. This is obvious after a quick glance at the main menu (Figure 3).

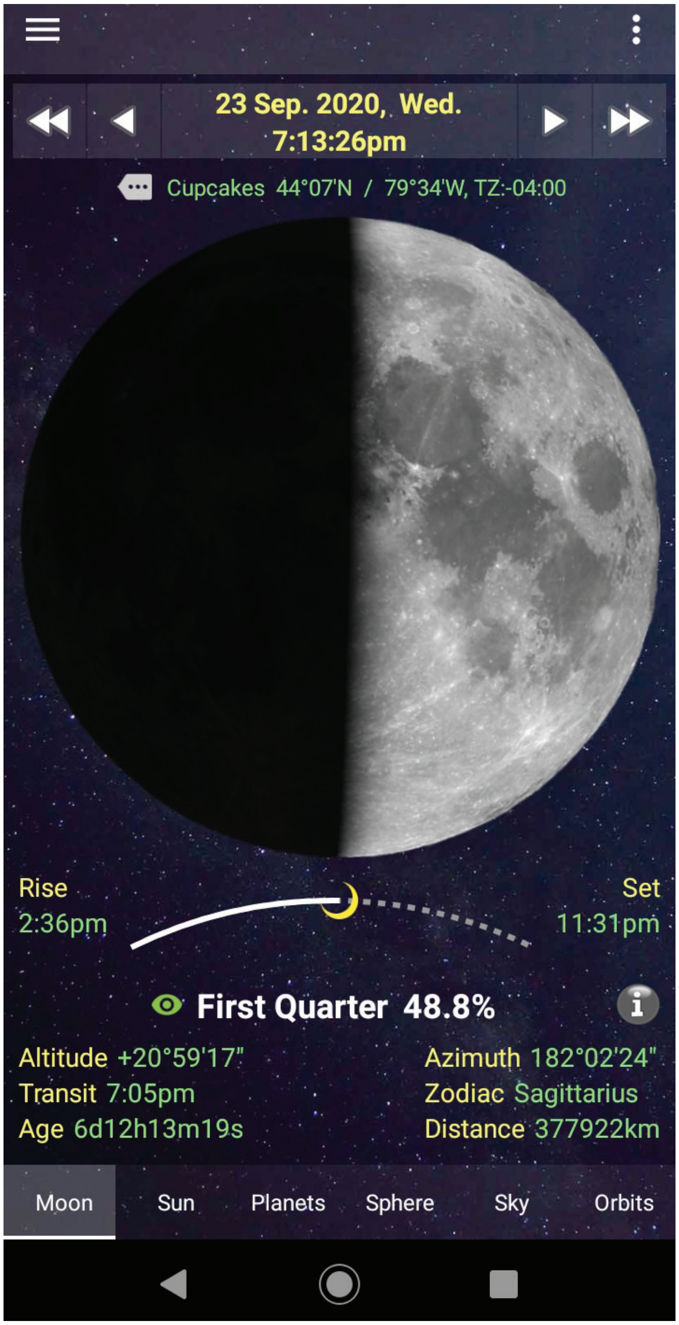
The Rise/Set command presents tables for the Moon, Sun, and planets (including Pluto) showing in fact the rise, transit, and set times.

The Phases command shows a month-at-a-glance calendar with an image for each day. Tapping on a day gives circumstances for the Moon and Sun along with the day's length. You may jump to the selected date or add an event to your personal calendar.

The Supermoon lists predict proximal Moon events on a year-by-year basis with the distance noted for each.

The Perigee/Apogee report (Figure 4) shows when our neighbour is close or far with a rather intriguing line graph.

The Eclipses page reports on lunar and solar alignments along with their type and additional information accessible via the "More" button. The eye icon tells if you'll be able to witness it from your locale. Animations can be played for lunar events while solar events offer links to maps.



23 Sep. 2020, Wed.
7:13:26pm

Cupcakes 44°07'N / 79°34'W, TZ:-04:00

Rise 2:36pm
Set 11:31pm

First Quarter 48.8%

Altitude +20°59'17"
Azimuth 182°02'24"
Transit 7:05pm
Zodiac Sagittarius
Age 6d12h13m19s
Distance 377922km

Figure 1 — Moon rendered for the detected location at current date and time. Moon and background style reflect user preferences.

18 Sep. 2020, Fri.
7:30:01pm

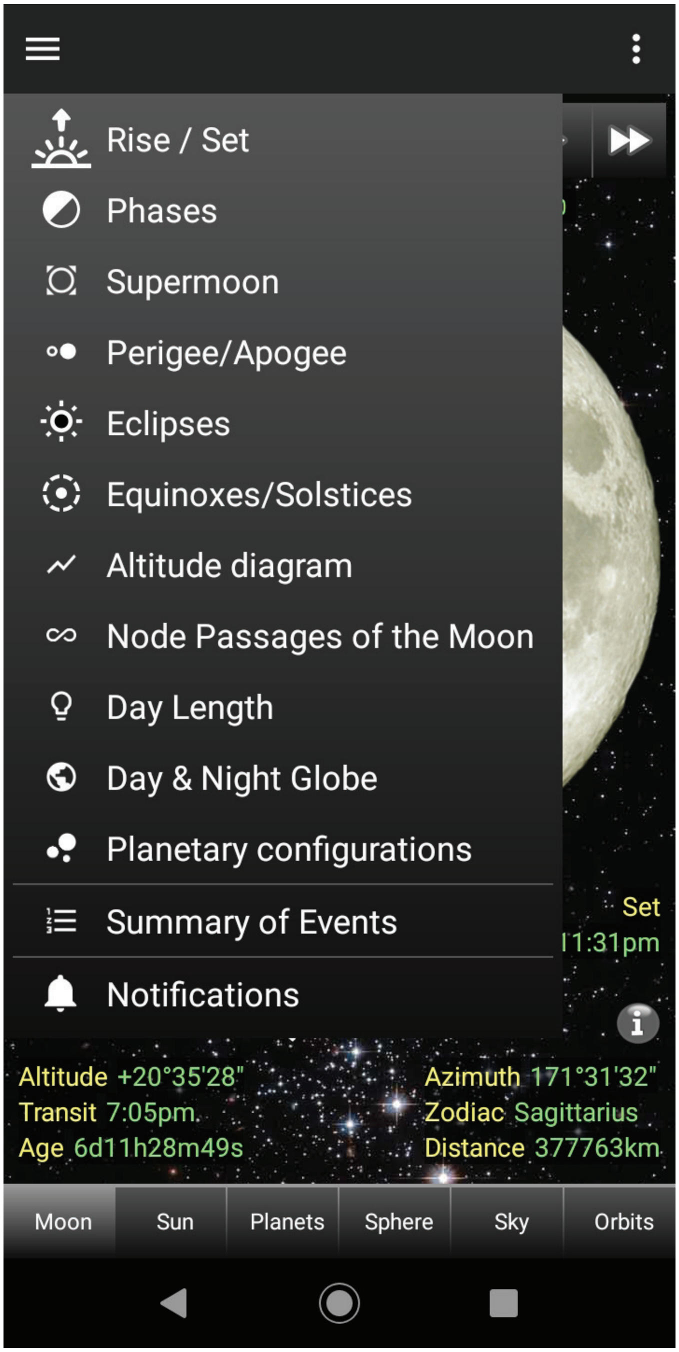
Location 44°07'N / 79°34'W, TZ:-04:00

Rise 8:14am
Set 8:27pm

Waxing crescent 3.5%

Altitude +9°09'59"
Azimuth 255°53'20"
Transit 2:28pm
Zodiac Libra
Age 1d12h29m54s
Distance 359219km

Figure 2 — Moon on Friday, September 18 at dusk near Georgian Bay. 36 hours old.

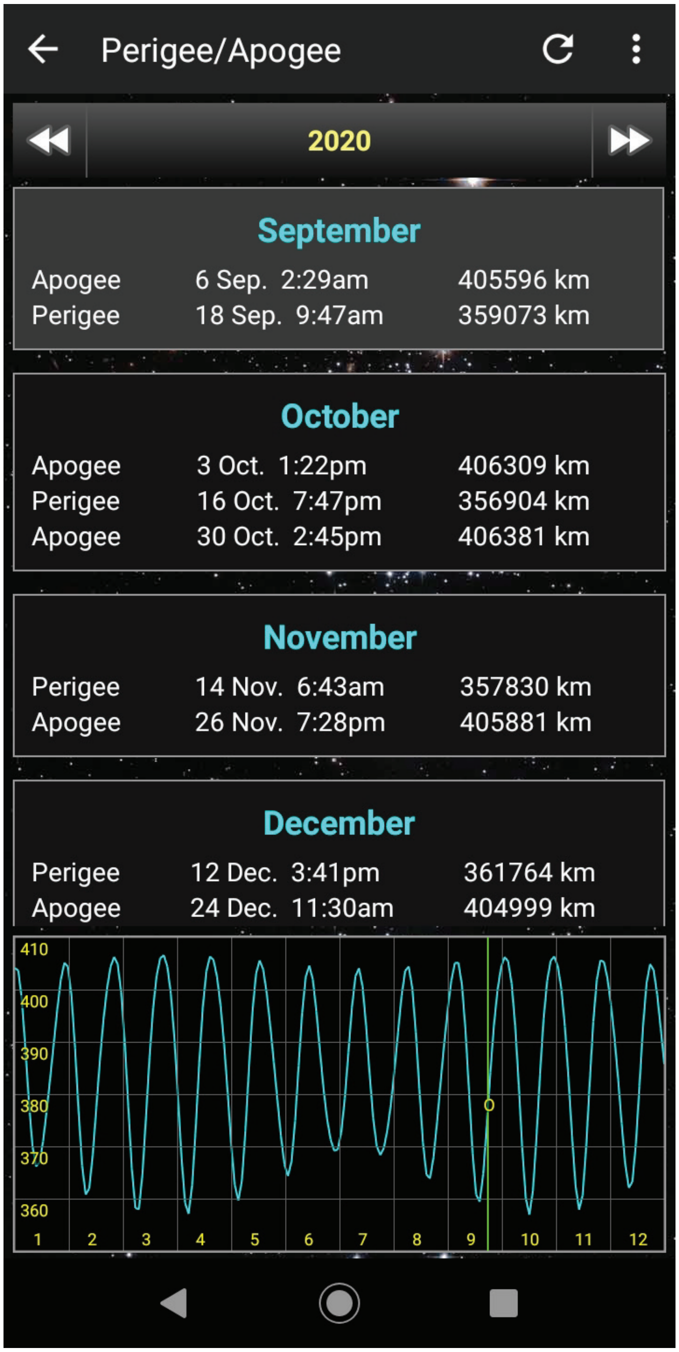


Set 11:31pm

Altitude +20°35'28"
Transit 7:05pm
Age 6d11h28m49s

Azimuth 171°31'32"
Zodiac Sagittarius
Distance 377763km

Figure 3 — Main menu alluding to a dozen different useful displays and reports.


Perigee/Apogee

2020

September

Apogee	6 Sep. 2:29am	405596 km
Perigee	18 Sep. 9:47am	359073 km

October

Apogee	3 Oct. 1:22pm	406309 km
Perigee	16 Oct. 7:47pm	356904 km
Apogee	30 Oct. 2:45pm	406381 km

November

Perigee	14 Nov. 6:43am	357830 km
Apogee	26 Nov. 7:28pm	405881 km

December

Perigee	12 Dec. 3:41pm	361764 km
Apogee	24 Dec. 11:30am	404999 km

Figure 4 — Instances of perigee and apogee for the upcoming months. Graph shows entire year.

Extraordinary Information

The Altitude diagram is interactive like many of the displays in the app, allowing you to plot the bodies in the Solar System.

The Summary of Events is a very thorough listing for a day and can trigger device notifications. You will see all upcoming events down to the minute, including the stages of twilight, Golden hour, Blue hour, rise, transit, and set times for celestial bodies.

There are also a good number of other reports that speak to extraordinary programming efforts and forethought on the part of the developer, too many to discuss in any detail.

All these fantastic features are available under the Moon mode. The toolbar at the bottom of the screen can be used to switch to other modes.

The Sun mode is similar to the Moon display.

Planets shows a listing with rise and set times and a visibility indicator along with the current location by altitude and azimuth.

The Sphere mode (Figure 5) is an interactive three-dimensional view. The landscape button draws you inside the celestial sphere, presenting a classic chart-like mapping with stars and constellations.

The Sky view presents an interesting, specialized display with altitude scale.

And finally, the Orbits mode shows a simulated view of the Solar System that you can zoom, pan, and tilt.

Settings

The app works well in landscape orientation, which is handy when viewing the built-in charts. I am somewhat astonished by all this app has to offer and I've not relayed every single capability. That said, there's one thing missing: red or night mode.

The well-thought-out preferences allow you to run the app the way you want.

While your location can be automatically used, you can also set and save custom locations. Real-time mode is automatically enabled but you can override it as needed.

Themes allow you to change the spacey background and show the menus and reports in a semi-transparent style.

Widgets

The programmer didn't stop at just the app proper. He provides a number of interesting widgets, including a simple dynamic Moon-phase indicator (with or without text), altitude diagram, phase calendar, and special sky display. The fully scalable widget allowed me to replace an older, limited Moon app.

App Details

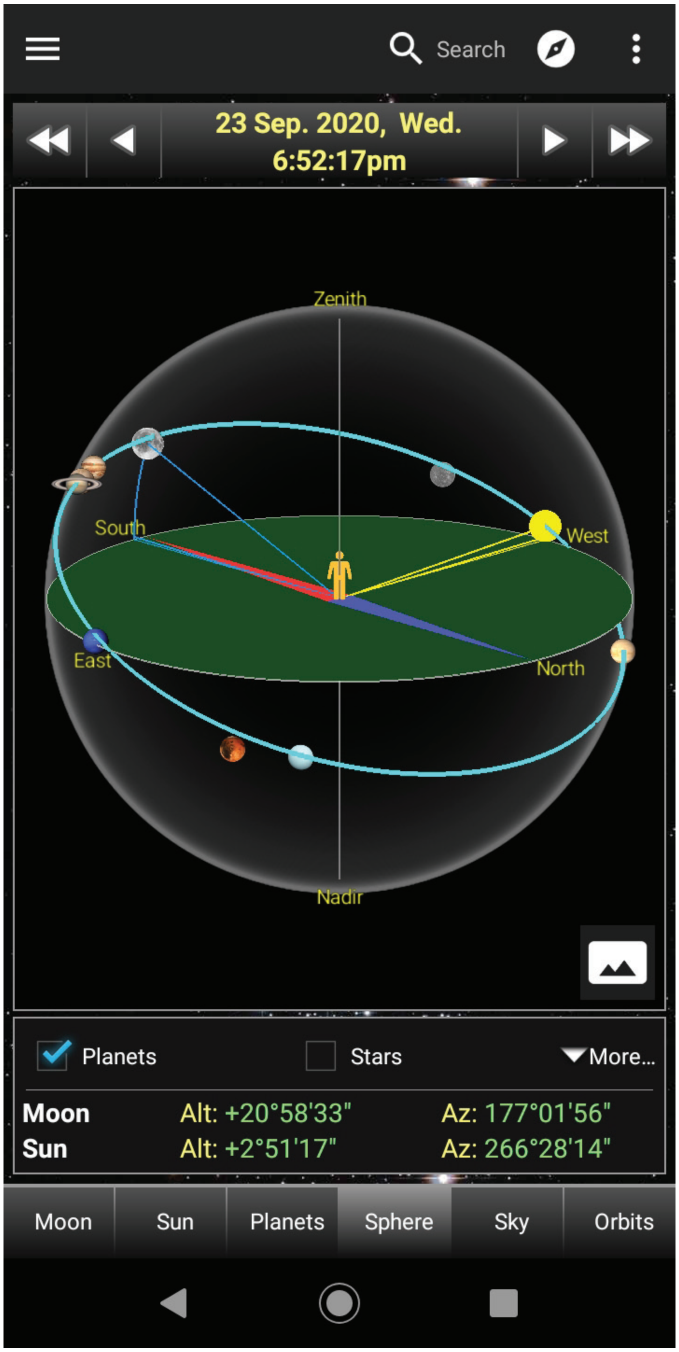
I tested *Daff Moon Phase* version 3.00 by Evgeny Fedorischenko on my Motorola e6 running Android 9. The author is from the Russian Federation and offers the app in English, Czech, Spanish, Italian, and Polish languages. I chatted with the author and he told me red mode is in the works.

The software was recently updated in September 2020. It is popular, with over one million installs. Some 24,000 users rated the app and it scores 4.9 out of 5.

The app appears to be completely free and without any pop-up ads. The author accepts donations.

This is an app made by a programmer with an excellent understanding of astronomical phenomena, a very good sense of design and layout, and a deep understanding of the operating system. This is how it should be done.

I look forward to using this app for my own projects, as well as consulting it for general planning and education and outreach situations. I urge you to try out *Daff Moon Phase*.



23 Sep. 2020, Wed.
6:52:17pm

☑ Planets ☐ Stars

Moon	Alt: +20°58'33"	Az: 177°01'56"
Sun	Alt: +2°51'17"	Az: 266°28'14"

Figure 5 — Celestial sphere rendered with the observer at the centre, ecliptic in blue, and the Solar System bodies.

Bits and Bytes

Good To Stargaze was updated with a new information bar at the bottom of the main screen. The "night bar" allows you to quickly assess the upcoming evening. Nearby buttons for the days in the week allow you to preview future conditions. ✶

Blake's interest in astronomy waxed and waned for a number of years but joining the RASC in 2007 changed all that. He helps with volunteer coordination in the RASC Toronto Centre and is a member of the national observing committee. In daylight, Blake works in the IT industry.

CFHT Chronicles

Updates

by Mary Beth Laychak, Director of Strategic Communications, Canada-France-Hawaii Telescope
(mary@cfht.hawaii.edu)

While life on Earth took a messy turn in 2020, the skies above Maunakea remain excellent. Machine learning and galaxies took centre stage this summer in our CFHT science news.

Machine Learning

Machine learning, a new technology revolutionizing the analysis of large data sets, has gained traction in the astronomical community for the past decade. A team of researchers led by Carter Rhea from the Université de Montréal and Laurie Rousseau-Nepton of the Canada-France-Hawaii Telescope are spearheading efforts to bring machine learning into the flow of SITELLE data analysis. The team wrote their first paper, which shares their application of a convolutional neural network to SITELLE spectra to estimate kinematic parameters.

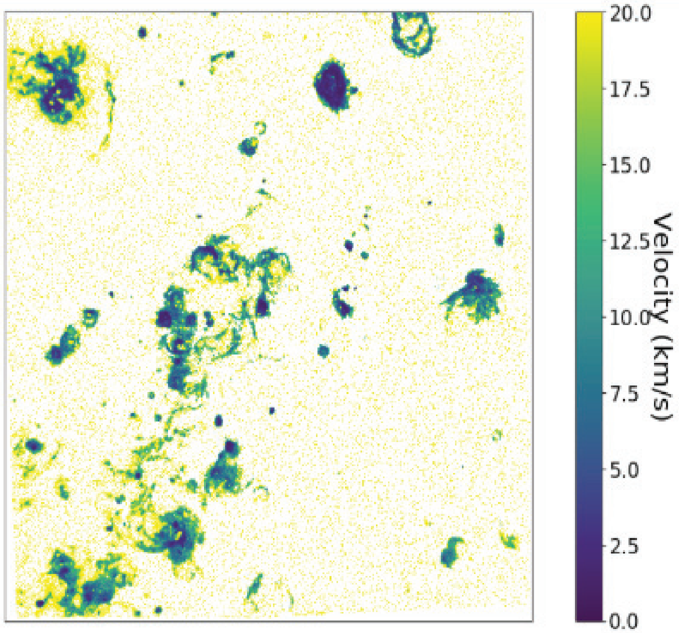


Figure 1 — Residual map of the recovered velocity parameter in the southwest field of M33. The residual was calculated by taking the difference between the network's estimate and that of the ORCS fitting software.

SITELLE, the CFHT's unique imaging Fourier Transform Spectrograph, generates 3-D data cubes containing more than 4 million spatial pixels and a spectral resolving power of 10,000 resulting in a total of over 40 billion spectral pixels or spaxels. Data analysis on such volumes of data require dedicated tools designed specifically for SITELLE—ORCS (Outils de Réduction de Cubes Spectraux) software package written by Thomas Martin, an astronomer at the Université Laval. Using ORCS, an astronomer can fit each spectrum in the data cube. SITELLE measures the amount of light, or photons, that hits each pixel during the exposure. ORCS "fits" those photon counts into a scientifically usable spectrum, enabling astronomers to learn about the complex physics in planetary nebulae and HII regions.

Before fitting a spectrum, ORCS requires the user to input an initial estimate for the velocity and broadening parameters. Astronomers rely on previous studies of their objects to determine these initial estimates. Frequently the estimates come from older, potentially outdated, research, which may not be appropriate or available for all nebulae. If the initial estimate is inaccurate, it triggers a series of unsound calculations culminating in an incorrect solution. Prior to the team's work, SITELLE users did not have a standard method for determining initial estimate values.

"When we started this project, we were hoping to capitalize on recent successes employing a machine-learning technique known as a convolutional neural network to calculate spectral parameters," said Simon Prunet, CFHT resident astronomer. "Convolutional neural networks are becoming increasingly common in the field of image processing including recent success in astronomy."

These networks take spectra and break them down into their most important components, using artificial intelligence to learn to extract key parameters from the input. Convolutional neural networks are trained with labelled data through a process known as supervised learning, where the networks learn to associate patterns in the input images with corresponding output parameters. The networks are trained on pre-labelled data until they properly categorize inputs based on their labels. In the case of SITELLE, the team trained their algorithm on a suite of synthetic spectra specifically tailored to mimic actual data from the instrument. The synthetic data were generated using preexisting tools in another custom designed SITELLE software package, ORBS (Outils de Réduction Binoculaire pour SITELLE). After training the algorithm, it was extensively tested on freshly generated synthetic spectra. Once the algorithm demonstrated its capability to accurately estimate the velocity and broadening parameters of emission lines in SITELLE spectra, the team progressed their testing to include real observations taken by SITELLE.

The network was applied to a SITELLE field from the galaxy M33. The team selected M33, a spiral galaxy hosting an assortment of emission-line nebulae, supernovae remnants, and planetary nebulae, due to M33's well established velocity and line-broadening input estimates. The results indicate that the network recovers the broadening and velocity values with errors similar to those found by ORCS.

Carter Rhea, the machine-learning project's lead and graduate student at Université de Montréal, said: "This is the beginning of what we can do with machine learning to revolutionize data analysis from instruments such as SITELLE. It is incredibly exciting for me to work on the intersection of machine learning and astronomical data sets."

CFHT resident astronomer and PI of the first SITELLE LP, The Star Formation, Ionized Gas and Nebular Abundances Legacy Survey (SIGNALS), Laurie Rousseau-Nepton and the SIGNALS team will receive an incredible amount of data over the course of the survey. Any increase in data analysis speed is welcome with 54 nights of CFHT time, creating an estimated 800 GB of raw data. Adding to the challenge, SITELLE generates cubes of data as opposed to individual images. A single SIGNALS cube may be 10 GB. Loading the data is computationally intense, let alone analyzing it. To work around the size of the data, the SIGNALS team is working with the Canadian Astronomical Data Center (CADC) to give PIs access to the data virtually.

"The machine-learning type of analysis is a game-changer for astronomers using SITELLE," said Laurie Rousseau-Nepton, CFHT resident astronomer and SITELLE instrument scientist. "The network analyzes the data in a fraction of the time previously required, greatly speeding up the time it takes to reduce the enormous amounts of data generated by projects like our large program SIGNALS."

As mentioned in previous columns, SIGNALS aims to study 50,000 star-forming regions in nearby galaxies. The main goals of SIGNALS are to quantify the impact of the surrounding environment on the star-formation process, link feedback processes to the small-scale chemical enrichment and dynamics around star-forming regions, and measure variations of the resolved star-formation rate with respect to the indicators used for high-redshift galaxies. SIGNALS' datasets will be extremely rich and valuable for investigating many other physical mechanisms as well. It will produce complementary results to study planetary nebula abundance distributions and luminosity functions, supernova remnant ionization conditions, occurrence, and feedback contributions, background emission-line objects (e.g. [OII] and Ly-a emitters), and much more.

Extreme Galaxy Origins

Astronomers have found that the key to understanding galaxies with "extreme" sizes, either small or large, may lie in their surroundings. In two related studies, an international team found that galaxies that are either "ultra-compact" or "ultra-diffuse" relative to normal galaxies of comparable brightness appear to reside in dense environments, i.e. regions that contain large numbers of galaxies. This has led the team to speculate that these "extreme" objects could have started out resembling normal galaxies, but then evolved to have unusual sizes through interactions with other galaxies.

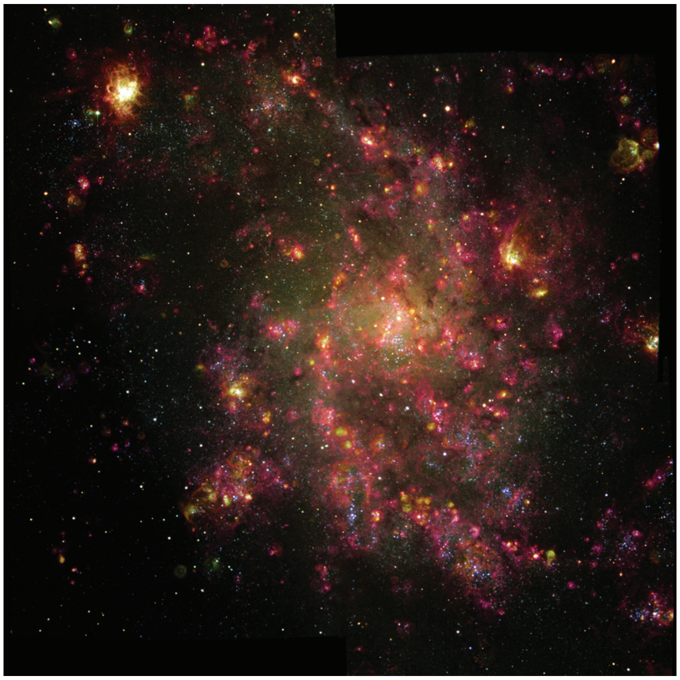


Figure 2 — Four-field mosaic of the centre of M33 with SITELLE. The colours are associated with blue, green, and red SITELLE filters. The image was made by combining emission lines and continuum. Photo credit: Laurie Rousseau-Nepton

The team identified both ultra-compact and ultra-diffuse galaxies as part of an unprecedented census of galaxies residing in the nearby Virgo cluster. The investigation used data from the Next Generation Virgo Cluster Survey (NGVS) obtained at the CFHT using MegaCam, a wide-field, optical camera. At a distance of 50 million light-years, Virgo is the galaxy cluster nearest to the Milky Way, and contains several thousand member galaxies, the majority of which are revealed, for the first time, in the NGVS data.

Astronomers discovered ultra-compact dwarf galaxies (UCDs) a quarter century ago, and they are the densest known galaxies in the Universe. Competing theories describe UCDs as either large star clusters, or as the remnants of larger galaxies that have been stripped of their stellar envelopes.

"We found hundreds of UCDs in the nearby Virgo galaxy cluster, and at least some of them appear to have started their lives as larger galaxies," said Dr. Chengze Liu of Shanghai Jiao Tong University, lead author of the first study.

While UCDs are similar in appearance to a large star cluster, a number of UCDs in this study were found with faint stellar envelopes surrounding the central, compact core. These envelopes could be the last remnants of a galaxy that has gradually been stripped away by gravitational tidal forces from neighbouring galaxies. Additionally, UCDs were found to inhabit preferentially the regions of the Virgo cluster with the highest galaxy densities. Together, these pieces of evidence point to an environmentally induced transformation as being responsible for producing some UCDs.

Ultra-diffuse galaxies (UDGs) are a mystery at the other end of the size spectrum. They are much larger, and more diffuse, than typical galaxies with similar brightness. Some theories suggest that UDGs are massive galaxies whose gas—the fuel for their star formation—was removed before many stars could form. Others suggest that they were once normal galaxies that have been made more diffuse through mergers and interactions.

"We found that the ultra-diffuse galaxies in the Virgo cluster are more concentrated toward the dense cluster core, indicating that a dense environment may be important for their formation," said Dr. Sungsoon Lim of the University of Tampa, and the lead author of the second study. "The diversity in their properties indicate that, while no single process has given rise to all objects within the UDG class, at least some UDGs have appearances suggesting their diffuse nature is due to tidal interactions or to the merger of low-mass galaxies."

Another mystery is that some ultra-diffuse galaxies were found to contain significant populations of globular star clusters.

"The intense star-forming events needed to make globular clusters generally make a galaxy less, rather than more diffuse, so understanding how we get globular clusters in ultra-diffuse galaxies is an interesting challenge," said Prof. Eric Peng of Peking University's Kavli Institute for Astronomy and Astrophysics, and co-author on both studies.

"To find galaxies that are truly unusual, you first need to understand the properties of so-called normal galaxies," said Dr. Patrick Côté of the National Research Council of Canada's Herzberg Astronomy and Astrophysics Research Centre, and an author on both studies. "NGVS provides the deepest, most complete look at the entirety of the Virgo cluster galaxy population, allowing us to find the most compact and most diffuse galaxies, advancing our understanding of how they fit into the general picture of galaxy formation."

The Next Generation Virgo Survey (NGVS) ran at CFHT for six years with Megacam. NGVS took advantage of Megacam's wide-angle coverage, observing the Virgo cluster in its entirety—an area of the sky equivalent to over 400 full Moons. The depth and resolution of the survey significantly exceeded any other existing survey of Virgo. The resulting mosaic comprised nearly 40 billion pixels and is the deepest, widest, contiguous field ever seen in such detail. The NGVS team developed a data-analysis technique that allowed them to discover many more times the number of galaxies in the field than were previously known. These discoveries included some of the faintest and most diffuse objects ever discovered, including the galaxies used in the ultra-diffuse galaxies work done by Lim and his collaborators. ✶

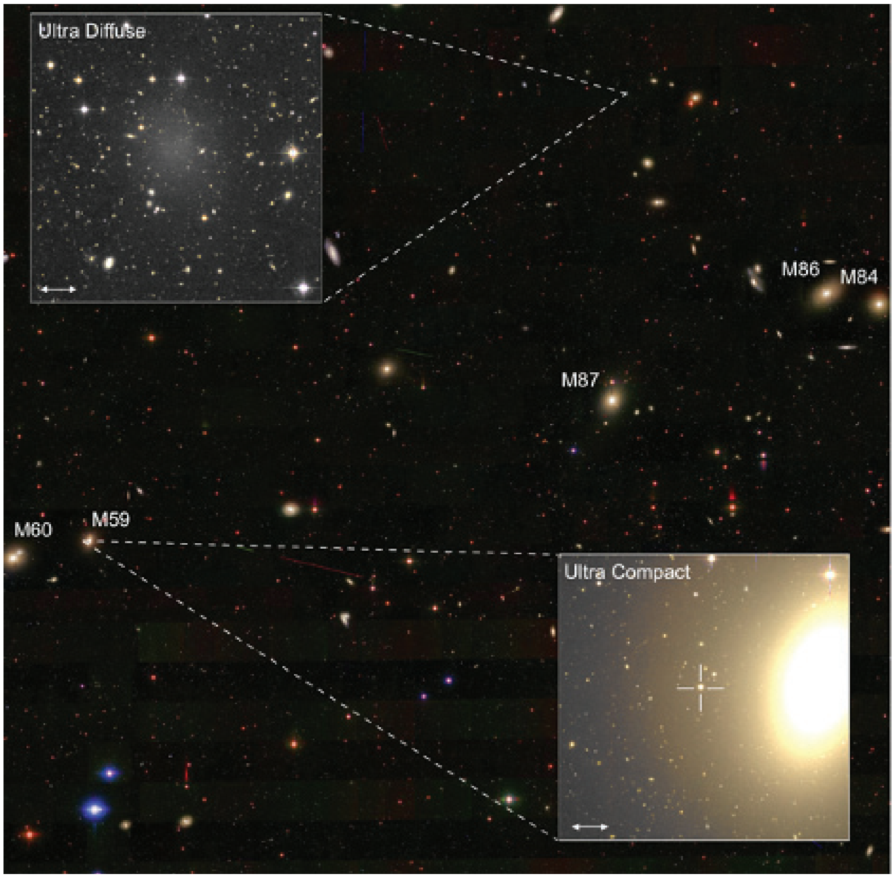


Figure 3 — A wide-field view of the central region of the Virgo Cluster, measuring 4.4 million light-years on each side, from the Sloan Digital Sky Survey. Some of Virgo's brightest member galaxies are labelled, including Messier 87, or M87, which is located close to the cluster centre. Insets show deep images of two structurally extreme galaxies, taken with the MegaCam instrument on CFHT as part of the Next Generation Virgo Cluster Survey. An ultra-compact dwarf is within the crosshairs in the lower inset, while an ultra-diffuse galaxy is featured in the upper inset. These galaxies are nearly a thousand times fainter than the bright galaxies visible on this image. Although the compact and diffuse galaxies contain roughly the same number of stars, and their total brightness is similar, they differ in area by a factor of more than 20,000. The scale bars in each inset represent a distance of 10,000 light years. Image credits: Sloan Digital Sky Survey, Canada-France-Hawaii Telescope and the NGVS team.

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

John Percy's Universe

Reflections

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

The retired faculty college at my university recently asked its members to contribute reflections on the changes in their discipline over the course of their career. This column is inspired by my contribution. Many of my reflections have already appeared in *John Percy's Universe.*

Advances in Astronomy

In the 60 years since I was an undergraduate astronomy student (Figure 1), humans have flown in space and landed on the Moon (men only, so far). Space probes have explored all the planets in the Solar System, including the ex-planet Pluto—I was at the meeting in Prague when it was demoted!—and many of their moons. Several bright comets have come and gone. The Kuiper Belt was hypothetical until 1992. Thousands of exoplanets have been discovered around other stars, including dozens of Earth-like ones, and many unlike the planets in our Solar System. The first ones were detected using a technique developed right here in Canada. Astronomers now understand, reasonably well, the life cycles of the Sun and stars, including their bizarre end products—white dwarfs, neutron stars, and black holes. They have shed new light on the origin and evolution of galaxies and the Universe itself and made superb maps of the afterglow of the Big Bang.

When I started, most optical astronomy imaging was still done with photographic plates. Radio astronomy was in its youth. Space astronomy blossomed in the 1970s. Research advances have come about through bright ideas, of course, but also through new instruments and techniques: giant telescopes on mountaintops in Chile and Hawaii, telescopes in space, super-sensitive electronic detectors, observations across the electromagnetic spectrum from gamma rays to radio waves, and powerful computers and software to operate telescopes remotely, analyze the "big data" from them, and model the structure and evolution of planets, stars, galaxies, and the Universe. Canada has been part of many of these projects. The costs of modern astronomy are high, which requires either international collaboration (e.g. the European Southern Observatory in Chile) or a rich patron (e.g. the Keck Observatory in Hawaii). This research also requires an increasingly interdisciplinary approach, which I like: physics, engineering, mathematics, statistics, computer science, Earth and planetary science.

Figure 1 — The author at the beginning of his career, receiving the 1962 RASC Gold Medal from RASC National President Professor Ruth Northcott. His mother, a teacher, looks proudly on.

I evolved from a theoretician to an observer to a data-miner. My observational research has been "small telescopes, small science" (Percy 1980), starting with telescopes at the David Dunlap Observatory and on my university campus in the 1960s, to the Kitt Peak National Observatory in Arizona, to robotic telescopes—most recently the All-Sky Automated Survey for Supernovae. I have also enjoyed a long and warm collaboration with the American Association of Variable Star Observers (AAVSO) and its staff, promoting and using its century-long database of visual observations, and co-leading its part in the "photoelectric revolution" in the 1980s. The work of the AAVSO is made possible by the voluntary efforts of thousands of amateur astronomers around the world—citizen scientists. Indeed, citizen science is still alive and well, even in this day of astro-mega-projects.

Professional Astronomy

In the 1960s and 1970s, there were a few professional astronomers in a small number of universities (notably Toronto), in federal government facilities such as the Dominion Observatory (DO) in Ottawa, Dominion Astrophysical Observatory (DAO) in Victoria, Dominion Radio Astrophysical Observatory (DRAO) in Penticton, and Algonquin Radio Observatory (ARO), and in a handful of planetaria. DAO and DRAO are still active as part of the Herzberg Institute of Astrophysics (HIA), but the federal role now emphasizes securing and maintaining international partnerships, planning and operating international facilities, and building instrumentation for them. HIA staff continue to do forefront research.

The number of professional astronomers and astronomy graduate students in Canada has quadrupled since the birth of the professional Canadian Astronomical Society in 1971. This is in part because of the steady growth of university enrolments, and exciting research opportunities, but also because of the popularity of astronomy courses—especially introductory courses for non-science students.

Defining our professional values, and improving our professional culture—equity, diversity, inclusivity, and sustainability—is now an increasing priority for astronomers across Canada. Half a century ago, for instance, most astronomers were male—one exception being my eminent colleague Helen

Sawyer Hogg. Almost all my classmates were white. Now, at least half of my bright young colleagues are women, and they are all a diverse bunch.

New attention is being given to indigenous rights and indigenous knowledge. Maunakea is home to a dozen major observatories, some shared by Canada. It is also sacred land for indigenous people of Hawaii, and this has sparked local demands for "no more observatories on the sacred peak"—at least not without respectful consultation and agreement.

At the same time, universities encourage their academic units to incorporate indigenous ways of thinking and knowing in their courses, where appropriate. At U of T, this has led to a course on Indigenous Astronomy, and discussions of how to indigenize other parts of the formal and informal curriculum.

Another concern is the preservation of our astronomical heritage—buildings, instruments, libraries, and especially research data. Do you remember magnetic tapes? CASCA's Heritage Committee, led by Elizabeth Griffin, has been a leader in this, in partnership with the RASC and its archivist Randall Rosenfeld.

Graduate Education

When I was a grad student in the 1960s, the boom in graduate enrolments was just beginning. Things were still rather formal (jacket and tie were occasionally required), but less so, I suspect, than earlier. We didn't address faculty members by their first names until we had acquired our Ph.D. But with "student power" in the 1970s, that changed (as did hair styles). Students raised their voices and were heard. Now, they are fully involved in planning for their education.

One thing that's stayed the same is the endless discussion of the relative role, in graduate education, of research, coursework, independent learning, and the dreaded "general exam." We are having this discussion as I write this column. How can we develop and use "best practices" in graduate education and supervision? In my department, and in the university as a whole, there is now more emphasis on professional development and skills, and on entrepreneurship, partly because many of our graduates are going to careers in high-tech industry, rather than into academe.

Undergraduate Education

When I began teaching in 1967, the introductory astronomy course for non-science students began with spherical astronomy and trigonometry! That didn't last long. By 1970, the Hall-Dennis Report brought student-centred learning to Ontario's schools, and the Macpherson Report brought it to my university. The nature of teaching and learning had to change. Back then, there was no training for beginning instructors. We taught our students as we had been taught. Luckily, I had good role models, such as Don MacRae, and I had spent a year in teacher's college. Now, there's an abundance of useful resources for both beginning and experienced instructors. Teaching excellence is rewarded and celebrated. As for a/v, it was 16-mm films and 35-mm slides, much later overheads, and much later PowerPoint. We had some ancient lantern slides, but I never used them. In teacher's college in 1963–64, I had mastered the chalkboard. I retired before the days of courseware and personal response devices (clickers). There were good textbooks back then (notably Abell's) and there still are. And now we have the internet, for better or worse.

I've always been a strong supporter of undergraduate research (Percy 2018). In the 1960s, it was rather sparse and informal. Course lab work tended to be "cookbook style." But when I had research grants, and when there were a few government summer scholarships and work-study opportunities, and undergraduate research courses, I took full advantage of them. Now, we have a "senior thesis" course, and a large, well-organized summer undergraduate research program, with lots of skills development included.

Outreach

Astronomy appeals to many of the public, and their interests range from the technological to the philosophical. Astronomers respond through communication and outreach.

As a student, I was steeped in astronomy outreach, thanks to my professors' example. I did school and public programs at the David Dunlap Observatory, often using the superb NFB film *Universe* (1960). My colleague Helen Hogg published a weekly column *With the Stars* in the *Toronto Star* for over 30 years. And let's not forget Terence Dickinson's superb books, and his role as editor of *SkyNews.* On the screen, there was *Star Trek* (1966), *Star Wars* (1977), and *2001: A Space Odyssey* (1968)—my favourite. Soon came Carl Sagan's superb *Cosmos* (1980), which includes both the book and the TV series. These all generated huge interest in space and astronomy for students and the public. I still have memories of appearing on Helen Hogg's TV program with Carl. The start of my astronomical career also coincided with the opening of Toronto's McLaughlin Planetarium and the Ontario Science Centre, where I served as vice-chair of the Board of Trustees for six years in the 1990s—another highlight.

We partner in astronomy outreach with enthusiastic amateur astronomers, especially the RASC; I joined the RASC in 1961. In 2003, the RASC won the prestigious national *Michael Smith Award* for excellence in science outreach in Canada. In 2009, professional and amateur astronomers and educators in 148 countries marked the International Year of Astronomy, a celebration of the 400th anniversary of Galileo's development and first use of the astronomical telescope. We organized over 3700 events in Canada, reaching almost 2 million people. There were also wildly popular commemorative stamps, and engaging posters on buses and subway trains, and creative partnerships with new audiences. These included, for me, Toronto's Tafelmusik Baroque Orchestra and Heritage Toronto.

Despite our efforts, science literacy remains mediocre at best. Studies indicate that over one-third of Americans believe in astrology, space aliens, and young-Earth creationism. Canadians do a bit better—but not much. Very few people understand the cause of the seasonal changes in temperature (hint: it has nothing to do with the distance from Earth to the Sun). There is a wide gap between scientists' knowledge and public knowledge, which we must try harder to close. But interest is high, and scientists remain trusted (at least in Canada). So, there is much work to be done. I'm still doing it. And I know that you are, too. ✶

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

Second Light

Atomic Hydrogen at a Redshift of 1

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

In the early days of radio/millimetre-wave astronomy, atomic hydrogen through the 21-cm spin flip transition was detectable at distances far greater than carbon monoxide, which is the main tracer of molecular hydrogen. (As a graduate student/post-doc, I held the record for the highest redshift CO for about six months.) The Atacama Large Millimetre/submillimetre Array (ALMA to those in the know) changed that—galaxies at redshifts greater than seven have been seen in CO and some other prominent lines. Aditya Chowdhury and his colleagues have used the upgraded Giant Metrewave Radio Telescope (GMRT) in India to partially catch up (see the 2020 October 15 issue of *Nature*) and report that, on average, the mass of atomic hydrogen is about equal to the mass of the stars in a sample of galaxies at a redshift of one.

One of the problems with observing HI (how astronomers often refer to the 21-cm line) is that at any significant redshift the line is moving into the frequency range that communications use. There is in fact an international committee that regulates usage, to try to reserve important bands for astronomers. The rest frequency of the HI line is 1420 MHz. For galaxies with redshifts around 0.5, the line is in the range of cell-phone transmissions, and at z=2, broadcast television. For any galaxy with a redshift of more than 13, the line is smack in the commercial FM radio range. Technology has outstripped the law. When I was a grad student, a redshift of 0.1 was high, and 10 was barely imaginable. Now ALMA and the Very Large Telescope (optical), both in Chile, can observe galaxies at a time just a few hundred million years after the Big Bang (redshifts of about 10). We see the local Universe 13.8 billion years after the Big Bang.

Figure 1 — One of the 30 GMRT antennae, near Pune, India. Credit: Nissim Kanekar of the National Centre for Radio Astrophysics.

Galaxies are now thought to grow in the early Universe through a series of mergers between smaller clusters of matter with masses something like what Milky Way globular clusters have now (about a million solar masses). They start out as mostly gas associated with dark matter. The first stars probably formed at redshifts of 15–20, but there is only one observational paper to support that (see Hashimoto et al. in the 2018 May 16 issue of *Nature*), and that involved an extrapolation of what we know about star formation in the local Universe to the early Universe.

Stars mostly form out of molecular hydrogen because it is difficult to get atomic hydrogen cold enough to condense into stars. The floor temperature for atomic hydrogen is about 100 K—the 21-cm line cannot cool the gas below that—while the floor temperature for molecular hydrogen is about 10 K. But molecular hydrogen arises from atomic hydrogen, which is the ultimate source of gas. That is why it is important to know how the masses of atomic and molecular hydrogen change over time, and how they change relative to the mass of stars.

Based upon the optical light, the peak of star formation happens at a redshift of about 2.5, which is about 2.6 billion years after the Big Bang. This makes physical sense because it takes time to enrich gas with elements like carbon and oxygen, which are needed to cool the gas, and it takes time to assemble galaxies that are large enough to drive a lot of star formation. We know from ALMA observations that there is a lot of molecular gas (comparable to the mass of the stars) at a redshift of 2.5, but what about the source that feeds the formation of the molecular gas?

This is where Chowdhury and his collaborators enter the picture. They drew a sample of galaxies from a survey where the redshifts are known, and although the HI line was not detectable in any individual galaxies, they aligned the spectra using the known redshifts and added them all together. That gives them an "average" mass of atomic gas in the redshift range of the sample (0.7–1.45). It turns out that the mass of atomic gas is about equal to the average mass of the stars in those galaxies. Because galaxies at a redshift of about 1 are still forming stars quite vigorously, even if not at the peak rate, the time it will take to deplete the store of gas is only about one to two billion years. This explains why the average star formation rate declines very quickly about five billion years after the Big Bang.

What next? The Square Kilometre Array, components of which are now under construction in South Africa and Australia, aims to see HI at redshifts of 10–20. Canada is part of the consortium building the telescopes, just as it is a partner in ALMA. Perhaps in 10 years I will be writing about atomic hydrogen being seen just as the first clusters of gas and dark matter are forming. ✶

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

Dish on the Cosmos

Biosignatures and the Phosphine Mystery

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

The news that astronomers had observed phosphine in the atmosphere of Venus spread across popular media this fall, catching global attention because it was held up as a possible sign of life in the Venusian atmosphere. While life is a plausible explanation, the mystery of why there is a relatively large amount of phosphine remains open and there are several unknowns that could plausibly solve the mystery.

The discovery of phosphine used two telescopes that are frequently used by the Canadian astronomical community. The initial work for the discovery came from the James Clerk Maxwell Telescope (JCMT) near the summit of Maunakea in Hawaii. The top of this mountain is an amazing site for astronomical observations, where the altitude places the telescope above much of the water vapour that contaminates observations in the millimetre range of the electromagnetic spectrum. Here, "millimetre" means that the wavelength of the light used for observation is approximately 1 mm. The JCMT is great facility for this sort of discovery since it has a sheet of Gore-tex fabric across the opening of the dome, making it impossible to see the telescope dish from outside. The Gore-tex fabric is transparent to the millimetre-wave radiation but blocks the wind and sunlight from distorting the observations. This shield means that the JCMT is capable of twilight and daytime observations, which makes it possible to routinely observe Venus. Since Venus is always found near the Sun, such observations are difficult without the shield in place. With these special capabilities, the UK-led observing team eked out a weak detection of phosphine in the atmosphere. Such a detection was promising but could easily be explained away as an observational artifact. An independent observation would be needed.

The observing team then used the Atacama Large Millimetre/Submillimetre Array (ALMA) to map out the phosphine in Venus's atmosphere (Figure 1). Such observations require careful timing with ALMA and would never have been scheduled without the first hints of a detection from the JCMT. ALMA is the world's best millimetre-wave observatory and is able to make maps of where the phosphine is found in the atmosphere. The observations showed three things. First, the signature of the phosphine line was clear and definitely present in the atmosphere. Second, the phosphine was only found in the mid-latitude atmosphere of the planet. The equatorial and polar regions of the atmosphere showed no signs of the molecule. Finally, the strength of the line was clearly inconsistent with the expected amount of phosphine from simple atmospheric models.

The new observations indicated that the phosphine content in the mid-latitude atmosphere was a mere 20 parts per billion.

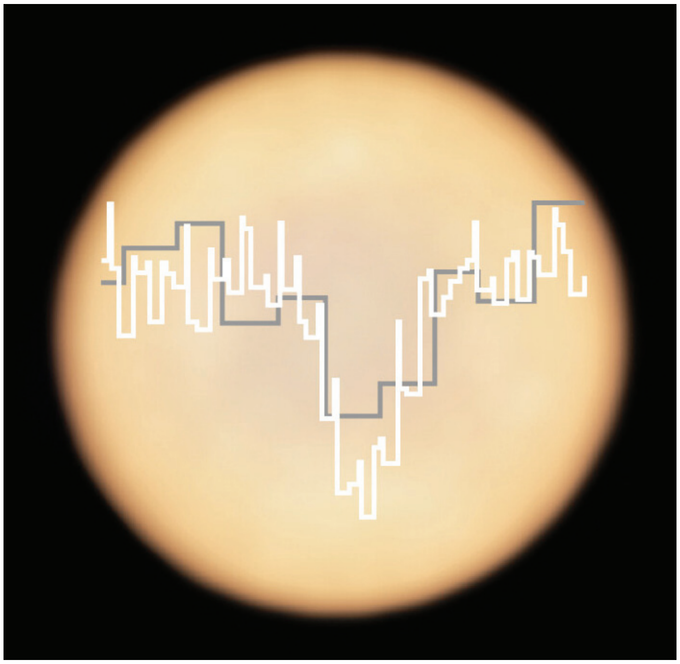


Figure 1 — Image of Venus with spectral profiles from the JCMT and ALMA superimposed. The spectral profiles are graphs of the amount of light received from the atmosphere at different observing frequencies. The actual signature of phosphine is this simple absorption line profile in the spectrum from the atmosphere. The line occurs at a specific frequency of radiation unique to the phosphine molecule. The depth of the absorption feature will indicate how much of the molecule is present. The darker profile is the preliminary JCMT data and the higher-quality ALMA profile is shown in the white profile. Credit: ALMA (ESO/NAOJ/NRAO), Greaves et al. & JCMT (East Asian Observatory)

Even so, this was an unexpectedly large amount. The expectation for far lower concentrations of phosphine comes from the chemical structure of the molecule: PH_3, i.e. one phosphorous and three hydrogen atoms. While hydrogen is common in the Universe overall, it is relatively rare on the terrestrial planets. Since hydrogen is light and the gravity from planets like Venus and Earth is relatively weak, free hydrogen typically boils off the planets and is blown by the solar wind into the outer Solar System. This process has been happening since the inception of the Solar System and explains why the gas giants are so hydrogen rich but the terrestrial planets are mostly made of heavier elements like iron, oxygen, and silicon. The hydrogen-rich gas giants have a significant amount of naturally occurring phosphine. The common chemicals found in the gas giants are usually a single atom of a heavier element plus the extra hydrogen atoms. Methane (CH_4), Ammonia (NH_3), Water (H_2O), and Phosphine (PH_3).

What little hydrogen is found in the inner Solar System is locked up in tightly bound molecules like water. Water is non-reactive because of the strength of the chemical bounds between the hydrogen and oxygen. Phosphorous is left to join up with other elements to make oxygen-rich species like phosphites (PO_3) or phosphorous acid (H_3PO_3). Hydrogen-saturated species like phosphine should have a short lifetime and low abundances in the oxidizing terrestrial atmospheres.

In the discovery article, the authors cite a few different reasons why there may be more phosphine than expected, citing unknown aspects of atmospheric chemistry, geochemistry, and life. The last of these grabbed the attention of the popular press, but this measurement is not clearly indicative or even strongly suggestive of there being life in Venus's atmosphere. If you read through popular articles in astronomy, the headline usually starts "Astronomers surprised by..." Given the prevalence, one might think that astronomers should stop being so complacent about the possibilities in the Universe and perhaps we should start to expect the unexpected more frequently.

Even so, we have explored a bit of Venusian atmospheric chemistry. Through a few direct missions and decades of remote observations with telescopes like the JCMT, we know the conditions are dramatically different from Earth's atmosphere, with a thick carbon-dioxide-rich atmosphere. The greenhouse effect leads to a surface temperature of 450 °C and an inhospitable chemistry with effects like sulphuric acid rains. Venus has a slow rotation leading to vast global circulation of air currents from the day to night side and back. Finding phosphine in the atmosphere is quite strange, but some unstudied reaction chain in the atmosphere or with volcanic activity could still explain the presence of the molecule.

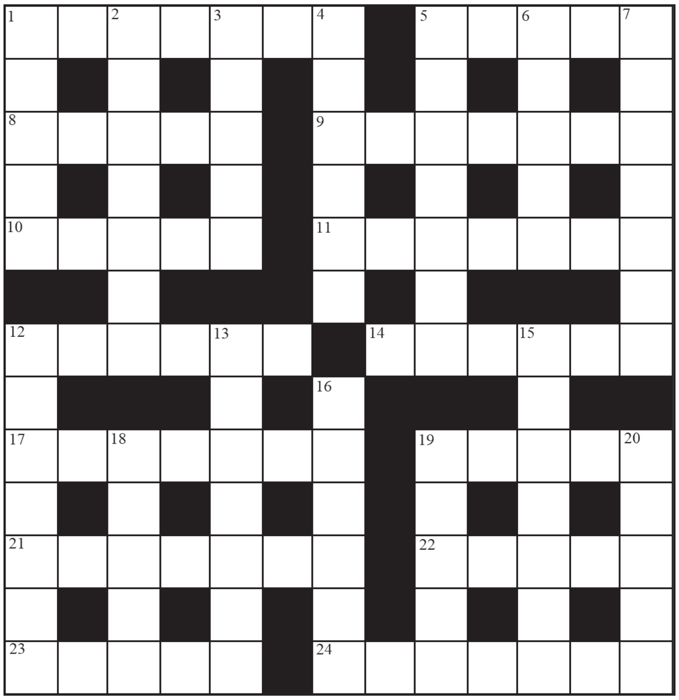
Life enters the list because there are bacterial species on the Earth that lead to extra phosphine in our own atmosphere. Such life could easily produce the amount of phosphine seen in the observation and plausibly could be held aloft in particular parts of Venus's planet-wide air currents. This would help explain why phosphine is not mixed throughout the atmosphere, but only found at certain latitudes.

This discovery is interesting and points to exciting new directions for observations. While directly sampling the atmosphere with a probe could be definitive, space flight remains expensive. Instead, the next steps will be to explore the hypothesized channels further and try to predict abundances of other chemicals under different scenarios. No atmospheric chemistry exists in isolation, so finding other species indicative of active geochemistry or a new pathway through atmospheric chemistry would suggest these mechanisms as explanations. Similarly, finding other unexpected and more complex biosignature molecules could indicate actual life in the atmosphere. Life does clearly exist in our Universe and arguably the biggest challenge in finding life may simply be recognizing it in unexpected places. ✶

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

Astrocryptic

by Curt Nason



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1. Get poor posture from going around Neptune (7)
5. British satellites studied cosmic rays around Uranus (5)
8. Pale as scattered light on Venus (5)
9. Age ungracefully before a billion years in the G Ring (7)
10. Swiss orbital whiz sounded like Gretzky once (5)
11. Strangely starve after holiday starts with this Moon (7)
12. Catch Arctic fish on a distant moon (6)
14. The distance space is curved around Rigel (6)
17. Uranian observer was all confused about less return (7)
19. Outreach performed while orbiting Jupiter (5)
21. Be a woman or another woman about Uranus (7)
22. Heartbreaking place for all to live (5)
23. In Greece, Mars follows north star to clear his nostrils (5)
24. Due to turn back, Babe leads us to a Greek astronomer (7)

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1. What makes the Moon change shape (5)
2. Brewing 1-hop ale near Uranus (7)
3. Hertzsprung turned Jane to Russell initially (5)
4. With his Tak modified he still couldn't see what went around Saturn (6)
5. Tattered regalia worn where Tin Bader is a big hole (7)
6. Hind's peaceful asteroid (5)
7. One afflicted with phased insanity (7)
12. Tempestuous mooncalf was mad about Uranus (7)
13. Canoe upset us in a stormy lowland plain (7)
15. X-rays detected around small company going about Uranus
16. Scale a region of a rocky fall, now in France (6)
18. Tricky orals given as a test for daytime observing (5)
19. Roland's cohort was also a nerd in orbit (5)
20. Those twist-up eyepieces are expensive (5)

Answers to October's puzzle

Across: **1** CANCER (2 def); **4** CANNON (2 def); **9** MOORE (anag); **10** SYNODIC (anag); **11** TWITTER (2 def); **12** YALIE (hid); **13** DECLINATION (2 def); **18** YEARS (Y+ears); **20** MINIMUM (M+in+i+mum); **22** NUCLEAR (anag); **23** VESTA (anag); **24** SCROLL (hid); **24** SECRET (anag+t)

Down: **1** COMETS (co(me)ts); **2** NEOWISE (anag+wise); **3** EVENT (even+t); **5** ALNIYAT (anag); **6** NODAL (Don+Al (rev)); **7** NICKEL (2 def); **8** ASTRONOMERS (anag); **14** LASSELL (lass+ell); **15** OH MASER (anag); **16** CYGNUS (Cy+gnus); **17** IMPACT (I'm+pact); **19** ALCOR (hid); **21** NOVAE (Avon (rev)+E)

The Royal Astronomical Society of Canada

Vision

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

Mission

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

Values

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

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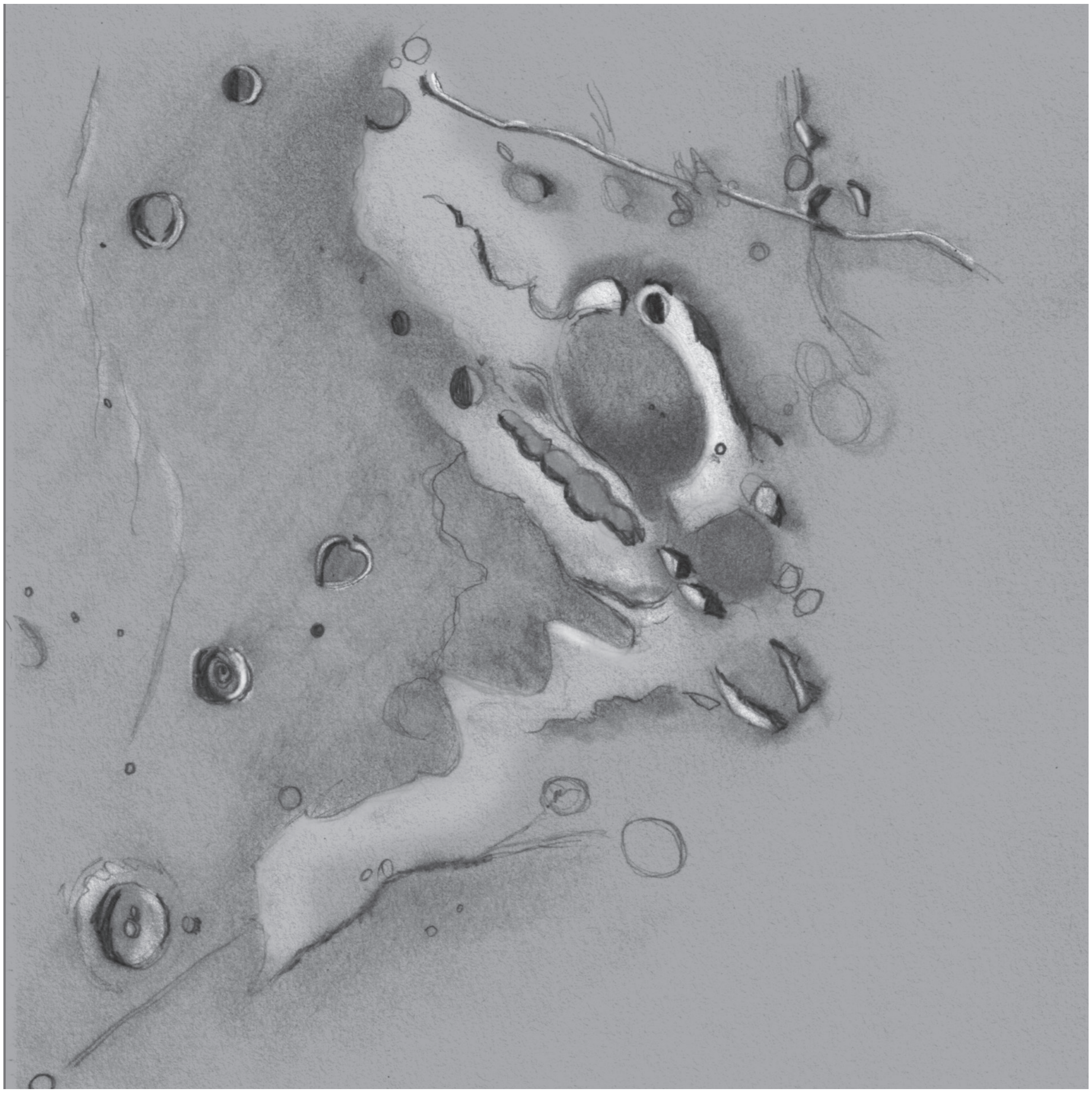
Great Images

by Michael Gatto



Halifax Centre member Michael Gatto sketched this image of the Moon back in 2019 April 11, between 8:30 and 9:30 p.m., from Cole Harbour, Nova scotia. There are four objects here that count toward the RASC's Explore the Moon program. Plinius (bottom left), Ross (up from Plinius), Arago (top left) and finally Julius Caesar (large crater above centre). Very notable was Rima Ariadaeus, running left to right along the top. Seeing was excellent, 9/10. Sketched at the eyepiece of an 8″ ƒ/8 Newtonian, scanned and coloured on an iPad using Procreate.

Journal

The Pleiades is a favourite target of many astrophotographers. Klaus Brasch captured the Seven Sisters using his AP-155 refractor at ƒ/5.2, with an IDAS LPS V4 filter, and a modified Canon 6D Mark II at ISO 3200. The image was processed in Photoshop CS6.