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PROMOTING ASTRONOMY IN CANADA

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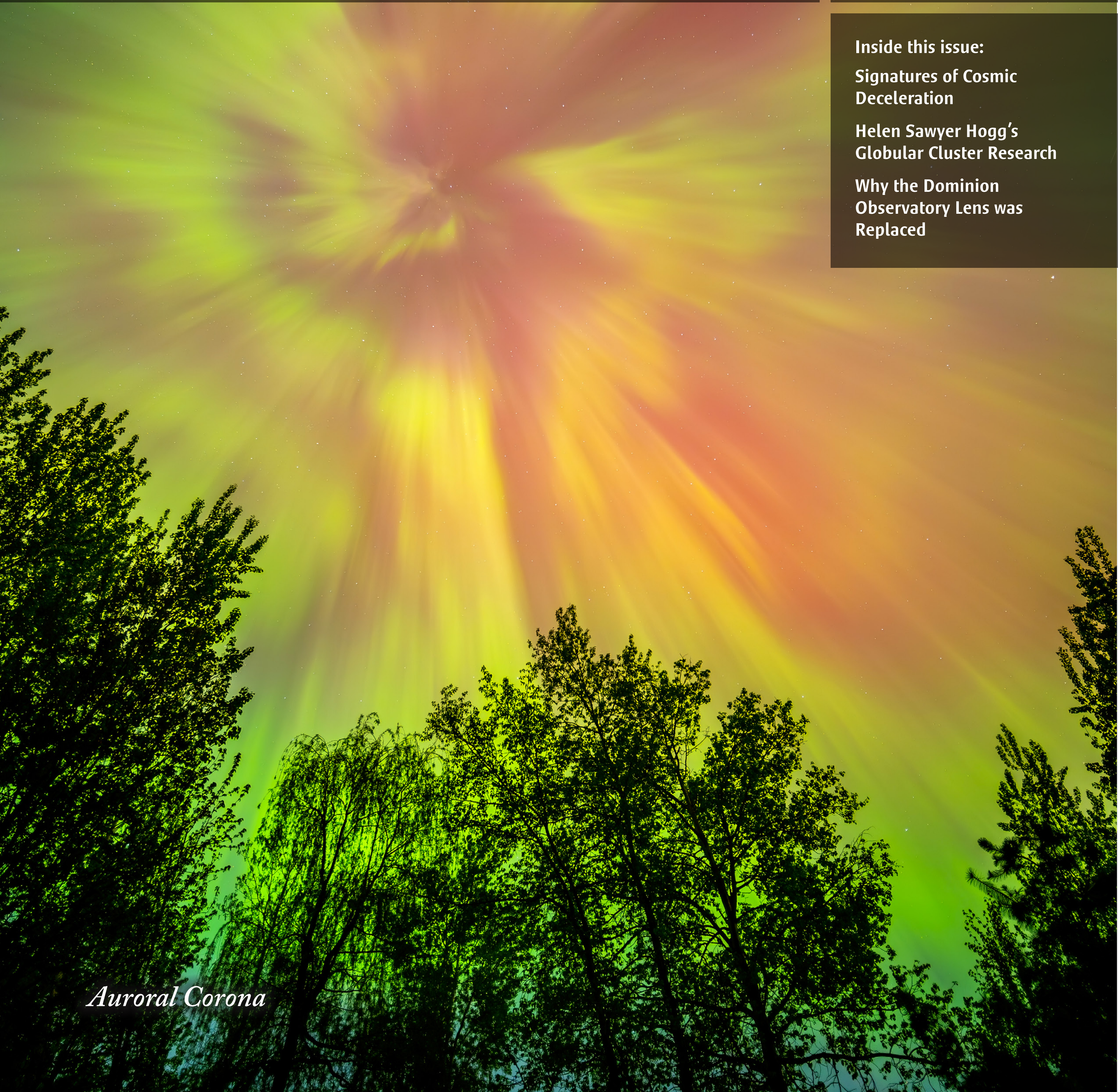
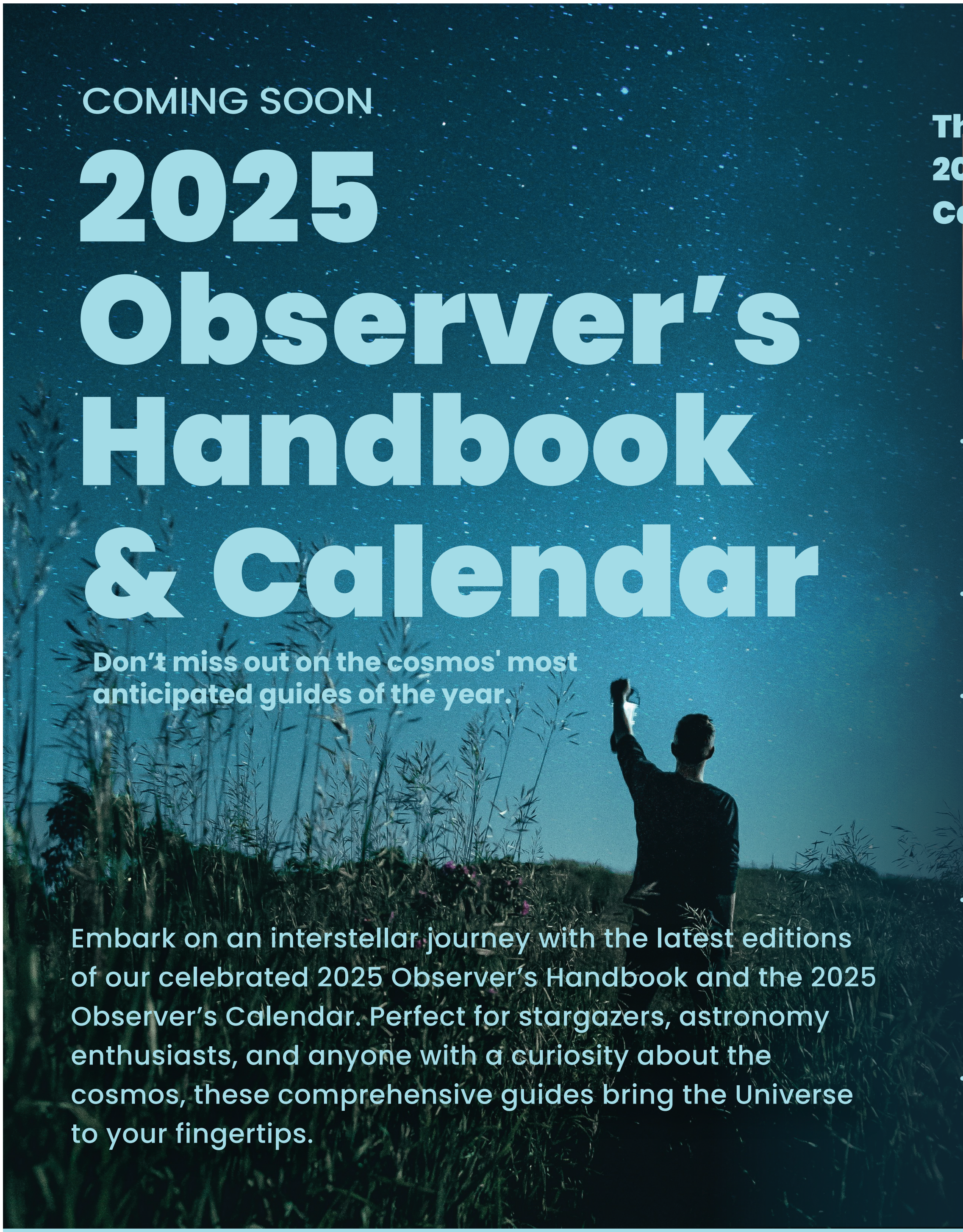


Auroral Corona



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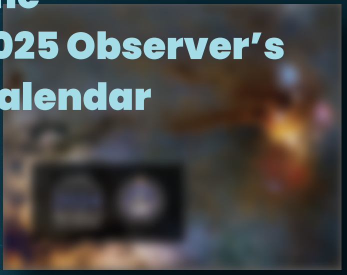

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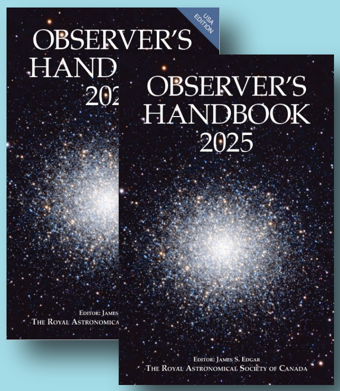

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Royal Astronomical Society of Canada

Société Royale d'Astronomie du Canada

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Great Images / Superbes images

On May 10th, people all over the planet were treated to a rare intense geomagnetic storm which produced stunning aurorae. And of course, the show was seen across Canada. Andrea Girones had just returned home from the RASC Ottawa Centre Public Star Party nearby where an early evening auroral outburst had thrilled visitors. Clouds rolled in but cleared early on the morning of May 11. "I don't think I will ever forget what I experienced," she says. "The auroral corona was directly above me for hours and naked-eye visible." Andrea took this image using a Nikon Z6ii, a Laowa 15mm lens at ISO 3200, 1 second, and ƒ/2.8.

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

The One-Minute Deep-Sky Astrophotographer

by Michael Watson, President
Michael.Watson@gowlingwlg.com

Our astronomy club boasts among its members an impressive number of skilled, experienced, and dedicated astrophotographers, whose staggeringly beautiful and technically accomplished images can be seen in every issue of this *Journal*. I'm thinking of such craftspeople as Andrea Girones of the Ottawa Centre, Blair MacDonald of the Halifax Centre, and National Treasurer Stuart Heggie. There are many others. Every time I gaze at the images that they produce I am awed, as well as envious of both their knowledge and the technical skills they have developed and honed to produce their detailed, high resolution works of art.

I am also envious of something else: Certainly not all of them, but many of the RASC's best astrophotographers have their own observatories, with permanently mounted astrophotographic telescopes that they are able to point at a single object during an entire observing session—or even over many nights spanning weeks or even months—in order to capture hours of photons from which they can work their digital darkroom magic and produce their superb finished images.

Some of us RASC astrophotographers don't have such observatories. Many of us live in cities that are not the most conducive environments for producing decent deep-sky images. We have to drive, often long distances, to place ourselves in dark-sky sites for the few precious hours that we have between the end of evening twilight and the lightening of the sky as morning comes up in the east. Then it's time to disassemble our gear, pack the car, and, after a night under the stars, drive back home.

That describes your national President. I live in the centre of light-polluted Toronto, and have to drive some hours to get to an observing site that is dark enough for at least half-serious deep-sky astrophotography. As some readers will know, my favourite, most readily accessible observing site in the Northern Hemisphere is in Algonquin Provincial Park, about 285 km north of my city home. When I am there, and especially since I am still working full-time and weekends are usually the only available time for astronomy, I want to make the most of the few nights during the year, and the few hours on those nights, to capture on the camera sensor what I can of the sky. Rather than concentrating for hours on a single object, over the past years I have chosen to produce images of as many of the familiar and striking deep-sky objects as I can using integration times of a few minutes to half an hour. Of course, with such short integration times I can't get nearly the depth and detail as do the astrophotographers whom I admire so

Figure 1 — Cygnus, Sigma 50mm ƒ/1.4 DG HSM Art lens; 5 subframes × 1 min. exposure; ISO 4000 at ƒ/ 4.5.

much. But I've found that even images produced with such short integration times can be of decent quality and are much appreciated by deep-sky enthusiasts, particularly when several images are assembled into presentations for RASC meetings, either at the RASC General Assembly or at Centre get-togethers.

The majority of my images, a few of which accompany this article for illustration, are made by stacking from 5 to 30 identical exposures of 1 minute each; that's right, just 1 minute. For years I have used a 35-mm Nikon D810a dedicated astro camera for all of my deep-sky photography, and I have found that the full-frame sensor on this camera is of sufficiently high quality that I can shoot at an ISO of up to about 6400 and (stacking numerous frames to reduce the noise in individual subframes) to produce pleasing images. There is a great deal of image stacking software available, from a simple-to-use beginner's program such as DeepSkyStacker, to the very advanced, such as PixInsight. Most of these programs also come complete with image processing functions, in addition to subframe stacking capabilities.

I have been a fan of wide-angle astroimages for many years. Many of my images are of entire constellations and well-known star patterns, and are made with camera lenses with focal lengths from 28 to 400 mm. The sharpest lenses that I use

Figure 2 — Large Magellanic Cloud, 660 mm focal length Tele Vue telescope; 20 subframes × 1 min. exposure; ISO 5000 at ƒ/ 5.2

Figure 3 — The Trifid Nebula (M20, left) and Lagoon Nebula (M8, right): 660 mm focal length Tele Vue telescope; 12 subframes × 1 min. exposure; ISO 4000 at ƒ/ 5.2

for this type of work are the 35-mm and 50-mm ƒ/1.4 DG HSM ART lenses, which I stop down to at least ƒ/2.8 and often to ƒ/4.5. I do this for two reasons: (i) in order to reduce almost to the point of elimination the noticeable vignetting (dark shading) that one sees in the corners of a frame when the lens is used wide open at ƒ/1.4, and (ii) to get the sharpest pinpoint star images out to the very edges of the frame, rather than just in the centre. When I am shooting with my favourite Nikkor AF-S 70-200-mm ƒ/2.8 G ED VRII lens, I'll stop down to ƒ/4 or ƒ/5.6. Naturally, stopping lenses down in this fashion requires an increased ISO setting, but very good wide-field images can be made at ISO 1600 to 4000. The sensors on modern 35-mm DSLR and mirrorless cameras are so good that, with stacking of half a dozen to two dozen subframes, noise (or pixellation) is almost undetectable in the finished images.

For higher magnification photography I use either (i) a Tele Vue NP127is apochromat with a focal length of 660 mm and a focal ratio of ƒ/5.2, or (ii) an Explore Scientific 152-mm apochromat, with a focal length of 1253 mm and a focal ratio of ƒ/8, as is typical for refractors of the size. The Tele Vue 127 is a magnificent scope in my experience, giving a 3.1 by 2.1 degree field on a 35-mm frame, and producing images that to my eye are quite pleasing even with short, 1-minute exposures for the subframes.

Of course, the best camera lenses and astrophotographic telescope are of little use without a good mount. I use either a heavy-duty Astro-Physics 1100GTO mount (www.astro-physics.com/1100gto) or a smaller, lighter and more portable Sky-Watcher EQ6-R PRO mount (www.skywatcherusa.com/products/eq6-r-pro), both of which keep even my longest focal-length scope pointed precisely at my target without guiding for the short exposures I use.

I'll conclude by saying this: Certainly hours-long integration times are necessary for the ultra-high resolution, highly detailed observatory quality images that we marvel at in magazines and at RASC meetings. But with the right equipment, pleasing deep-sky astrophotographic images can definitely be made with short exposures. Would-be or neophyte astroimagers should try being a one-minute deep-sky astrophotographer; you might be very surprised at your results! ✶

The October 2024 *Journal* deadline
for submissions is 2024 August 1.

See the published schedule at
rasc.ca/sites/default/files/jrascschedule2024.pdf

News Notes / En manchette

Compiled by Jay Anderson

Solar magnetism is only skin deep

When telescopes first became widely available in Europe, it was not long before those fortunate to possess one turned it to the Sun. Thomas Harriot was likely the first, in late 1610, but others were not far behind: Galileo, Johannes Fabricius, and Christoph Scheiner, in particular. Scheiner believed the spots were small bodies in orbit around the Sun; Fabricius and then Galileo, suggested clouds in the solar atmosphere. Today we recognize that sunspots are places where the solar magnetic field emerges from the Sun's photosphere and now research has turned to discovering the source of that magnetic field.

Our magnetic sheath is generated by a dynamo in the Earth's outer core: a convective region within an electrically conductive fluid that turns turbulent motions into a magnetic energy. A parallel process operates beneath the solar surface. Investigation and research in the century after the discovery of the solar magnetic field in 1910 suggest that the solar dynamo process begins at the bottom of a deep ocean of churning gases more than 210,000 km below the surface.

Now, mathematical modelling using a NASA supercomputer by a team led by Geoffrey Vasil of the School of Mathematics at the University of Edinburgh indicates instead that the process originates relatively nearer to the surface, some 32,000 km below. Using observations from the Global Oscillation Network Group (GONG) solar telescopes, the team associated a low-latitude longitudinal flow (called a torsional oscillation) in the outer 5 to 10 percent of the solar disk as being a part of the generation of the solar magnetic field. The GONG network, by observing the solar disk continuously with a global web of telescopes, is able to decipher the subsurface structure of the Sun through a process akin to seismology networks on the Earth. One of the clues to a shallower dynamo was the realization that the cyclical movement of torsional oscillations matched the sunspot cycle. The traditional description of the solar magnetic field could not explain the origin of torsional oscillations, which are only found close to the solar surface. The deep-dynamo theories also predicted a strong high-latitude magnetic field, which doesn't occur, and were unable to reproduce the sunspot cycle.

According to Dr. Vasil, "The solar dynamo is the oldest unsolved problem in theoretical physics; it's absolutely fascinating. We know the dynamo acts like a giant clock with many complex interacting parts, but we don't know all the pieces or how they fit together. Knowing how something starts is essential to understanding and predicting it. My colleagues and I have been working out the details of these ideas for 20 years; it's very satisfying to see the model fit nicely with observational data. We found a new idea about how the Sun's dynamo happens, which was quite unexpected but makes a lot of sense in the context."

"Understanding the origin of the Sun's magnetic field has been an open question since Galileo and is important for predicting future solar activity, like flares that could hit the Earth," said study co-author Daniel Lecoanet of Northwestern University. "This work proposes a new hypothesis for how the Sun's magnetic field is generated that better matches solar observations, and, we hope, could be used to make better predictions of solar activity."

With a better understanding of the Sun's dynamo, researchers hope to improve forecasts for solar storms. When solar flares and coronal mass ejections launch toward Earth, they can severely damage electrical and telecommunications infrastructure, including GPS navigation tools. The strong solar storm in May, for example, knocked out navigational systems for farming equipment—right at peak planting season.

"While the recent solar storms were powerful, we're worried about even more powerful storms like the Carrington Event," Lecoanet said. "If a storm of similar intensity hit the United States today, it would cause an estimated $1 trillion to $2 trillion in damage. Although many aspects of solar dynamics remain shrouded in mystery, our work makes huge strides in cracking one of the oldest unsolved problems in theoretical physics and opens the way to better predictions of dangerous solar activity."

Compiled with material provided by the University of Edinburgh and Northwestern University.

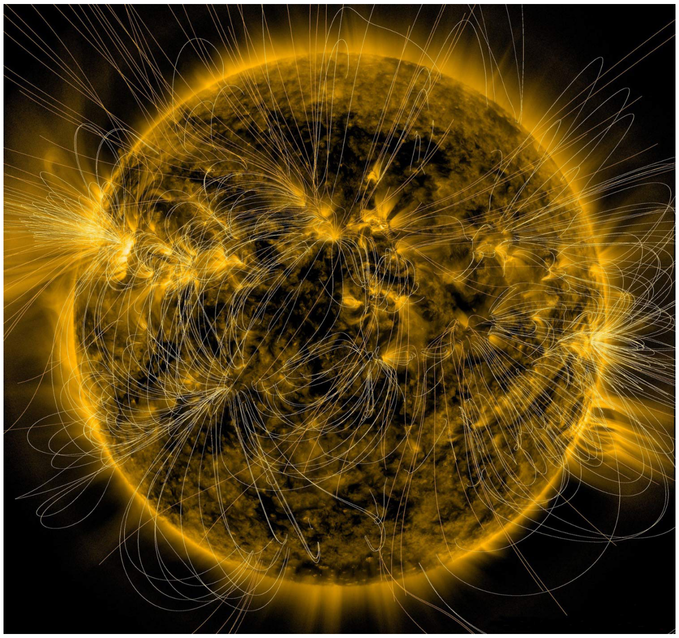

Figure 1 — Solar Dynamic Observatory *image of the solar corona in UV light with superimposed magnetic field lines (yellow). Image: NASA / SDO / AIA / LMSAL.*

Companions—but not forever

There are millions of asteroids floating around the Solar System. Many have companions—in fact, about 15 to 40 percent of asteroids larger than 200 m in diameter are thought to be binaries. With so many of them, it should be no surprise that some are unusual configurations. A recent example of one of these was discovered when *Lucy*, NASA's mission to the Trojan asteroids, passed by a main-belt asteroid called Dinkinesh.

Lucy discovered that Dinkinesh had a moon—and that moon was a contact binary. Now known as Selam, it is made up of two objects that physically touch one another but aren't fully merged. Just how and when such an unexpected system might have formed is the subject of a new paper by Colby Merrill, a graduate researcher at Cornell, with co-authors at the University of Colorado and the University of Bern. His co-authors were Alex Meyer, a doctoral candidate at the University of Colorado Boulder, and Sabina Raducan, a postdoctoral researcher at the University of Bern in Switzerland.

"Finding the ages of asteroids is important to understanding them, and this one is remarkably young when compared to the age of the Solar System, meaning it formed somewhat recently," said Merrill, a doctoral student in the field of aerospace engineering. "Obtaining the age of this one body can help us to understand the population as a whole."

The research team modelled how the system might have formed and how it might have evolved, in particular, how two forms of the Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect would cause secular changes in rotation state. The YORP effect changes the rotation state of a small astronomical body—that is, the body's spin rate and the obliquity of its pole(s)—due to the scattering of solar radiation off its surface and the asteroid's emission of thermal radiation. Photons interacting with the surface carry off or bring momentum, spinning up the rotation rate of the asteroid to a point where its gravity is no longer capable of holding all of its material on its surface. Some of that material is ejected out into space, eventually coalescing into a moon of the larger asteroid.

Dinkinesh isn't a large asteroid by any measure—at its widest point, it only measures about 790 metres in diameter. The satellite is named after the fossil remains of a three-year-old *Australopithecus afarensis* female hominin (the same species as the Lucy fossil) found in Dikika, Ethiopia, in 2000, and is also the Amharic word for "peace." Selam is about 220 metres at its widest point but actually has two widest points because it is unusually shaped in what is technically called bilobate but more commonly thought of as having a "dumbbell" shape.

When an asteroid has a companion, two other evolutionary processes can take place. One, nicknamed BYORP, is simply the YORP process acting on the orbital parameters of the binary system. The second process is the tidal interactions between the partners in their orbital dance. Both the BYORP process and the tides can either expand or contract the secondary's semi-major axis but tides tend to be expansive, as the spin rate of the primary is almost always greater than the orbit rate of the secondary; the BYORP process tends to bring a contraction. Eventually the two opposing forces will settle into a stable equilibrium.

That stability is not absolute, as it requires that the primary partner's spin rate remains constant, even though the YORP torques are still acting on the individual members of the pair (particularly the primary partner). Stability then requires that the ongoing YORP torques be balanced by ongoing tidal torques.

The authors conducted over a million Monte Carlo simulations of the orbital evolution to obtain statistical approximation of the age taken by Selam to settle into a stable state from its initial formation from ejecta released by Dinkinesh. This method attempts to find a "correct" answer by varying the inputs to the equations and randomly sampling the results. The authors used

Figure 2 — The Dinkinesh/Selam binary system showing that Salem itself is a contact binary. Image: NASA/Goddard/SwRI/Johns Hopkins APL

inputs such as each object's sizes and orbital speeds. In the end, the majority of the solutions suggested that the binary system evolved over a time limit between 1 and 10 million years, with a median age of 3 million—not very long in the grand scheme of the Solar System's evolution.

Studying these kinds of unexpected systems could prove fruitful in understanding how asteroids more generally are formed. More work is needed, especially an analysis of the craters present on Selam, which could provide an alternative view of its age. Given that we only just discovered this binary system by chance in November 2023, those data, and much else from the *Lucy* mission, will doubtless be forthcoming.

Composed with material provided by Cornell University.

Pluto's depths hold up planet's surface

A proposed ocean of liquid water deep beneath the icy surface of Pluto is coming into focus thanks to calculations by Alex Nguyen, a graduate student in Earth, Environmental and Planetary Sciences in Arts & Sciences at Washington University in St. Louis, and Patrick McGovern of the Lunar and Planetary Institute in Houston.

Nguyen and McGovern used mathematical models and images from the *New Horizons* spacecraft that passed by Pluto in 2015 to take a closer look at the ocean that likely covers the planet beneath a thick shell of nitrogen, methane, and water ice. Their attention was focused on Sputnik Planitia, a large impact basin filled with nitrogen ice. The weight of that ice must be supported by underlying structures, presumably a water ocean.

For many decades, planetary scientists assumed that Pluto could not support an ocean. The surface temperature is about –220 °C, a temperature so cold even gases like nitrogen and methane freeze solid. Water shouldn't have a chance. "Pluto is a small body," said Nguyen. "It should have lost almost all of its heat shortly after it was formed, so basic calculations would suggest that it's frozen solid to its core."

But in recent years, scientists have gathered evidence suggesting Pluto likely contains an ocean of liquid water beneath the ice. That inference came from several lines of evidence, including Pluto's cryovolcanoes that spew ice and water vapour. Although there is still some debate, "It's now generally accepted that Pluto has an ocean," Nguyen said.

The new study probes the ocean in greater detail, even if it's far too deep below the ice for scientists to ever see. Nguyen and McGovern created mathematical models to explain the deformations and stresses in the ice covering Pluto's Sputnik Platina Basin. Their calculations suggest the ocean in this area exists beneath a shell of water ice 40 to 80 km thick, a blanket of protection that likely keeps the inner ocean from freezing solid.

Figure 3 — NASA's New Horizons *spacecraft captured this high-resolution enhanced colour view of Pluto on 2015 July 14. The large white basin at centre right is Sputnik Planitia. Credit: NASA/JHUAPL/SwRI*

They also calculated the likely density or salinity of the ocean based on the fractures in the ice above. They estimate Pluto's ocean is, at most, about 8 percent denser than seawater on Earth, or roughly the same as Utah's Great Salt Lake. That level of density would explain the abundance of fractures seen on the surface: if the ocean was significantly less dense (particularly if it was fresh water), the ice shell would collapse, creating many more fractures than actually observed. If the ocean was much denser, there would be fewer fractures. "We estimated a sort of Goldilocks zone where the density and shell thickness are just right," Nguyen noted.

The modelling results also predict an ocean depth of no more than 6 km with most likely values in the 3–4-km range.

Space agencies have no plans to return to Pluto any time soon, so many of its mysteries will remain for future generations of researchers. Whether it's called a planet, a planetoid, or merely one of many objects in the outer reaches of the Solar System, it's worth studying, Nguyen said. "From my perspective, it's a planet."

Composed in part by material provided by Washington University in St. Louis.

CO_2 stretches across the Solar System

For the first time, carbon dioxide and carbon monoxide ices have been observed in the far reaches of our Solar System on trans-Neptunian objects (TNOs).

A research team, led by planetary scientists Mário Nascimento De Prá and Noemí Pinilla-Alonso from the University of Central

Figure 4 — Arrokoth, a trans-Neptunian world captured by New Horizons *as the spacecraft passed the 30-km-long rock on 2019 January 1. Image: NASA.*

Florida's Florida Space Institute (FSI), made the findings by using the infrared spectral capabilities of the *James Webb Space Telescope* (JWST) to analyze the chemical composition of 59 trans-Neptunian objects (TNOs) and Centaurs.

The researchers reported the detection of carbon dioxide in 56 TNOs and carbon monoxide in 28 (plus six with dubious or marginal detections), out of the sample of objects observed with the JWST. Carbon dioxide was widespread on the surfaces of the trans-Neptunian population, independent of the dynamical class and body size, while carbon monoxide was detected only in objects with a high carbon-dioxide abundance, according to the study.

The study suggests that carbon-dioxide ice was abundant in the cold outer regions of the protoplanetary disk, the vast rotating disk of gas and dust from which the Solar System formed. Further investigation is needed to understand the carbon monoxide ice's origins, as it is also prevalent on the TNOs in the study.

"It is the first time we observed this region of the spectrum for a large collection of TNOs, so in a sense, everything we saw was exciting and unique," says de Prá, who co-authored the study. "We did not expect to find that carbon dioxide was so ubiquitous in the TNO region, and even less that carbon monoxide was present in so many TNOs."

"Trans-Neptunian Objects are relics from the process of planetary formation," de Prá says. "These findings can impose important constraints about where these objects were formed, how they reached the region they inhabit nowadays, and how their surfaces evolved since their formation. Because they formed at greater distances to the Sun and are smaller than the planets, they contain the pristine information about the original composition of the protoplanetary disk."

Possible reasons for the lack of previous detections of carbon dioxide ice on TNOs include a lower abundance, non-volatile carbon dioxide becoming buried under layers of other less-volatile ices and refractory material over time, conversion into other molecules through irradiation, and simple observational limitations.

The discovery of carbon dioxide and carbon monoxide on the TNOs provides some context while also raising many questions, de Prá says.

"While the carbon dioxide was probably accreted from the protoplanetary disk, the origin of the carbon monoxide is more uncertain," he says. "The latter is a volatile ice even in the cold surfaces of the TNOs. We can't rule out the carbon monoxide was primordially accreted and somehow was retained until the present date. However, the data suggests that it could be produced by the irradiation from carbon-bearing ices.

"The spectral imprint of carbon dioxide revealed two distinct surface compositions within our sample. In some TNOs, carbon dioxide is mixed with other materials like methanol, water ice, and silicates. However, in another group—where carbon dioxide and carbon monoxide are major surface components—the spectral signature was strikingly unique. This stark carbon-dioxide imprint is unlike anything observed on other Solar System bodies or even replicated in laboratory settings."

It now seems clear that when carbon dioxide is abundant, it appears isolated from other materials, but this alone doesn't explain the band shape, Pinilla-Alonso says. Understanding these carbon dioxide bands is another mystery, likely tied to their unique optical properties and how they reflect or absorb specific colours of light, she says.

"In comets, we observe carbon dioxide as a gas, released from the sublimation of ices on or just below the surface," she says. "However, since carbon dioxide had never been observed on the surface of TNOs, the common belief was that it was trapped beneath the surface. Our latest findings upend this notion. We now know that carbon dioxide is not only present on the surface of TNOs but is also more common than water ice, which we previously thought was the most abundant surface material. This revelation dramatically changes our understanding of the composition of TNOs and suggests that the processes affecting their surfaces are more complex than we realized."

Study co-authors Elsa Hénault, a doctoral student at the Université Paris-Saclay's Institut d'Astrophysique Spatiale, and the French National Centre for Scientific Research, and Rosario Brunetto, Hénault's supervisor, brought a laboratory and chemical perspective into the interpretation of JWST observations.

Hénault analyzed and compared the absorption bands of carbon dioxide and carbon monoxide across all objects. While there was ample evidence of the ice, there was a great diversity in abundance and distribution, Hénault says.

"While we found CO_2 to be ubiquitous across TNOs, it is definitely not uniformly distributed," she says. "Some objects are poor in carbon dioxide while others are very rich in carbon dioxide and show carbon monoxide. Some objects display pure carbon dioxide while others have it mixed with other compounds. Linking the characteristics of carbon dioxide to orbital and physical parameters allowed us to conclude that carbon dioxide variations are likely representative of the objects' different formation regions and early evolution."

Through analysis, it is very likely that carbon dioxide was present in the protoplanetary disk, however, carbon monoxide is unlikely to be primordial, Hénault says.

"Carbon monoxide could be efficiently formed by the constant ion bombardment coming from our sun or other sources," she says. "We are currently exploring this hypothesis by comparing the observations with ion irradiation experiments that can reproduce the freezing and ionizing conditions of TNO surfaces."

The research brought some definite answers to longstanding questions dating back to the discovery of TNOs nearly 30 years ago, but researchers still have a long way to go, Hénault says.

"Other questions are now raised," she says. "Notably, considering the origin and evolution of the carbon monoxide. The observations across the complete spectral range are so rich that they will definitely keep scientists busy for years to come."

Composed in part with material provided by the Florida Space Institute, University of Central Florida. ✶

Feature Article / Article de fond

Highlights of Helen Sawyer Hogg's Globular Cluster Research

by Christine Clement
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Abstract

Helen Sawyer Hogg was an esteemed member of the RASC. She served as the Society's President from 1957–1959 and Honorary President from 1977 to 1981. She was famous for her research on globular clusters, particularly their variable stars. In addition, her bibliographies and catalogues were highly valued. However, it is not as widely known that some of her early research had a significant impact on the cosmic distance scale.

Introduction

Helen Sawyer Hogg (1905–1993) was a well-known astronomer who carried out most of her research at the University of Toronto's David Dunlap Observatory. She was born in Lowell, Massachusetts, and obtained her undergraduate degree from Mount Holyoke College in 1926. After that, she pursued graduate studies at the Harvard College Observatory.

When she was at Harvard, her supervisor was the eminent astronomer Harlow Shapley, who was acclaimed for his ground-breaking research on the Milky Way globular clusters. By deriving their distances and mapping their distribution over the sky, he had demonstrated that the Sun was not at the centre of our galaxy. In fact, it was far from it (Shapley 1919). With this breakthrough, he accomplished for our perception of the galaxy what Copernicus had done for the Solar System centuries earlier.

Shapley completed his seminal research a decade earlier when he was working at the Mount Wilson Observatory in California. In the meantime, he had moved to the east coast to become director of the Harvard College Observatory. This move gave him access to Harvard's extensive photographic plate collection that covered the entire sky, both Northern and Southern Hemispheres. In addition, there was a group of competent people, many of them women, to assist him with his various research projects (Broughton 2002). Of particular interest to him were the numerous globular cluster photographs in the collection. These provided an opportunity for him to expand the data sample for his research on establishing the size of the galaxy. However, in order to do this, he needed to find a suitable person to assist with the project. That person turned out to be Helen Sawyer Hogg, then known as Miss Sawyer.

During her time at Mount Holyoke College, she had developed a great interest in globular clusters; they were her favourite celestial objects (Sawyer Hogg 1988). So, it was an ideal arrangement. The plan was for her to help Shapley with a book on star clusters.

The Shapley-Sawyer collaboration

Helen began working with Shapley in September 1926. Their objective was to redetermine the distances of the Milky Way globular clusters using Harvard observations, and over the next few years they co-published a series of papers to achieve their goal.

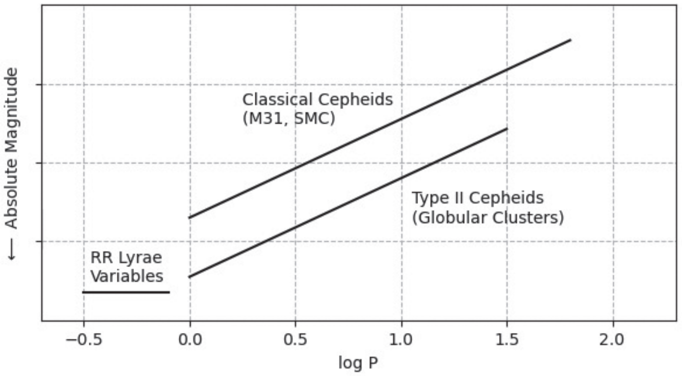

Figure 1 — Schematic diagram illustrating the period-luminosity (P-L) relation for Baade's two populations. The relation for the classical Cepheids (population I) is 1.5 magnitudes brighter than the one for the type II Cepheids (population II). Baade and Thackeray did not know this when they were searching for RR Lyrae variables in M31 and the SMC. They assumed that the Cepheids in these galaxies followed the same P-L relation as the ones in the globular clusters in our own galaxy. Therefore, they expected the RR Lyrae variables to be 1.5 mag. brighter than they turned out to be.

In those days, the best technique for estimating cluster distances involved studying their RR Lyrae variable stars, then known as cluster type Cepheids. The method was based on the assumption that the mean absolute magnitude of an RR Lyrae was essentially invariable and independent of the length of the period. This was the conclusion reached by Harvard astronomer Solon Bailey and his colleagues, based on the results of their early studies of variable stars in the globular clusters Omega Centauri, M3, M5, and M15 (Bailey 1902, 1913, 1917; Bailey et al. 1919). Unfortunately, only 19 of the 93 clusters investigated by Shapley and Sawyer had enough available data to make this approach viable. For the remaining clusters, they had to employ other methods.

In his earlier work, Shapley (1918b) had shown that the difference between the mean apparent magnitude of the 25 brightest stars and the median magnitude of the RR Lyrae variables in a cluster was a constant. Thus, if the apparent magnitudes of the brightest stars in a cluster could be estimated, the mean magnitude of the RR Lyrae variables could be inferred, and its distance computed. This was painstaking work that involved estimating the apparent magnitudes of thousands of stellar images, but Helen demonstrated that she was up to the task. By applying this method to the clusters in the Harvard plate collection, they were able to increase the number of cluster distances to 48.

To further increase their sample, they measured general cluster properties, such as integrated brightness and apparent size (angular diameter). To a first approximation, the integrated brightness of a cluster is related to its distance because nearby objects appear brighter. Similarly, the apparent size is also related to distance because nearby clusters will appear larger.

By combining all of these methods, they were able to extend the number of clusters with known distances to 93. In Shapley's (1918b) earlier investigation, that number was only 69. They published their results in a series of papers: Sawyer & Shapley (1927), Shapley & Sawyer (1927a, 1927b, and 1929). They noted that there was a systematic decrease in distances by 11 percent, compared with Shapley's earlier results, due to a change in the zero point of the period-luminosity relation, as we shall see shortly. Because of this, and also because of the increase in the basic photometric data and in the number of clusters with variable stars involved, their revised distances were much more secure than those previously determined by Shapley. The results of their study were subsequently published in Shapley's (1930) book on star clusters.

Meanwhile, in California, Edwin Hubble was using the Mount Wilson 100-inch reflector to observe nebulous objects in M31, the Andromeda Galaxy. He found 140 objects that he provisionally identified as globular clusters and derived their absolute magnitudes (Hubble 1932). When he compared them with the clusters in the Milky Way, based on Shapley's (1930) results, he found there was a range of about 3 magnitudes in absolute magnitude of the objects in both systems. However, the mean magnitude of the ones in M31 was fainter by about 1.5 mag.

At the time, it was generally assumed that the globular clusters in the two systems should have similar properties and that the difference was probably due to uncertainties in the integrated magnitudes of the Milky Way globular clusters. Obtaining reliable values for these, particularly the ones with large angular diameters, was a challenging problem. In fact, Shapley and Sawyer (1929) acknowledged that their magnitudes were on an "open" system and not to be taken as true stellar magnitudes. Nevertheless, another possible explanation for the discrepancy was that there was an inconsistency in the methods used to determine the distances of the clusters in the two systems. Eventually, this turned out to be the case, but it was not recognized until more than a decade later, after Walter Baade (1944) discovered that there were two populations of stars.

Shapley and the period-luminosity relation

When Shapley (1918 a,b) derived the globular cluster distances, he used the period-luminosity (P-L) relation. This was a correlation that had been discovered a few years earlier by Henrietta Leavitt (Leavitt 1908, Leavitt and Pickering 1912) at Harvard. In the course of analyzing observations of Cepheid variable stars in the Small Magellanic Cloud (SMC), she found that there was a nearly linear relationship between the stars' apparent magnitudes and the logarithm of their period. Since these variables were probably at nearly the same distance from the Earth, she realized that the periods must be associated with their actual brightness. Thus, the Cepheid P-L relation could be used for distance determination. Even today, more than a century later, the relation is still being used to calculate distances to extragalactic systems. In recognition of Leavitt's fundamental discovery, it is now referred to as the Leavitt Law (Freedman & Madore 2010).

The first person to apply this law was Ejnar (1913) who used Leavitt's data to determine the distance to the Cepheids in

Figure 2 — Helen Sawyer Hogg standing beside the 74-inch telescope at the David Dunlap Observatory in Richmond Hill, Ontario, Canada. She used this telescope to photograph globular clusters for 35 years, beginning in 1935. Prior to that, she observed for 4 years with the 72-inch telescope at the Dominion Astrophysical Observatory in Victoria, British Columbia. Credit: University of Toronto Archives - B1994-0002/005P (33) Janine Photo Studio Toronto

the SMC. He derived the slope of the P-L relation from her observations, but in order to compute the distance, he needed to establish a zero point, the absolute magnitude of a Cepheid with known period. He accomplished this by determining the distances of Cepheids in our galaxy. This involved performing a statistical analysis of their proper motions and radial velocities.

Shapley (1918b) used the same technique when he derived the globular cluster distances. However, in order to achieve this, he had to be creative because the vast majority of globular cluster variables were the RR Lyrae type. These stars had periods less than a day, while Leavitt's SMC variables had periods that ranged from 2 to 127 days. It turned out that, when Bailey (1902) investigated Omega Centauri, he had discovered five Cepheids with periods ranging from 1.3 to 29.5 days, in addition to the numerous (more than 100) RR Lyrae variables. So, Shapley's modus operandi was to match the slope of the P-L relation of these longer-period Cepheids to the ones in the SMC. This made it possible for him to estimate a mean absolute magnitude for the RR Lyrae variables in Omega Centauri. Three other clusters were also included in his study, but none of them could be used to verify the slope. M3 had only one long-period Cepheid, with a period of 15.8 days; M15 had one with a period of 1.4 days; and M5 had two, but both had periods of approximately 26 days.

At the time, some astronomers were concerned that Shapley's P-L relation was based on so few clusters and so few variables that it had little meaning. Helen heard about this at a meeting of the American Astronomical Society in 1927. It came as quite a shock to her because Shapley was her mentor. Nevertheless, it motivated her to investigate the literature on the subject and she soon realized there was too little material to warrant the significance being given to it. She related this story many years later when she gave her presidential address to the Canadian Astronomical Society in 1972 (Sawyer Hogg 1973a), and also at a symposium held at Harvard in 1986 to celebrate the Shapley centenary (Sawyer Hogg 1988).

This inspired her to embark on a program to determine periods in clusters that had not been well studied. At first, she made use of the backlog of plates obtained at the Harvard southern stations in Arequipa, Peru, and Bloemfontein, South Africa. Then later, after she moved to Canada, she had the opportunity to make her own observations.

Helen Sawyer Hogg's globular cluster observing program

While Helen was at Harvard, she met her future husband, Canadian Frank Hogg, who was also an astronomy graduate student. In 1931, after they had both completed their Ph.D. degrees, they moved to Canada. First, they lived in Victoria, British Columbia, where they worked at the Dominion Astrophysical Observatory (DAO). Then, they relocated to Richmond Hill, Ontario, to continue their work at the University of Toronto's David Dunlap Observatory (DDO) when it opened in 1935.

All of this happened during the Great Depression years when it was not possible for both husband and wife to be employed. However, at both observatories, Helen was given access to the main telescope to set up her own observing program. At the DAO, this was the 72-inch reflector and at the DDO, it was the 74-inch. In those days, the only telescope that had a larger aperture than these two was the 100-inch at Mount Wilson in California. It was a testament to her outstanding achievements at Harvard that she was given access to these world-class facilities, and she used them both to great advantage.

The motivation for her program was to photograph globular clusters so that she could search for variable stars. During the course of her research with Shapley, she became well aware of the importance of RR Lyrae variables for determining globular cluster distances. However, she also recognized that, in order to better establish the globular cluster P-L relation, it was important to discover Cepheids with periods greater than a day. (Nowadays, these longer-period variables are called type II Cepheids, see Fig. 1). Clearly there was much work to be done. In the ensuing years, she identified and characterized the variable-star population in numerous globular clusters.

Most of the variables were of the RR Lyrae type, which is the most frequently occurring variability type among globular cluster stars. They outnumber type II Cepheids by about a factor of 30 (Clement 2017). She used her RR Lyrae data, along with previously published material, to make a preliminary study of the period distribution of globular cluster RR Lyrae variables (Sawyer 1944). However, she also discovered a significant number of type II Cepheids and this was where her research had the most impact. Three of the clusters she investigated contained type II Cepheids with a range of periods. These were M2, which had four (Sawyer 1935), M14 with three (Sawyer 1938), and M13 with three (Sawyer 1942). In all of these clusters, she showed that the slope was in agreement with the one that Shapley derived for Omega Centauri. In addition, she identified type II Cepheids in six other clusters: M10, M12, M22, M28, M56, and M80 (Sawyer 1939, 1955). With these discoveries, she added numerous data points to Shapley's globular cluster P-L relation, giving it greater significance.

While Helen was carrying out her investigations, Baade (1944) determined that there were two populations of stars, based on the structure of their colour-magnitude diagrams. Stars in the solar neighbourhood, which included the classical Cepheids, belonged to population I, while the globular cluster stars belonged to population II. Thus, it was possible that the classical Cepheids and the globular cluster (type II) Cepheids might have different physical properties. This raised the possibility that they might not follow the same P-L relation.

To follow up on this, Alfred Joy (1949) made a spectroscopic study of population II variables at the Mount Wilson Observatory. He observed all of the high-luminosity globular cluster variables that could be accessed from Southern California. This included 17 type II Cepheids, 5 RV Tauri and 12 semi-regular variables. Helen's research was instrumental for his investigation because 28 of the 34 variables, including 15 of the type II Cepheids, had been discovered and/or classified by her. In fact, Joy acknowledged that, without her untiring interest and kind co-operation, his observations would have had little significance.

In the course of his analysis, Joy found two characteristics that set the globular cluster Cepheids and RV Tauri stars apart from population I variables. One was their period distribution. They fell into two groups: a short-period group with periods ranging from 1 to 5 days and a longer-period group with periods greater than 13 days. None had periods between 5 and 13 days, a period range in which there are numerous classical Cepheids. Another striking difference was their spectral properties. When compared with classical Cepheids of like period, the globular cluster variables had spectral types that were earlier. He concluded that they were probably fainter. This conclusion was later confirmed by Baade.

Baade and the P-L relations of the two stellar populations

When Baade began observing with the newly installed 200-inch telescope on Mount Palomar in the early 1950s, he expected to detect RR Lyrae variables in the Andromeda Galaxy. According to the zero point of the P-L relation accepted at the time, he predicted that they would have an apparent photographic magnitude of about 22.4, which was the limiting magnitude for the 200-inch telescope. However, none were discovered. Instead, the stars he detected at the telescope limit were the brightest globular cluster stars, which were 1.5 magnitudes brighter than the RR Lyrae. This indicated that there was a 1.5 magnitude shift between the P-L relations for the population I and II variables as illustrated in Fig. 1.

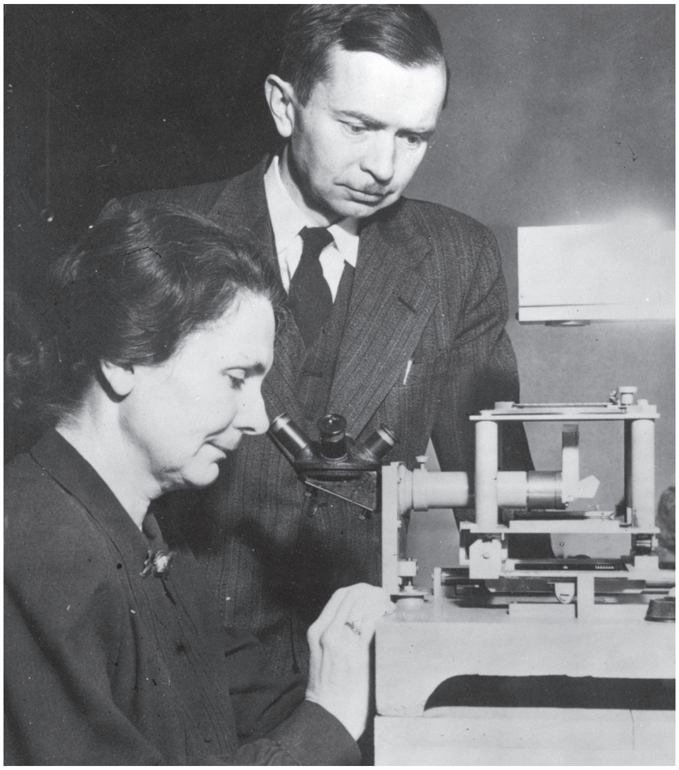

Figure 3 — Helen Sawyer Hogg working with a blink microscope. This is the device she used for discovering globular cluster variable stars on photographic plates. Her husband Frank is looking on. Credit: University of Toronto Archives - B1994-0002/005P (08)

Baade reported these results at the meeting of Commission 28, Extragalactic Nebulae, at the IAU General Assembly held in Rome in 1952 and later published in the IAU Transactions (Hoyle & Baade 1954). At the same meeting, David Thackeray of Pretoria, South Africa, reported that a few RR Lyrae variables had been recently discovered in a globular cluster in the Small Magellanic Cloud and they were also about 1.5 magnitudes fainter than predicted. Subsequently, A.D. Thackeray and Adriaan Wesselink (1953) announced that RR Lyrae variables had been discovered in two clusters in the Large Magellanic Cloud as well and all were fainter than previously expected.

Thus, it was clear that the variables of population I and II followed different period-luminosity relations, separated by about 1.5 magnitudes. The type II Cepheids were fainter. This was a particularly significant result because it accounted for the 1.5 magnitude discrepancy that Hubble (1932) found earlier between the globular clusters in M31 and the Milky Way.

This discrepancy had occurred because there was, indeed, an inconsistency in the methods used to determine the distances of the clusters in the two systems. The distances that Shapley & Sawyer (1929) derived for the Milky Way clusters were based on the mean magnitudes of RR Lyrae variables, which were population II stars. On the other hand, Hubble's M31 distance was based on the P-L relation for the classical Cepheids, which belonged to population I. Once it was recognized that there were two P-L relations, the discrepancy was removed.

This discovery had important consequences for the cosmic distance scale. At the time, the zero point that Baade was using for the P-L relation was based on a statistical analysis of the motions of the RR Lyrae variables that were population II stars. This meant that distance determinations based on RR Lyrae variables were unchanged, but distances derived from the classical Cepheids had to be doubled (Baade 1956). The distances that Hubble had derived for Andromeda and other external galaxies were all based on classical Cepheids. As a result, they all had to be doubled. The size of the Universe was doubled!

In addition, another important discrepancy was resolved—the age of the Universe. In the 1940s and 1950s, the age of the Earth was believed to be 3 to 3.5 billion years, based on geological evidence and radioactive dating. On the other hand, the age of the Universe, derived from the expansion rate (the Hubble constant) was thought to be only 2 billion years. Increasing the size of the Universe made the Hubble constant lower and the age higher. Therefore it brought the two ages into closer agreement (Osterbrock 2001, see page 162).

The name Helen Sawyer Hogg is not generally associated with this discovery because Baade and Thackeray played a more important role. However, it is necessary to acknowledge that many people contributed along the way and, because of her collaborations with Harlow Shapley and Alfred Joy, she was one of these people.

In the past 70+ years, there have been more revisions to the cosmic distance scale and to the estimated age of the Universe because science does not stand still. The current best estimate for the age of the Earth is about 4.5 billion years and the Universe is thought to be more than 13 billion years old. However, the most striking development has been the discovery of dark matter and dark energy, neither of which are yet understood.

Epilogue

By the time Baade and Thackeray announced their discoveries in Rome in 1952, there had been major changes in Helen's life.

Her husband Frank died suddenly and tragically on 1951 January 1, leaving her as a widow with three teenage children to look after. In addition, her professional activities had greatly expanded so that she had less time for research. She was an Assistant Professor at the University of Toronto and had a full teaching load. Furthermore, she was writing a weekly newspaper column on astronomy for the Toronto Star. Nevertheless, she managed to continue with her bibliographic work, a project she started while she was at Harvard. Based on the material she assembled, she published three editions of a catalogue of variable stars in globular clusters (Sawyer 1939, 1955; Sawyer Hogg 1973b). These were a valuable resource for astronomers working in the field. However, she was accumulating a backlog of observations, particularly of RR Lyrae variables, that she didn't have time to analyze.

Meanwhile, advances in technology were making it possible to reduce data more efficiently. Helen had always used a handheld eyepiece to estimate stellar magnitudes, but throughout the 1950s, astronomers were starting to employ iris photometers for this task. Also, the use of electronic computers was speeding up the process of period determination. Helen was too busy to adapt to these new techniques, but in 1962 she solved this problem by hiring Amelia Wehlau to work with her. Amelia had a Ph.D. in astronomy and was living in nearby London, where her husband Bill, also an astronomer, was a professor at Western University. Because of that, Amelia had access to an iris photometer and an electronic computer. The Sawyer Hogg/Wehlau collaboration proved to be very productive, and as a result, Amelia obtained an academic appointment at Western a few years later. In 1963, Helen acquired an iris photometer for the David Dunlap Observatory, and I used it when I began my graduate studies with her.

When Helen retired, a conference was organized to honour her for her life-long contributions. IAU Colloquium No. 21 on Variable Stars in Globular Clusters and in Related Systems was held in Toronto in August 1972. Astronomers from 14 countries on 5 continents participated.

An obituary, Helen Sawyer Hogg (1905–1993), by Clement and Broughton (1993) was published in this *Journal*.

Acknowledgements

I first met Helen Sawyer Hogg when I began my astronomical career as a graduate student in 1963. She was an important role model for me and for other women of my generation. She subsequently became a good friend and often gave me sound advice. I miss her.

I am grateful to Peter Broughton for encouraging me to publish this article. It is based on a poster paper that I presented at IAU Symposium #376 in Budapest, Hungary in April 2023. ✶

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Mystery Solved? Why the Historic Dominion Observatory Objective Lens was Replaced

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Abstract

In 1905, a National Observatory for Canada was constructed to house a 15-inch equatorial telescope and other instruments in its complex. A Warner & Swasey telescope with a John A. Brashear lens was purchased and used for the study of the Moon, spectroscopic binary stars, and other pursuits. Curiously, the Brashear objective was unceremoniously replaced in 1958 with the world's largest apochromat. But there was no announcement in the Journals or even mention in the Observatory Annual Reports. Why replace the Brashear? And why no announcement? Was the Brashear defective? Was it assembled backwards? Was there something to hide? The personal papers and daily journals of the principal actors are examined to uncover the truth.

In the summer of 1998, I was invited by Dr. Randall Brooks to observe and photograph the cleaning of the massive 15-inch objective of the Helen Sawyer Hogg observatory in Ottawa. That lens is a well-known Perkin-Elmer triplet (apochromat or simply apo) replacement lens for Dominion Observatory's original 1905 John A. Brashear lens. Although I had often visited the renowned telescope, first at the old Dominion Observatory (DO) on Carling Avenue in 1973 and numerous times at its second home at Canada's Museum of Science and Technology (CMST), this was my first close-up examination of the lens.

I was in awe of that Perkin-Elmer lens, with its heavy stainless steel cell construction and tubes leading from the cell to a nitrogen tank next to the mount. But, being a bit of an astronomical historian, it made me wonder aloud about the original Brashear lens. Dr. Brooks kindly invited me to examine that one, too, now in storage in the CMST facilities. Figure 3 is one of the many photos I took that day. It appeared pristine—hardly a stria or inclusion to be seen by my eye. And certainly, no sleeks from its many cleanings throughout the years. I could even make out John A's postage stamp spacers between the elements—it looked to me like they've never been moved. The elements were probably never separated since they left the Brashear factory.

Was this Brashear lens yet another example of the outstanding workmanship for which the company was known? If so, it should have been a spectacular performer. Why, then, was the lens replaced in 1958? It was in the back of my mind - for some 20 years.

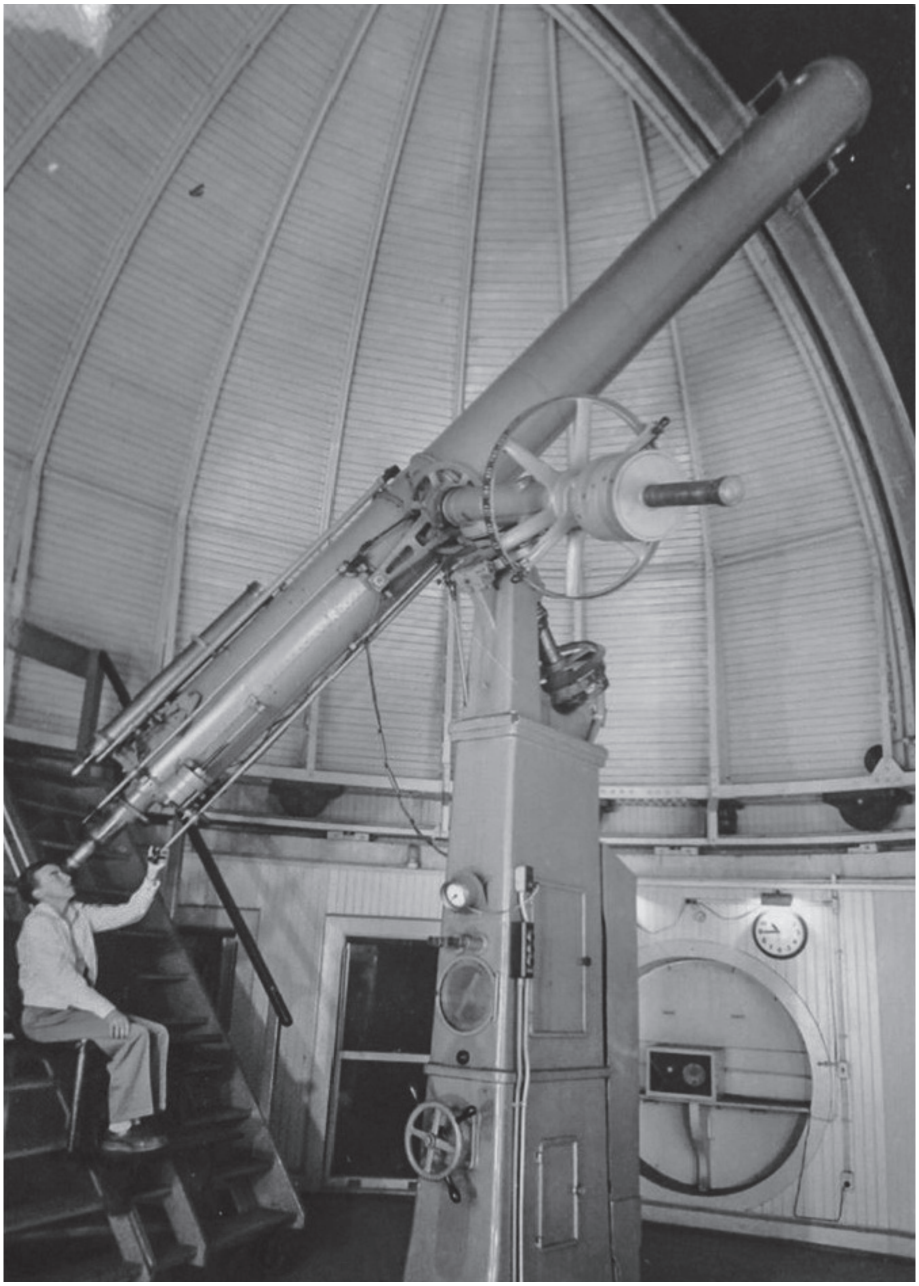

Figure 1 — 15-inch telescope at Dominion Observatory. Mirian Burland at the eyepiece. c: 1940. Credit: Canada Museum of Science and Technology Archives

Fast forward to 2022. The Antique Telescope Society (ATS), of which I am a longtime member, had issued a call for papers for its annual fall convention. The subject of Brashear lenses had often come up in its online forum, and issues that might be seen with the flint-forward Hastings design (common with many Brashear lenses) are often discussed. One of those threads turned to the Dominion Observatory Brashear lens and the fact that it was replaced with an apochromat. Speculation ensued. Why an apochromat? Was there an unusual chromatic aberration issue with the Brashear lens? Was it defective from the factory? Were the crown and flint elements reversed (as is sometimes seen with flint-forward designs)? Were the lens spacers replaced with a different thickness during cleaning? Or was an apo required for some special research program? Most curiously, why, in a cursory search through JRASC and Dominion Observatory Annual Reports in the 1950s (thanks to the internet), was such a major lens replacement not publicized? Although I did not immediately know the answers, I was encouraged by Peter Ceravolo (RASC and ATS member) and others to find the answers and present them at the ATS convention.

It seemed straightforward enough. Perhaps Dr. Brooks or his successor as curator of physical science at CMST, Dr. David Pantalony, would know the answers. They did not but offered some theories. Undeterred, I thought that the RASC archivist, Randall Rosenfeld, would surely have records that might point to the answers. Unfortunately, he did not. But Randall was also intrigued as to why the reason for replacement was not widely publicized—after all, the replacement lens was the world’s largest apochromat. The observatory staff should have been rightfully proud. Eager to assist in finding the answers, Randall was most helpful in suggesting areas of research, including searching at the National Archives of Canada for more obscure journals and diaries and the CMST archives themselves.

The mystery was afoot! I ordered ten boxes of seemingly relevant information to view at the National Archives. Then, I requested similar information from the CMST archives—where the librarians were most helpful in pulling boxes of material from Dominion Observatory (1950s to 1970s) in hope of finding answers for me. After spending a day at each archive and corresponding with some principals, including Dr. Victor Gaizauskas, the last living person to have used both the Brashear and its replacement lens, I may be closer to “the answer.” At least I have a better educated guess as to why the lens was replaced without a lot of fanfare.

To some, it may seem obvious. An apochromat is better than an achromat. If you can get one, go for it! For smaller telescopes, that may be true. But it’s a different case with a 15-inch objective. An apochromat is no panacea. Lenses of this size are not usually anti–reflection coated. Adding a third element adds two reflection surfaces, or about an eight percent light loss. In addition, the design called for a special optical glass, KzFs1, for the middle element. This type of glass is notorious for its sensitivity to moisture and will readily etch

Figure 2 — 15-inch pier, showing nitrogen tank to dry the Perkin-Elmer apo lens, Credit: CMST collection—Warner & Swasey Co., Telescope, *circa 1905, artifact no. 1974.0488.001, Ingenium – Canada's Museums of Science and Innovation, http://collection.ingeniumcanada.org/en/item/1974.0488.001/*

if exposed to humid air for any length of time. This required three silica gel desiccants (later replaced with a nitrogen tank apparatus) to keep that centre element dry. Add to that its sheer weight—82 kgs compared to 16 kgs for the Brashear lens and cell. The weight at the objective end necessitated large counterweights at the eye end. These mechanical issues were a real headache for the observatory support staff (Gaizauskas 2022). Especially for a telescope used widely by the public, the loss of an historically significant 1905 lens should also be a major consideration. Finally, the cost for the world's largest apochromat is not trivial! To justify these "downsides," Carlyle Smith Beals, the Dominion Observatory director in 1958, must have had powerful reasons.

In an attempt to solve the mystery, I tried to consider all potential reasons that might justify the replacement. First and foremost was the Brashear lens itself. I needed to know if it was a good performer—both its overall optical quality and its colour curve—or chromatic aberration. The easiest way to determine that is to test the lens, either on bright stars or at a bench test. Since it was a CMST asset, physical testing was out of the question. The next best solution was to look at historical tests and personal accounts. John Stanley Plaskett was the first observer using the Brashear lens after it was installed at Dominion Observatory in 1905, He performed numerous tests and declared "the objective for visual purposes is excellent" (Plaskett 1907a).

But Plaskett was interested in more than visual work. He was interested in spectroscopy, and there he was disappointed with the objective. He demanded that Hastings (the principal optical designer for the Brashear company) produce a correcting lens (installed between the objective and eyepiece) to alter the colour curve. Since no achromat focuses all colours at a single point, he wanted the minimum focus to change from 560 nm (yellow-green, close to maximum eye sensitivity) to 434 nm (blue, closer to photographic plate sensitivity). This would enable a much greater length of star spectrum to be photographed in one exposure. He had difficulties in obtaining a satisfactory corrector from Hastings, and even threatened to send the objective back to the optician (Plaskett 1907b).

So was spectroscopy the reason the lens was replaced—some 50 years after these colour-curve issues arose? Well, Plaskett finally obtained a useful (although not perfect) corrector from Hastings. The issue apparently was not raised by Plaskett or others in the intervening 50 years. To me, it is unlikely that spectroscopy alone, especially with the corrector lens in place, would justify an objective lens replacement.

If the objective, when delivered and tested by Plaskett, was excellent visually, could it have been changed in some way during its 50 years of use and cleaning? Potentially, the crown and flint elements could have been swapped or the element spacers could have been changed. When I examined the lens in 1998, it appeared to me to be flint forward. More telling was the accession documentation that accompanied the artifact

Figure 3 — 15-inch Brashear lens at CMST storage facilities. Photo by James Gort, courtesy of Canada's Museum of Science and Technology.

when it was acquired by CMST, which included a drawing clearly showing its flint-forward design. Finally, Dr. David Pantalony assured me that the very knowledgeable technical staff at Dominion Observatory, who would have been responsible for cleaning the lens, would not have made such an error. Similarly, the lens spacers appeared to be original when I examined the lens. I conclude that, in all probability, the Brashear lens, in 1958, had the same performance characteristics of the Brashear lens in 1905.

Next, I looked at new research programs in the 1950s that might justify an apochromatic lens. The primary candidate was the Moon Camera program for the International Geophysical Year (1957–58). The purpose was to measure the Moon's centre of gravity among a background of stars using the Markowitz Moon camera, an ingenious device that held the Moon stationary for 30-second exposures. The camera actually required modifying the eye end of the Dominion Observatory telescope tube from 4 inches to 9 inches. To provide precise star images, a narrow-band colour filter was used (which obviously would negate any potential benefit an apo might offer). What turned out to be a major issue was the long focal length (f/15) of the Brashear (and Perkin-Elmer) lenses, which resulted in a narrow field of view and relatively few comparison stars. In the end, the results from Dominion Observatory had greater errors than other participating observatories and the program ended early. This agrees with Dr. Victor Gaizauskas's recollection (Gaizauskas 2022). The conclusion is that an apo would offer no benefit to the Moon Camera program.

My research then found what appeared to be a smoking gun. In the CMST archives was a letter from Beals to Richard Perkin (co-owner of Perkin-Elmer) dated 1954 August 23. Beals mentioned Perkin's visit to Ottawa the week before and the gift of a book from Perkin that showed a picture of Saturn taken with one of Perkin-Elmer's new apochromats. Beals then mentioned that "our 15-inch telescope, now mainly used for demonstrating to the public, is by no means satisfactory for this purpose, due to the lack of complete achromatism in the objective. It would be much appreciated, therefore, if you could estimate on the cost of a new objective...in bringing the various rays of the spectrum to the same focus."

Figure 4 — 15-inch Perkin-Elmer triplet apo lens and cell, showing multiple reflections of ceiling fluorescent lights from the uncoated elements. Photo by James Gort, courtesy of Canada's Museum of Science and Technology.

Four months later, on 1954 December 15, Beals wrote to the Deputy Minister of the Department of Mines and Technical Surveys (Beals's boss), saying "You may recall that sometime [sic] ago I had a discussion with you about the defects in our 15-inch telescope which we use for demonstrating astronomical objects to visitors. While this telescope has essentially a good lens, it is corrected only for the visual region and the visual image of a star or planet is always surrounded by a blue halo as a consequence of the short wavelength being out of focus. This blue halo does not really constitute a difficulty for

Figure 5 — Side view of the massive Perkin-Elmer lens cell. Photo by James Gort, courtesy of Canada's Museum of Science and Technology.

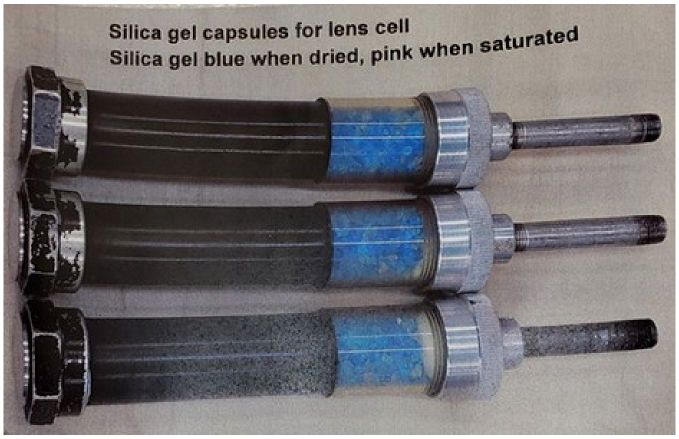

Figure 6 — The silica gel capsules required to keep the middle lens element dry (prior to installation of nitrogen tank). Photo by James Gort, courtesy of Canada's Museum of Science and Technology.

Figure 7 — Moon, taken with 9-inch Brashear lens (Cooley Telescope). Photo by Peter Ceravolo.

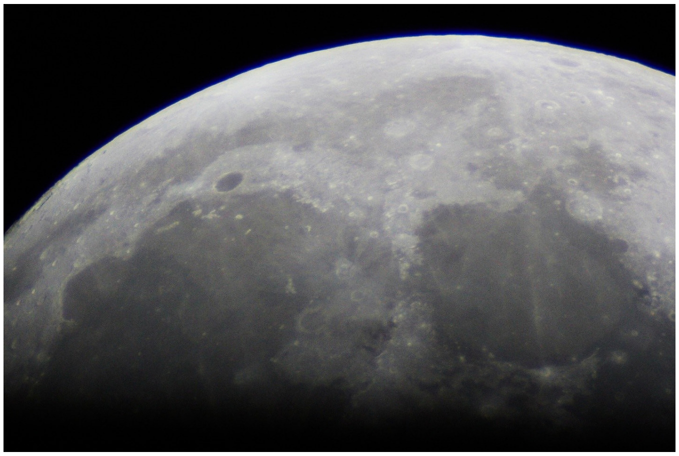

Figure 8 — Moon, taken with 13-inch Fitz-Clark lens at Allegheny Observatory. Credit: Louis W. Coban, Allegheny Observatory.

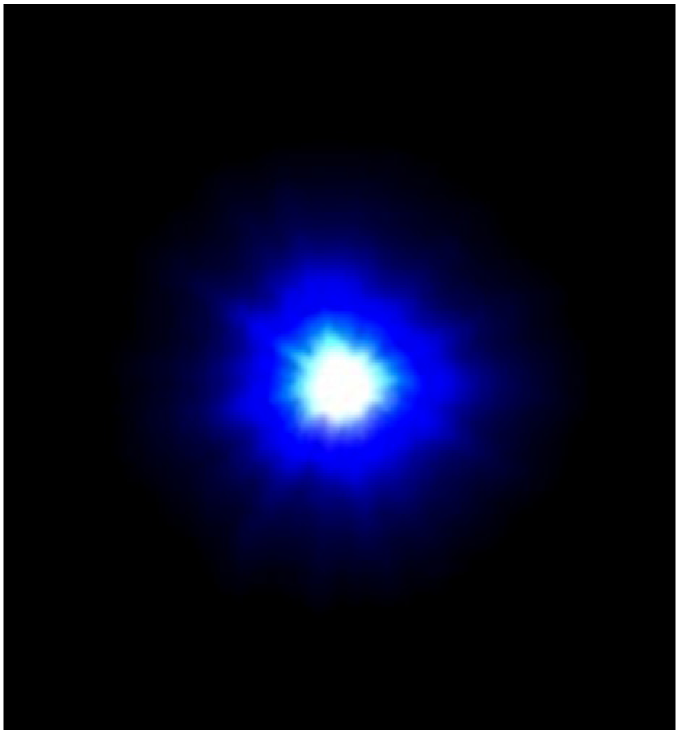

Figure 9 — Sirius, taken with 13-inch Fitz-Clark lens at Allegheny Observatory. Credit: Louis W. Coban, Allegheny Observatory.

our purely scientific observations, but it does interfere with the value of the telescope when used for visitors. Since the number of visitors to the observatory is increasing every year and since observations with the present telescope cannot help but give people a bad impression of our scientific equipment, I should like to request that we order a new lens for which a requisition is enclosed herewith. As you will see the approximate cost of the lens is $8000."

According to Beals, the lens had "defects." People would get "a bad impression." Gaizauskas agreed. He told me, referring to the chromatic aberration, "It was so bad that a deep yellow (towards the orange side) filter was inserted in the tube holding the eyepiece. So, the question from a perceptive lay person was no longer "I didn't know that the Moon had a blue atmosphere. What's it made of?" to "I didn't know the Moon had a yellow surface. It looks white to me without a telescope." (Gaizauskas 2022)

Was this the last word? Not quite. With due respect to Drs. Beals and Gaizauskas, I don't believe the Brashear lens was defective. Were the views not palatable for public consumption? Although telescopic views are always subjective, the Brashear lens is a typical achromat with some residual colour around bright objects. In trying to determine whether that residual colour is objectionable (or will give a "bad impression of scientific equipment"), I obtained a few colour photographs from similar large achromatic refractors. Although photos never render colour exactly as seen visually, it can be a close approximation. In Figures 7 and 8, the Moon is seen with a slight colour halo. Sirius (Figure 9) has a bright blue halo, but Mars (Figure 10) is much dimmer and does not show much of a halo at all. The 18.5-inch image of Jupiter (Figure 11) shows the most pronounced halo, but, since it is larger than the 15-inch Brashear, it would exhibit worse residual colour. In all cases, the halos are not very bad (to my eyes). In my experience at public nights with large refractors, I've never seen the public complain or even comment about the strange colours. In the case of Dominion Observatory, some comments about coloured halos may have been made by visitors, but such comments could be a teaching moment about optics and certainly not reason to disparage Canada's scientific equipment.

What, then, is the solution to this mystery? I believe we must consider the broader context of Beals's role as Director of DO, the personal relationship between Beals and Perkin, and the goals of Perkin-Elmer itself.

According to Gaizauskas, "Perkin-Elmer's origins lay in the original partner's mutual fascination with astronomy. They founded their company in 1937 with only $20K capital to produce precision optics and instruments. Perkin had the engineering smarts while Elmer had long business experience. The military demand for precision optics in WWII made them filthy rich in no time. They were smart enough

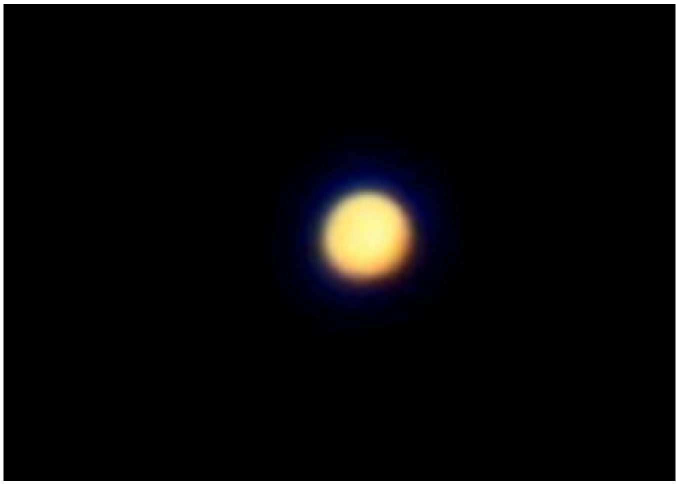

Figure 10 — Mars, taken with 13-inch Fitz-Clark lens at Allegheny Observatory. Credit: Louis W. Coban, Allegheny Observatory.

Figure 11 — Jupiter, taken with 18.5-inch Clark lens at Dearborn Observatory. Credit: Michael Smutko, Northwestern Observatory.

to diversify their manufacturing abilities to supply emerging technical markets. By the end of the war, they were well into mass production of infrared spectrometers for spectrochemical analysis. Through the 1950s, that market exploded in their favour. I did my Ph.D. studies (1952–55) on infrared bands of CO2 on a Perkin-Elmer Model 12 B infrared spectrometer that was acquired by the U of T Physics Department ~1947. With the advent of solid state detectors and circuitry around the same time and its rapidly growing sophistication, it's no wonder that Perkin-Elmer made a huge fortune that led to even greater diversification. So I am pretty confident that already around 1950 the company founders' financial problems were mostly about what to do with their immense profits. Also, Beals was a Nova Scotian who was very adept in charming New Englanders. Yeah, the apochromat was a freebie." (Gaizauskas 2022)

My interpretation: The apochromat was offered to Beals at a very favorable price: $8000. That would equate to about $88,000 in 2024 currency. No 15-inch apochromat could be purchased for that price today. In addition, Perkin-Elmer readily absorbed a $1000 price increase from Chance Brothers (UK) for the KzFS1 centre lens element. Perkin-Elmer obviously wanted the sale. They had recently made two 10-inch apochromats and were eager for the challenge to produce a 15-inch apochromatic lens.

The complementary consideration is that Beals was an astrophysicist. He knew that all the "interesting" work had transferred to the Dominion Astrophysical Observatory in British Columbia. The old Dominion Observatory would be relegated to public outreach. But Beals still wanted to make his mark, as best he could. What better way than to oversee the installation of the world's largest apochromat? Even so, I don't think he considered such an accomplishment for visitors worthy of publication in the scientific journals, since he was well aware of the technical "downsides." Nor could he justify it on scientific, research-oriented grounds. So, he made little mention of it in the journals, which, of course, were meant for his peers.

Beals could, however, justify the new lens to his superiors by appealing to the myth that Canadians would be embarrassed by the apparently defective optics. That was the story he would sell.

Is the mystery solved? Some of my proposed solution is conjecture, to be sure. But I believe it is supported by a good deal of evidence. Yes, achromats are inherently flawed in that all exhibit some residual chromatic aberration, or halos around bright objects. But the motive for replacing the historic objective with an apo was equally due to the combined egos of Carlyle Smith Beals and Richard Perkin. ✶

Acknowledgements

I would like to gratefully acknowledge the helpful advice and hospitality of Dr. David Pantalony and the archival staff at Canada's Museum of Science and Technology.

I would also like to acknowledge the vivid recollections and insights provided by Dr. Victor Gaizauskas.

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Research Article /
Article de recherche

Redshift Variation Asymptotics: Signatures of Cosmic Deceleration of Time in an Oscillating and Non-Expanding Universe.

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Abstract

Cosmological redshift suggests that the Universe expands at an accelerated rate. However, by segmenting cosmic redshift into intervals, the rate at which the intervals change with respect to distance diminishes following an inverse power-law relationship. At high redshifts, the impact of additional redshift increments, and the rate at which these intervals change, become marginal. The vanishing redshift intervals in the vertical asymptote suggests a form of temporal compression, indicating an early Universe characterized by higher frequency of events, *id est,* an increased pace of time. The elongated redshift intervals in the horizontal asymptote reveal a slower rate of time flow near the present. The temporal compression at high redshifts and elongation at low redshifts suggests that redshift is the imprint of the universal deceleration of time on the spectrum of light, not the result of cosmic expansion. The redshift analysis yields two new metrics to estimate the factor of time distortion between a source of emission and an observer in a non-expanding Universe, both predicting that time flows faster at the emitter's past than it does at the observer's present, by a factor (1+z).

Introduction

The ΛCDM (Lambda-Cold Dark Matter) model serves as the standard cosmological framework describing the evolution of the Universe and its large-scale structure (Peebles, 1981). The model postulates that the Universe is undergoing a continuous and accelerated process of expansion (Riess et. al., 1998) and (Perlmutter et. al., 1999). Evidence for the acceleration of the Universe is based on the redshift-distance relationship showing that the recessional velocity of celestial objects increases at an accelerated rate in proportion to their distance from an observer (Kirshner, 2004). Cosmological redshift is hence one of the pillars upon which the architecture of the ΛCDM model and our current understanding of the origin and evolution of the Universe is built.

However, despite successfully accounting for a multitude of cosmological observations, there are various discrepancies and significant uncertainties within ΛCDM (Peebles, 2022). Noteworthy enigmas include the Hubble tension, referring to critical inconsistencies between observational and theoretical calculations of the Universe's rate of expansion (Wei & Melia 2022); the "why now?" problem, regarding the coincidence in density of dark matter and dark energy (Carroll, 2001); and the "impossible early galaxy" problem, alluding to the recent discovery of well-formed galaxies that should not exist in the early stages of the Universe (Melia 2023).

This paper examines the asymptotic structure of discrete cosmological redshift increments as a function of distance and cosmic time. The result suggests a non-expanding Universe in which time flowed faster in the past than it does in the present. Redshift is therefore reinterpreted as the imprint of a universal-scale process of temporal deceleration on the spectrum of light.

The universal deceleration of time hypothesis finds support with current theory. Michel (2015) postulates that a plausible scenario of "redshift without expansion" is one in which time slows down, recognizing it as an "attractive possibility" and ascertaining that "General relativity would be sufficient to cause distant objects to appear redshifted as a consequence of an apparent slowing of time." Moreover, Mars, Senovilla & Vera (2018) elicit that the apparent acceleration of the Universe's expansion is linked to a scenario where time undergoes a deceleration before a "signature-change," of the brane. Vavrycuk (2022) furthermore elicits that "cosmological redshift is not a consequence of the space expansion but of time dilation" and ascertains that "…the evolution of the Universe is conformal with the static model." Peebles (2022) best summarizes the need for a new theory by affirming "I emphasize that the empirical case that the ΛCDM theory is a good approximation to reality remains compelling. But I argue in this paper that we have empirical evidence that there is a still better theory to be found."

Methodology

The Redshift-Distance relationship was demonstrated by astronomer Edwin Hubble in 1929, showing that the recessional velocity of galaxies is directly proportional to their distance (Hubble, 1929). Known as the Hubble-Lemaître Law, the relationship is expressed as:

Equation # 1

$$V = H_o \cdot D$$

Where (V) is the celestial object's recessional velocity; (H_o) is Hubble's Constant, indicating the present rate of expansion of the Universe; and (D) is the distance between the celestial object and the observer (Kirshner, 2004). Hubble provided the first observational evidence supporting Alexandr Friedmann, Georges Lemaître, and Howard Robertson's mathematical prediction for the Universe's expansion based on Albert Einstein's general relativity (Kirshner, 2004).

		Series 1	Series 1	
		Series 2		Series 2
		X	Y1	Y2
	Distance Interval In billion years (Gly.)	Distance Interval in Megaparsecs (Mpc.)	Age of the Universe at (z) in billion years (Gly.)	Redshift (z) Interval
		ConvertUnits.com		
			13.706	0.001
Distance covered by light from z=0 to z=1	7.803	2395.06	5.903	1
Distance covered by light from z=1 to z=2	2.587	792.63	3.316	2
Distance covered by light from z=2 to z=3	1.145	350.82	2.171	3
Distance covered by light from z=3 to z=4	0.613	187.82	1.558	4
Distance covered by light from z=4 to z=5	0.372	113.98	1.186	5
Distance covered by light from z=5 to z=6	0.244	74.76	0.942	6
Distance covered by light from z=6 to z=7	0.171	52.39	0.771	7
Distance covered by light from z=7 to z=8	0.125	38.30	0.646	8
Distance covered by light from z=8 to z=9	0.095	29.11	0.551	9
Distance covered by light from z=9 to z=10	0.073	22.37	0.478	10
Distance covered by light from z=10 to z=11	0.059	18.08	0.419	11
Distance covered by light from z=11 to z=12	0.047	14.40	0.372	12
Distance covered by light from z=12 to z=13	0.04	12.26	0.332	13
Distance covered by light from z=13 to z=14	0.032	9.80	0.3	14
Distance covered by light from z=14 to z=15	0.028	8.58	0.272	15
Distance covered by light from z=15 to z=16	0.024	7.35	0.248	16
Distance covered by light from z=16 to z=17	0.02	6.13	0.228	17
Distance covered by light from z=17 to z18	0.018	5.52	0.21	18
Distance covered by light from z=18 to z=19	0.016	4.90	0.194	19
Distance covered by light from z=19 to z=20	0.014	4.29	0.18	20

Table 1 — Distance travelled by light in Mpc at a given Redshift interval (z)

However, a new picture emerges if we divide redshift into discreet intervals and analyze the rate at which these intervals change with respect to cosmic distance or cosmic time. The methodology involves plotting the discrete increments of cosmological redshift against the corresponding value of distance covered within the redshift interval. The redshift space is defined as $0 < z < 20$ and the magnitude of each redshift interval is *1 ($\Delta z = 1$).*

The data in Table 1 was calculated using Edward L. Wright's online Cosmic Calculator (Wright, 2006) based on the following predefined parameters: $H_o = 69.6$; $\text{Omega}_M = 0.286$; $\text{Omega}_{vac} = 0.714$. Redshift (z) = 0 corresponds to the observer's position in the present, resulting in a Universe aged 13.72 billion years old. Redshift (z) = 20 corresponds to objects located 13.54 billion light-years away in the very distant past, when the Universe was only 180 million years old. To be consistent with the interpretation of redshift as evidence for the universal deceleration of time and not the expansion of the Universe, the comoving radius has been ruled out. Regular unfactored distances between the observer and the source of emission were used. Distances were converted using a cosmic unit converter calculator (www.ConvertUnits.com, 2024).

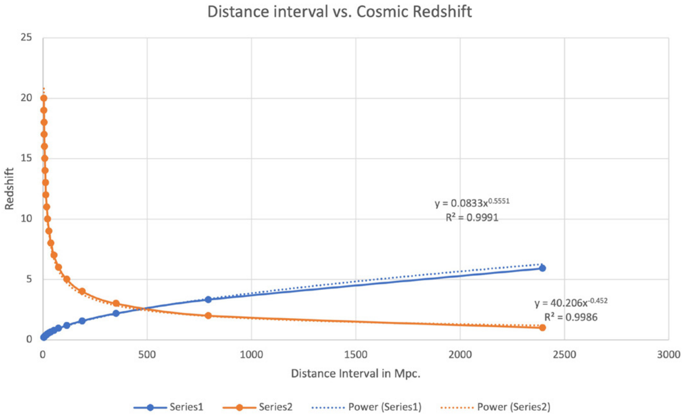

Figure 1 — Distance covered by light per redshift interval with coefficient of determination (fit) $R^2 = .9991$ and $R^2 = .9986$.

Table 1 correlates distance intervals in terms of time and length, the age of the Universe, and the redshift interval. The data demonstrates how one single redshift interval yields different magnitudes of distance and time, depending on the total redshift (z) between the observer and the source of emission. For example, between redshift z=19 and z=20, light travelled 4.29 megaparsecs, while the Universe aged 180 million years. Conversely, between redshift 0 and 1, light travelled 2 395 megaparsecs, and the Universe aged 5.9 billion years. The magnitude of the redshift interval is the same. However, the increment of distance and cosmic time in the early Universe per interval of redshift, compared to the increment of distance and cosmic time per interval of redshift in the present, are smaller by several orders of magnitude. The difference can be displayed visually when plotted into the Cartesian plane in Figure 1.

The data from Figure 1 show that when distance is considered as a whole, the resulting curve (Figure 1 curve in blue) can be

Continues on page 172

Figure 1 — Shakeel Anwar was yet another Canadian who enjoyed the May 10 northern lights display. This image is of the aurora over Collingwood, Ontario. He used a Canon D, with a Sigma 14-mm lens for ISO 1600 at 5 seconds.

Figure 2 —David Jenkins calls this photograph "Northern Contemplation." The image of his wife contemplating the brilliant skies was taken looking north along the shores of Lake Huron in Camlachie, Ontario. He says. "Such a memorable night!" This is a single 4-second exposure taken at ISO 800.

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What's Up in the Sky?

August/September 2024

Compiled by James Edgar

August Skies

The Moon is just a few days from new phase, so just a thin sliver and too close to the Sun for viewing. New Moon is on the 4th. The following day sees Venus 1.7 degrees south of the very thin sliver of the crescent Moon, and on the 9th, Luna reaches apogee of 495,207 km. The 10th has Spica 0.7 degrees south; on the 14th, Antares is 0.004 degrees north; and the Moon is full on the 19th. By the 21st, Saturn snuggles up only 0.5 degrees south of our satellite, which achieves perigee of 360,196 km. Later that evening, Neptune is 0.7 degrees south. These four close approaches are all occultations, but in distant parts of the world, not visible from North America. The Moon is in the Pleiades on the 25th, 6 degrees south of Jupiter and 5 degrees south of Mars on the 27th, and 1.7 degrees south of Pollux on the 29th.

Figure 1 — In early August, Mars, Jupiter, and Uranus are among the stars of Taurus, the Bull. Bright Aldebaran is to the south, and Uranus, further north, is close to the Pleiades. Image courtesy Starry Night Pro Plus 8.1.0

Figure 2 — August 21 in the southeast around 22:30 shows Saturn in Aquarius with the waning-gibbous Moon off to the east in Pisces. Image courtesy Starry Night Pro Plus 8.1.0

Mercury in the western evening sky rapidly moves in front of the Sun, not seen again until month-end.

Venus is making an entrance in the western sky, so named the Evening Star, but the angle of the ecliptic makes viewing difficult. The bright planet sets at almost the same time as the Sun.

Mars, in Taurus, rises around midnight, about 5 degrees north of Aldebaran, with Jupiter in conjunction on the 14th.

Jupiter, among the stars of Taurus in the very early morning sky, has double-shadow and transit events this month, on the 3rd, 7th, 9th, 10th, 14th, 17th, 21st, and 25th. Watch also for the fine conjunction with Mars on the 14th.

Saturn rises mid-evening, and crosses the sky all night in the constellation Aquarius. The waning gibbous Moon joins the Ringed Planet on the 20th.

Uranus rises around midnight in Taurus. The Pleiades are just off to the northeast. The Moon is just 4 degrees north of the blue-green gas planet on the 25th.

Neptune is in Pisces, rising just before midnight and crossing the sky until dawn obliterates it.

The **Perseid meteors** peak the night of August 12. That's when Earth passes through the cloud of particles left behind by Comet 109P/Swift-

Continues on page 170

The Sky August/September

Compiled by James Edgar with cartography by Glenn LeDrew

Celestial Calendar

(bold=impressive or rare)

Aug. 4	new Moon at 7:13 a.m. EDT (lunation 1257)
Aug. 4	**Venus 1.1° north of Regulus**
Aug. 5	**Venus 1.7° south of thin crescent Moon**
Aug. 8	Moon at apogee (405,297 km)
Aug. 12	**Perseid meteors peak at 10 a.m. EDT**
Aug. 12	Moon at first quarter
Aug. 14	**double shadows on Jupiter**
Aug. 14	**Mars 0.3° north of Jupiter**
Aug. 19	full Moon at 2:26 p.m. EDT
Aug. 21	Moon at perigee (360,196 km)
Aug. 21	**Saturn 0.5° south of waning gibbous Moon**
Aug. 24	**double shadows on Jupiter**
Aug. 25	**Moon in Pleiades (M45)**
Aug. 26	Moon at last quarter
Aug. 27	Jupiter 6° south of last-quarter Moon
Aug. 27	Mars 5° south of last-quarter Moon
Aug. 30	**Pollux 1.7° north of waning crescent Moon**
Sep. 1	Mercury 5° south of thin crescent Moon
Sep. 2	new Moon at 9:56 p.m. EDT (lunation 1258)
Sep. 4	Mercury at greatest elongation west (18°)
Sep. 5	Moon at apogee (406,211 km)
Sep. 6	**Spica 0.5° south of waxing crescent Moon**
Sep. 8	**Mars 0.9° south of M35**
Sep. 9	Mercury 0.5° north of Regulus
Sep. 11	Moon at first quarter
Sep. 17	full Moon at 10:34 p.m. EDT; partial lunar eclipse
Sep. 18	Moon at perigee (357,286 km)
Sep. 22	**Moon 0.2° north of Pleiades**
Sep. 22	Autumnal equinox
Sep. 24	Moon at last quarter
Sep. 25	Mars 5° south of Moon
Sep. 26	**Pollux 1.7° north of waning crescent Moon**

Planets at a Glance

	DATE	MAGNITUDE	DIAMETER (″)	CONSTELLATION	VISIBILITY
Mercury	Aug. 1	—	9.3	Leo	—
	Sep. 1	0.5	8.2	Leo	Morning
Venus	Aug. 1	—	10.2	Leo	—
	Sep. 1	−3.8	11.0	Virgo	Evening
Mars	Aug. 1	0.9	5.9	Taurus	Morning
	Sep. 1	0.7	6.5	Taurus	Morning
Jupiter	Aug. 1	−2.1	35.5	Taurus	Morning
	Sep. 1	−2.3	38.5	Taurus	Morning
Saturn	Aug. 1	0.8	18.7	Aquarius	Evening
	Sep. 1	0.6	19.2	Aquarius	Evening
Uranus	Aug. 1	5.8	3.5	Taurus	Morning
	Sep. 1	5.7	3.6	Taurus	Morning
Neptune	Aug. 1	7.8	2.3	Pisces	Evening
	Sep. 1	7.8	2.3	Pisces	Evening


NORTH
AURIGA
LYNX
NW
PERSEUS
TRIANGULUM
Double Cluster
CAMELOPARDALIS
ANDROMEDA
CASSIOPEIA
URSA MAJOR
M31
Polaris
Little Dipper
URSA MINOR
CEPHEUS
Big Dipper
CANES VENATICI
LEO
DRACO
LACERTA
Deneb
COMA BERENICES
BOÖTES
Venus (August 19)
WEST
PEGASUS
CYGNUS
Northern Cross
M13
Vega
LYRA
CORONA BOREALIS
Arcturus
st 25)
DELPHINUS
SAGITTA
VULPECULA
HERCULES
Altair
SERPENS CAPUT
VIRGO
AQUILA
SERPENS CAUDA
Spica
UARIUS
SCUTUM
OPHIUCHUS
LIBRA
CAPRICORNUS
M8
Antares
SW
SCORPIUS
SAGITTARIUS
M7
SOUTH

Continued from page 167

Tuttle in its many passes by the Sun. It has been confirmed that the earliest sighting was over 2100 years ago, returning approximately every 130 years. It is next due to appear in 2126.

September Skies

The Moon is almost at new phase, so "nothing to see here"–new Moon is on the 2nd. Venus is 1.2 degrees north on the 5th, but the bright planet hugs the horizon–could be a difficult sighting. That same day, the Moon is at apogee of 406,211 km. On the 6th, Spica is occulted for viewers in a band from northeastern North America to West Africa. For the rest of our continent, the separation is less than one degree. On the 10th, the bright red star Antares in Scorpius is occulted in the extreme south–here Antares is 0.1 north of the Moon. Saturn is occulted on the 17th for South Pacific observers–for northern viewers, it is 0.3 degrees south. The Moon is full that evening, beginning the second eclipse season of the year. A partial lunar eclipse happens, but it's one of those where the Moon only passes through the penumbral shadow–hardly noticeable! On the 18th, Neptune is 0.7 degrees south of the Moon, an occultation for most of North America. And, the Moon is at perigee, its closest point to Earth in its monthly orbit at 357,286 km. Large tides will occur in coastal waters. On September 22, the Moon is just 0.2 degrees north of the Pleiades (M44); Jupiter is 6 degrees south on the 23rd; Mars is 5 degrees south on the 25th; Pollux is 1.7 degrees north on the 26th.

Mercury rises in the pre-dawn eastern sky for the best apparition of 2024 for northern viewers. The very slender moon is nearby, but hardly visible. The speedy planet is rounding behind the Sun, reaching superior conjunction on the 30th.

Venus is almost the same angular distance as Mercury is from the Sun, except in the western twilight. The brightest planet rises higher each evening, becoming more and more prominent. The crescent Moon joins the scene on the 4th and 5th.

Mars rises around midnight and moves from Taurus into Gemini on September 5. The ruddy planet is about a degree away from the cluster M35 on the 8th. The waning crescent Moon is 5 degrees north on the 25th.

Jupiter and **Mars** are in the same part of the sky; Jupiter remains in Taurus, while Mars has moved into Gemini. The Moon, at last quarter, is 6 degrees north of the gas giant planet on the 23rd.

Saturn is at opposition on the 8th, meaning it is directly south at midnight. The Ringed Planet is visible throughout the night in the constellation Aquarius. The nearly full Moon glides by on the 17th, a mere 0.3 degrees away.

Uranus begins to retrograde, seeming to reverse course, on the 1st. It's the illusion caused by the Earth's more rapid orbital motion that had early astronomers stumped for centuries, until it was realized that the planets orbited the Sun, and the Earth was not at the centre of the Universe.

Neptune is at opposition on the 21st among the stars of Pisces.

The zodiacal light is visible before eastern morning twilight for the first two weeks of the month. The autumnal equinox occurs in the morning of September 22. ✶

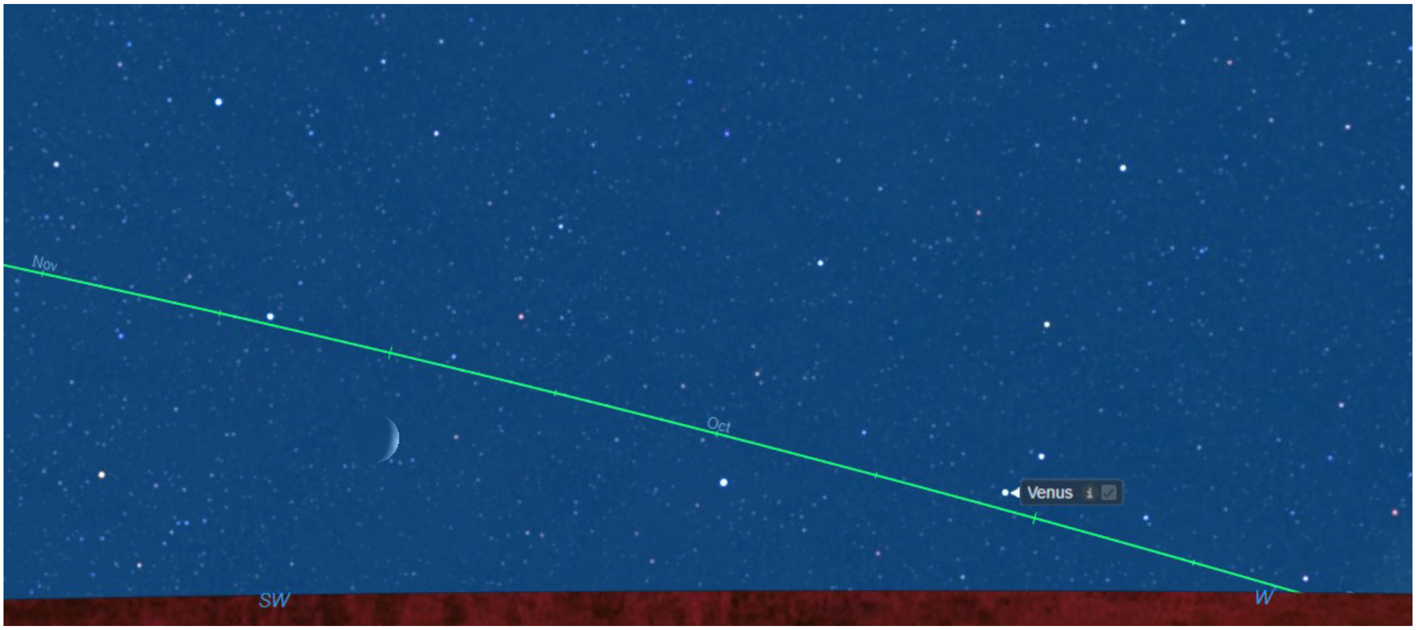

Figure 3 — Evening in the west sees Venus just after sunset — the thin waxing-crescent Moon gets brighter with each passing day. Image courtesy Starry Night Pro Plus 8.1.0

Continued from page 166

Figure 3 — This image of the Southern Pinwheel Galaxy was captured by UBC astronomy students Chantal Hemmann and Sean Heakes through the remote operation of "Thunderbird South," a Planewave CDK 500 telescope located in the Chilean deserts near La Serena. Configured and maintained by professors Aaron Boley and Paul Hickson, the telescope operates as UBC's southern observatory and was made possible by an NSERC RTI grant. Using an FLI Proline PL16803 camera and Johnson-Cousins B, V, and R filters, this image was taken over the nights of 2024 March 9 and 10, with 5-minute exposures totalling 3 hours of integration time.

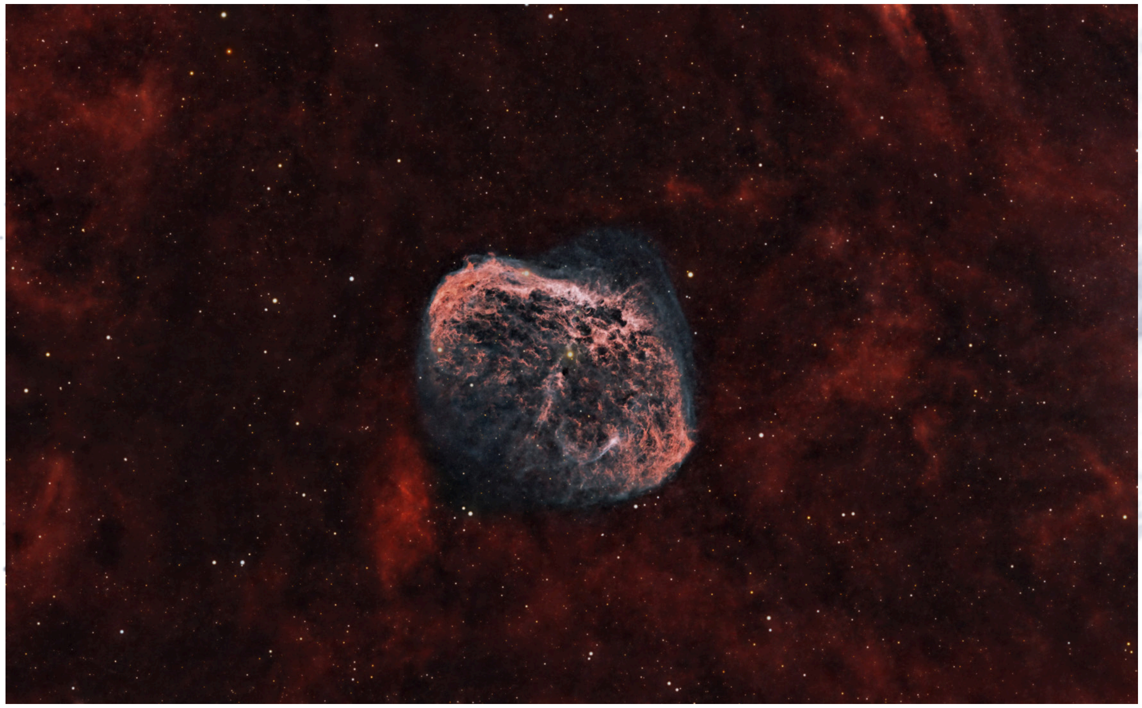

Figure 4 — This beautiful image of the Crescent Nebula (NGC 6888) was taken by Shelley Jackson from Kingston Centre. Shelley says, she's "quite happy that nebula season has arrived. This is one of many times I have imaged this target and the first time I am happy with the results." She used an Askar V at 80mm, a 50-mm guide scope, a ZW0 120 mono guide camera, on a Sky-Watcher EQ6-R pro mount, a ZWO ASI183MM CMOS camera and Hα, SII, OIII filters combined as Hα, SII/OIII, OIII. All processing and editing with PixInsight.

Continued from page 165

interpreted as an expanding Universe. Yet, when the distance is fragmented into intervals, the magnitude of each distance increment decreases as a function of the redshift (z) between the emitter and the observer (Figure 1 curve in orange).

Velten, Marttens, and Zimdah (2014) use a similar method to show that "the relation between intervals of cosmic time and intervals of cosmic redshift change substantially throughout the expansion of the Universe." Without further analysis, they attribute it to cosmic expansion. Yet, the inverse power-law relationship from Figure 1 expresses that the magnitude of redshift (y) is inversely proportional to the n^{th} power of distance (x), contending the assertion that "the relation between redshift and distance shows that we live in an expanding Universe" (Kirshner, 2004).

Asymptotic structure analysis

1. Vertical Asymptotic structure with vanishing Redshift Interval

- Light takes time to cover the distance between its source of emission and the observer. The farther away a celestial object is located from Earth, the further it is in the past. Hence, the total amount of redshift increases as a function of distance, as elicited by Hubble. However, at high redshifts, the magnitude of every redshift increment diminishes the farther the source of light is located from the observer, coming close to vanishing in the vertical asymptote.
- As per Hubble's Law, the recessional velocity of galaxies is proportional to their distance from the observer. Hence, in an accelerating Universe, galaxies at higher redshifts generally reflect an increasing expansion rate with distance. Yet, the diminishing redshift intervals in the asymptotic structure, and the marginal contribution converging to 0 at the vertical limit, suggest that the predicted expansion of space decreases at high redshifts until it comes to a stop. This contradiction evokes Zeno's Dichotomy Paradox, whereby a racer who always covers half the previous distance between two points will never reach the destination.

2. Horizontal Asymptotic behaviour

- At low values of redshift, events become separated by larger distance intervals as they approach the horizontal asymptote in the present, suggesting that increments of distance tend to expand with decreasing redshift. The distance covered by light within every redshift increment gets progressively longer toward the observer's position in the present.

3. Temporal Compression & Temporal Density:

- The fact that the cosmological redshift (z) intervals are diminishing as the total magnitude of the distance between the emitter and the observer increases, implies that, over cosmic time, the observed differences in redshift between consecutive events are becoming increasingly smaller at an exponential rate. The marginal contribution of each redshift increment at higher distances converges to zero in the (y) asymptote. The high-z time intervals between events are so short, that the upcoming event is practically immediate. The diminishing length of the time intervals is indicative of a temporal compression effect, not a time dilation effect, as currently believed. Events that were originally separated by larger redshift intervals near the present become compressed, leading to a denser cosmic timeline as we look back in time from our timeframe.
- Events near the observer's present are separated by increasingly longer intervals of time, suggesting that each additional increment of time is stretched toward the horizontal asymptote. The elongated temporal intervals reveal a slower rate of time flow near the present.

The asymptotic analysis therefore implies that time flowed faster in the past than it does in the present, demonstrating that time in the early Universe could not have been dilated, or flowing slower, as currently believed (Lewis & Brewer, 2023). In fact, the inverse power-law relationship derived from Figure 1, with its diminishing time intervals toward the past, coupled with the temporal elongation toward the present, reveals the existence of a temporal gradient along the entire redshift space. The temporal gradient determines the rate at which time experiences the universal scale process of deceleration as it flows from the past to the present.

Resulting from the analysis, this paper proposes that within the context of a non-expanding model of the Universe, redshift is the imprint of the universal deceleration of time in the realm of energy (the electromagnetic spectrum of light), not a consequence of cosmic expansion, as commonly interpreted. It submits the notion that the deceleration of time produces an elongation of the time interval, a time shift, yielding a longer period (T) as time progresses toward the present. We know that the period of an oscillation is inversely proportional to the frequency, and directly proportional to the wavelength, as per the function:

$$c = \frac{\lambda}{T} \qquad \textbf{Equation \# 2}$$

Where (c) is the speed of light, (λ) is the wavelength and (T) is the period (Michel, 2014). Based on Einstein's work on the photoelectric effect, we also know that the amount of energy carried by each quantum of light (photon) is directly proportional to the frequency of its corresponding electromagnetic wave, and that it is the frequency of the light wave what determines its colour (Rovelli, 2014). The relationship is described by the function:

$E=kv$ **Equation # 3**

Where (E) is the photon's energy, (k) is Planck's constant and (v) is the frequency of the corresponding electromagnetic wave. The fact that electrons change orbits as a function of the frequency (v) of light implies that the photoelectric effect depends solely on the colour of light, not on the intensity (Rovelli, 2014). This paper therefore also submits the notion that cosmic redshift has a quantum origin, reinterpreting it as the decrease in the frequency of a light wave by virtue of the universal deceleration of time. As the frequency slows down, the colour of light changes and the energy of the photons decrease. To maintain the invariability of the speed of light (Michel, 2014), the decrease in the frequency of the photons yields an increase of the wavelength of the light ray, thereby also causing a displacement of any spectral signatures present in the light toward the red end of the spectrum. This insight introduces the notion of Temporal Differential, defined as the difference in the energy that a light wave has by virtue of its position in time relative to the receiver's timeframe. Celestial objects located far from an observer, i.e. in the early Universe's distant past at large redshift values, have greater temporal potential energy than objects located closer to the receiver or observer, where the temporal density is lower.

However, it must be noted that the decrease in the energy is not related to the "tired light" theory proposed by Zwicky (1929) and (1933) as an alternative explanation for redshift in a static Universe. The "tired light" model has been ruled out because the proposed mechanisms behind the dissipation of the photon's energy are difficult to reconcile with the observational data (Geller & Peebles, 1972). But more importantly, the "tired light" model predicts no time distortion, a phenomenon that has been confirmed through observational evidence (Goldhaber et al. 1996). The decrease in energy elicited in this paper is more in line with Vavrycuk's (2022) finding eliciting that "Once the photon is emitted, its frequency decreases due to time dilation when photon propagates along the ray path from the emitter to the receiver."

The hypothesis that redshift is caused by the deceleration of time contradicts the current understanding redshift, and cosmic time flow. Within the framework of the ΛCDM cosmological model, the expansion of the Universe causes light to stretch, producing the observed redshift. It also causes time to dilate, appearing to flow slower in the distant Universe than it does in the observer's timeframe. This cosmological time dilation can be calculated from George Lemaître's equations (Sanejouand 2022) for the expansion of the Universe based on Einstein's theory of relativity with the function (Goldhaber et al., 1996):

$d = s(1 + z)$ **Equation # 4**

Where (d) is the factor by which time is dilated, $(1 + z)$ is the time dilation factor, (s) is the stretch factor scaling the time dilation effect, and (z) is the redshift between the source of emission and the observer's timeframe. The "dilated" time has been proven in phenomena like the slowed-down explosions of supernovae, demonstrated by Goldhaber et al. (2001); the slow durations of Gamma Ray Bursts, studied by Zhang et al. (2013); the "radioactive decay that powers distant super novae" appearing to run slower at high redshifts (Kirshner (2004); and the light variations in quasars unfolding in "slow motion," as confirmed by Lewis & Brewer (2023). The observed slow-motion effect observed in all these phenomena is believed to be caused by the cosmological time dilation resulting from the expansion of the Universe. However, this paper hopes to demonstrate that it is not the time dilation, but the fast pace of time in the past, that accurately explains the observed slow-motion effect. Which begs the question, why do events in the distant past appear to unfold in "slow motion" if time flows faster in the past than it does in the present?

Calculating the rate of temporal deceleration in a non-expanding Universe

The equation derived from the redshift-distance increments curve in Figure 1 (series 2) is:

$y = 40.206x^{-0.452} \approx y = a \cdot x^{-n}$ **Equation # 5**

This function is an inverse power-law relationship in the general form of $y = a \cdot x^{-n}$ where (y) is the cosmological redshift (z) increment; (x) is the distance between the emitter and the observer; (a) is the scaling factor of the relationship; and (n) is the exponent. Hence, the derivative (dz/dx) of the function $y = a \cdot x^{-n}$ allows us to find the rate at which redshift changes with respect to the distance increment between the emitter and the observer, as per the function:

$$\frac{dz}{dx} = \text{क} = -\left(n \cdot \frac{a}{x^{n+1}}\right) \; where \; n = \frac{fe}{fo}, hence \; \text{क} = -\left(\frac{fe}{fo} \cdot \frac{a}{x^{\left(\frac{fe}{fo}\right)+1}}\right)$$

Equation # 6

Where: (dz/dx) represents the rate at which redshift changes in the y axis for every single additional increment of distance in the x axis. Making the rate of redshift change equivalent to the rate of change in time, (dz/dx) will be expressed with the symbol *Kāla* (क), meaning "Time" in Sanskrit, representing the rate at which time is flowing in the context of a cosmological model based on a universal scale process of deceleration of time.

(–) the negative sign in the derivative indicates that the function dz/dx is decreasing as the value of (x) increases, or negative acceleration (deceleration).

(a) is the deceleration factor, the rate at which the speed of time is changing with respect to distance. In contrast, Hubble's constant defines the rate at which the Universe expands.

(x) is the distance between the emitter (x_e) and the observer (x_o) in the Cartesian plane.

(n) is the exponent determining the rate at which (y) decreases as (x) increases. (n) is the scale factor between the redshift experienced by the emitted light (z_e) and the redshift (z_0) at rest (for the observer in the present). Expressed in terms of frequency shift, it is the scalar ratio between the emitter's frequency (f_e) and the rest frequency at the position of the observer (f_0), $n=(f_e/f_0)$.

Calculating the Cosmic Doppler Effect due to the universal deceleration of time

According to Lemaître (1927), the expansion of the Universe causes light to experience a stretching of its wavelength as it travels through space. In Lemaître's own words, cosmic redshift is the "Doppler's effect due to the variation of the radius of the Universe."

It is possible to calculate the Doppler effect caused by the universal deceleration of time in a non-expanding Universe of a constant radius by transforming Lemaître's Doppler effect equation. Lemaître explains that a light ray is emitted at a position σ1 and observed later at position σ2, adding that "…a ray of light emitted slightly later starts from σ1 at time t1 + δt1 and reaches σ2 at time t2 + δt2. We have therefore" (Lemaître, 1927):

$$\frac{\delta t2}{R2}-\frac{\delta t1}{R1}=0,\ \frac{\delta t2}{\delta t1}-1=\frac{R2}{R1}-1$$

Equation # 7

"Where R1 and R2 are the values of the radius R at the time of emission t_1 and at the time of observation t_2. (t) is the proper time; if δt1 is the period of the emitted light, t_2 is the period of the observed light" (Lemaître, 1927). The transformation, nonetheless, involves changing the assumptions. In Lemaître's model, the Universe's radius changes with time, reflecting his interpretation of Einstein's relativity as the expansion of the Universe. Hence R2 is larger than R1, and the scale factor is given by R2/R1. Moreover, the difference between the time intervals for the emission (δt1) and observation (δt2) of light rays is zero. This means that the time it takes for a light ray to travel from σ1 to σ2 is the same regardless of when it's emitted or observed.

However, in a non-expanding Universe experiencing the deceleration of time, the radius of the Universe does not change, and the time that it takes a light ray to travel form σ1 to σ2 changes depending on when it is emitted and when it is observed. Therefore, the new scale factor must consider that time decelerates between the interval of emission of the two different rays of light. If the interval between the time of emission t_1 and t_2 doubles in size since the first ray of light was emitted, it would take twice as long for the second ray of light to travel the same distance.

Considering the variability of time and a constant radius, we can now transform Lemaître's equations. We will suppose that a light ray is emitted at a position σ1 with frequency f_{e1} and observed later at position σ2, with frequency f_{o1}. A second light ray, emitted a moment later, starts from the same position σ1 at time *t*1 + δ*t*1, with frequency f_{e2} and reaches the observer's position σ2 at time *t*2 + δ*t*2, with frequency $f_{o2.}$ We substitute the value for radius R_1 by (कe), corresponding to the rate at which time flows at the source of emission; and R_2 by (कo), the rate at which time flows at the point of observation (σ2). Yet, to keep the scale factor (R2/R1 >1), as per Lemaître's equations, we must invert the numerator and denominator of the temporal scale ratio equivalent. Hence, (R2/R1) becomes (कe/ कo). Moreover, given that in a non-expanding Universe the time it takes for light to travel between two points does not remain constant, we cannot equate the scale factors to zero, as Lemaître did. The resulting scale factors are:

$$\frac{\delta t2}{\text{क}o}-\frac{\delta t1}{\text{क}e}\neq 0\,,\frac{\delta t2}{\delta t1}-1=\frac{\text{क}e-\text{क}o}{\text{क}o}\ ,and\ \ \frac{\text{क}e}{\text{क}o}=\frac{fe1-Fo1}{fo1}$$

Equation # 8a, 8b and 8c

Subtracting 1 from both sides allow us to compare how much the time intervals and scale factors change relative to their initial values, where (δt2/ δt1) represents how much the time interval for observation (δt2) changes compared to the time interval for emission (δt1). If (δt2 δ1 > 1), it means the time interval for observation is longer than the time interval for emission (i.e. the observation is delayed compared to when the light was emitted). Similarly, the ratio (fe/fo) represents how much the frequency of the emitted light wave (fe) differs from the frequency of the observed light wave (fo). If (fe/fo >1), then the frequency of the emitted light wave is higher than the frequency of the observed light wave.

The transformed scale factors (कe/ कo) and (fe/fo) are in line with the prediction that time is slowing down in the Universe as suggested by the inverse power-law relationship. It shows that if time flows at a higher rate at the position of emission (कe), the scale factor is greater than 1. In a non-expanding Universe where time is undergoing a cosmic process of deceleration, the Doppler effect (z) is reinterpreted as the result of the variation in the speed of time in the Universe.

$$z=\frac{fe-fo}{fo}=\frac{fe}{fo}-1, and\ z=\frac{\text{क}e-\text{क}o}{\text{क}o}=\frac{\text{क}e}{\text{क}o}-1$$

Equation # 9a and 9b

Equation 9a yields the scale factor by which light is redshifted (fe/fo) (Ferreira, 2019). Equation 9b yields the scale factor by which the rate of time flow, Kāla (क), is distorted (time shift) between an emitter located in the past, and an observer in the present. In other words, the Doppler effect due to the universal deceleration of time. Given that the rate of time at the observer (क_o) is defined as 1 to use it as a scalar measure, it can be easily demonstrated that equation 9b becomes:

$$z = \frac{\text{क}e}{\text{क}o} - 1\,, therefore\ 1 + z = \text{क}e$$

Equation # 10

This equation suggests that the speed of time in the emitter's position in the past (कe) flows by a factor of (1+z) times faster than it does in the observer's position in the present, not slower by the same factor of (1+z), as commonly understood.

The slow-motion effect – time distortion in a non-expanding universe

The answer to the question regarding how a faster rate of time flow in the past yields the illusion of time dilation comes from the realm of cinematography, where the perception of slowed down time is the result of the ratio between the speed at which an action is recorded (measured in frames per second) and the speed at which the recorded action is played back. If the recording speed is higher than the playback speed, the time it takes for the action to unfold is slowed down by the lower rate of playback, and the illusion of time dilation, i.e. slow motion, is created as the images are projected on the screen (Ascher & Pincus, 1999). The factor by which the actions seem to be slowed down is given by the formula:

$$Slow\ Motion\ Scale\ Factor\ (Tcine) = \frac{frec}{fplayback}$$

Equation # 11

Where (T_{cine}) is the cinematic slow-motion scale factor expressing how many times the action appears to be slowed down; (f_{rec}) is the frequency at which the action is recorded, i.e. the filming frame rate expressed in frames per second (fps); ($f_{playback}$) is the frequency at which the action is played back, i.e. the playback frame rate. And this is where cinematography meets cosmology. Correlating the slow-motion factor from the realm of cinematography, and the time shift factor from equations 8, 9, 10, and 11, we can parametrize a cosmic slow-motion factor:

$$If\ Tcine\ \frac{frec}{fplayback} \approx \left(\frac{fe}{fo}\right)\ and\ \left(\frac{fe}{fo}\right) = 1 + z, and\ 1 + z = \text{क}e$$

$$then\ Tcine \approx \text{क}e = (1 + z)$$

Equation # 12

In line with cinematic slow motion, the Cosmic slow-motion scale factor (fe/fo) elicits that if:

1. *fe / fo is* < *1*, the higher frequency value for the observer's timeframe (denominator) implies that the rate at which time flows in the observer's timeframe कo is faster than at the emitter's realm कe. Hence, if कe < कo the accelerated rate of time at the observer's timeframe will appear to speed up events occurring at high redshifts in the emitter's timeframe. Such events would seem to unfold in high-speed motion when observed, very much like the time-lapse effect of a flower blossoming in nature films, for example.
2. *fe/fo* **is = 1,** then events unfold at the same pace because the speed of time at the emitter is the same as the speed of time at the observer's timeframe.
3. *fe/fo* **is > 1,** the higher frequency value for the emitter's timeframe in the numerator implies that the time interval in the emitter's timeframe is longer than what it is in the observer's realm. The decelerated rate of time at the observer's timeframe will slow down events occurring at high redshifts. Said events will seem to unfold in slow motion at the observer's present. The larger the distance, the slower the illusion of motion created by a factor (1+z).

This paper suggests that due to the past's higher temporal density, processes related to light emission, such as the excitation of electrons within atoms and the subsequent emission of photons, occurred more rapidly. Light, characterized by a specific frequency and wavelength corresponding to the state of the atoms in the emitter's timeframe, carries with it the distinct spectral signatures—dark absorption lines—that reveal the presence of elements within the source of emission (Kirchhoff and Bunsen, 1860). These absorption lines result from electrons transitioning to higher energy states and absorbing light at distinct frequencies (Bohr, 1913). As the emitted light travels through the vast distances of space, it carries with it the temporal characteristics of the era in which it was emitted. The black spectral lines become the "fingerprints" of each element, akin to a chemical barcode. The position of these spectral signatures is what helps determine how much a light wave has "shifted" from the moment it was emitted, to the moment it is observed.

This paper therefore proposes that when light emitted in the past reaches an observer in the present, it encounters the present's lower temporal density. Time processes related to the observation occur more slowly due to the present's lower temporal density. Observer's instruments, like spectrographs, experience "slowed down" time processes, compared to the past. The slowed down time processes in the present affect the measurement of the light's wavelength and frequency. The effect is akin to the lowering of the pitch when sound is played back at a slower rate in a tape recorder, or to the slow-motion illusion created when images are recorded at high speeds and projected at lower frame rates, leading to a shift in frequency, i.e. redshift.

Based on the analysis above, this paper submits the notion that the fast frequency of events in the emitter's past, coupled with a slower frequency of events in the observer's timeframe, are necessary and sufficient conditions for the slow-motion effect to be produced. Redshift is reinterpreted as the imprint of the slowing down of time due to the temporal differential between the past and the present, not as "stretch marks" of the expansion of space-time. Therefore, time dilation in the past, as elicited by ΛCDM, is inconsistent with the cosmic slow-motion effect observed in phenomena like radioactive decay, in the observed dimming of supernovae, the duration of gamma-ray bursts and the light variations in quasars. The variations associated with all these cosmic phenomena appear to run slower at high redshift values than at low redshift values, consistent with the (1+z) scalar ratio derived from the slow-motion scale factor. Lewis & Brewer (2023), for example, demonstrate that the fluctuations of the light emitted by distant quasars, out to redshift z=4, appear to flow 5 times slower than time in our present frame of reference, in line with the slow-motion scale factor (1+z) prediction. If time in the past were to be dilated, i.e. flowing slower, events would appear to flow faster by a factor of (1+z).

Another piece of observational evidence in support of the deceleration of time hypothesis is the temporal compression in the early Universe. According to the prevailing cosmological model, the Universe evolved at a vertiginous pace, instants after the Big Bang. Key evolutionary milestones like cosmic inflation, the origin of quantum fluctuations, the formation of particles all happen within the first second of existence. The nucleosynthesis of light elements, hydrogen and helium, occurs in the first 3 minutes. Most elements were produced in the first hour (Alpher, Bethe, Gamow, 1948). Stars and galaxies appear when the Universe is a mere 200 million years old, well within the first 1.5% of the total age of the Universe. The life span of stars was typically on the order of millions to tens of millions of years. George Gamow, who first came up with the evolutionary timeline of the Big Bang, was so struck by such a compressed timeline, that he joked "The elements were cooked in less time than it takes to cook a dish of duck and roast potatoes" (Gamow, 1952). The comment refers to the fact that "all the various atomic nuclei were created in the hour immediately following the Big Bang" (Singh, 2005).

How could such evolutionary milestones, the likes of which amount to the creation of the entire Universe, occur in such an infinitesimally short timeline? In the context of the universal deceleration of time, the extreme fast-paced cosmic dawn elicited in this article can potentially explain the accelerated rate of stellar mechanisms and the sped-up physics of star formation and galactic assembly suggested by Gamow (1948).

Cosmic time dilation and Hubble Law equivalent functions in the non-expanding model.

The universal deceleration of time metric yields functions equivalent to Lemaître's time dilation and Hubble's Law in a non-expanding cosmological model by transforming the inverse power-law equation # 6. We know that (n) represents the scalar ratio between the emitter's frequency (fe) and the rest frequency at the position of the observer (fo), (fe/fo). We also know that 1+z=fe/fo. Substituting the variable in the exponent (n) by the frequency shift, equation 6 yields:

$$\overline{\text{क}} = -\left(\frac{fe}{fo} \cdot \frac{a}{x^{\left(\frac{fe}{fo}\right)+1}}\right), substituting: \overline{\text{क}} = -((1+z) \cdot \frac{a}{x^{(1+z)+1}})$$

Equation # 13

Where the derivative (dz/dx) represents the rate of change in redshift (y axis) for every single additional increment of distance (x axis). Therefore, (x) is the magnitude of one single increment of distance as light travels between the emitter and the receiver, resulting from the difference (Δx) between x_0 and x_1. Hence, $(xo - xe = 1)$, meaning that $\Delta x = 1$ By substituting (x) by 1 in the denominator $x^{(z+1)+1}$, and rearranging the order of the factors, we obtain the equation:

$$\overline{\text{क}} = -a(1+z)$$

Equation # 14

Juxtaposing equation 14 above with equation 4, the cosmological time dilation formula d = s(1+z), where (d) is the time dilation factor, we validate that the inverse power-law metric does yield a time distortion factor in line with observational evidence.

Furthermore, given that redshift is a measure of distance, we can make a further transformation by substituting (1+z) by a distance variable (d), to obtain:

$$\overline{\text{क}} = -(a \cdot d)$$

Equation # 15

Juxtaposing the equations equation 16 and Hubble's Law $V = H_o \cdot D$ we verify that they are mirror images of each other. On one hand, Kāla (क) defines the rate at which time is slowing down in the Universe (with a negative sign indicating deceleration); on the other, Hubble's Law defines the rate at which space is expanding in the Universe. We can therefore conclude that the metric derived from the inverse power-law relationship that describes the rate at which time is decelerating in the Universe is conformant with the existing body of observational evidence.

Discussion: The oscillating Universe—an alternative cosmological model.

This article has hopefully illustrated that, although cosmological redshift has long been regarded as a fundamental observational component supporting the theory of the Universe's expansion, it can also be interpreted as the imprint of the universal deceleration of time on the spectrum of light in a non-expanding Universe. However, explaining redshift is a necessary but not sufficient condition for an alternative cosmological theory to be successful. Static Universe models have difficulties accounting for variety of phenomena that are well substantiated by the ΛCDM model, including the

Cosmic Microwave Background (CMB) radiation, a form of relic radiation theorized to be the glow from the early hot Universe (Peebles, 2013), predicted by Gamow (1948) and Alpher &Herman (1948a), and discovered by Penzias & Wilson (1965). The standard model also explains the relative abundance of light elements, elicited by Alpher, Bethe and Gamow (1948); the large-scale structure of the Universe, elucidated by Peebles (1980); the isotropy and homogeneity, as proposed by Guth (1981) in his inflation calculations for the Big Bang model; and Olbers' Paradox (Roos, 2008), among other cosmic phenomena.

Upcoming papers will explore these aspects as touchstones to hopefully validate this new model, including how the universal deceleration of time tackles some of the discrepancies challenging the prevailing understanding of the Universe, such as the Hubble tension, the cosmic coincidence problem, and the "impossible early galaxy" problem. Briefly elucidating some of the main aspects of the research, the theory explains how the inverse power-law relationship describing the decay in the universal deceleration of time mirrors the decay in the dynamics of an oscillatory system. Following this insight, the theory suggests that time is decelerating in the Universe because the Universe itself, the very fabric of spacetime and energy, is oscillating. The oscillation, hence, is proposed to be the architect behind the evolution of the Universe.

The oscillatory Universe model proposes that the Universe originated as an infinite, boundless, not expanding, non-contracting, 5-dimensional expanse made up of space, time, and energy woven together into one single fabric called Spacetime-energy. It suggests that the Universe undergoes a cyclical process of creation and destruction and theorizes that it began as a vacuum state, devoid of large-scale structures or matter. Driven by the purely stochastic nature of quantum vacuum fluctuations, our current cosmic era originated in a simultaneous, ubiquitous, universal-scale conversion of vacuum energy into matter and antimatter. The subsequent annihilation produced a colossal pulse of energy that set the fabric of the Universe into a perpetual state of harmonic oscillation, instead of triggering the inflation of the Universe, as currently believed. The cosmic-scale vacuum energy transformation also heated the Universe, reaching the high temperatures described in the Big Bang model by Gamow (1948). This hot genesis accounts for the origin of the chemical elements and their relative abundance, and the CMB radiation, as elicited in the Big Bang model. Moreover, the ubiquity and simultaneity of such cosmic-scale quantum fluctuations produced the flatness and the large-scale uniformity observed in the Universe.

The theory further suggests that the oscillatory process is slowing down due to the dissipation of the initial potential vacuum energy stored in the system. This dissipation of energy is proposed to account for the Dark Energy thought to be accelerating the expansion of the Universe in the ΛCDM model (Reiss et al. 1998). In a process loosely analogous to the dynamics and structure of vibrations made visible in cymatics experiments (Jenny, 2001), the oscillation of the Universe is further proposed to be responsible for the initial coalescence of matter in nodes where the local frequency of the oscillation was lower, planting the seed for the observed large-scale structure of the Universe. The model also presents that the frequency of the oscillation decays attenuated by gravity, following the inverse power-law. Time also slows down, following the same inverse power-law relationship. The initial high frequency of the oscillation in the early Universe, and its subsequent decay toward the recent Universe, establishes an entropy gradient, evolving from a high-vibration, low-entropy past, to a low-vibration, high-entropy present, in line with the Second Law of Thermodynamics and with the chronological evolution of entropy accounted by the expansion model (Penrose, 2010). The arrow of time (Eddington 1927) is also determined by the same gradient, "rolling downhill" from the high-oscillatory frequency in the past to a low-oscillatory frequency future. The theory concludes by proposing that our current era will exist until another stochastic, cosmic-scale process of quantum fluctuations driven by the Law of Large Number (Loève, 1977) re-energizes the Universe, yielding a new era of oscillation.

Acknowledgments

The notions and ideas submitted in this paper build upon the inspiration, the wisdom, and the hard work of generations of curious human beings who have contributed to our current understanding of the Universe. The author wishes to manifest that this exploration has been captained by curiosity, awe, and the conviction that to advance knowledge, we must not only look for new answers to old questions, but we must also look for new questions to old answers. I hope that in the adventure of writing this paper, some new answers have emerged.

I want to thank my late uncle, Hernando Domínguez, who guided my gaze toward the night sky by giving me my first telescope when I was a young kid. I acknowledge the support and help of my dear friend Freddy Jiménez, who has always taken sincere interest in my work. My sister, Tania, for sharing philosophical insights that have helped shaped this theory. My wife, Tatiana, for her support while I dedicated long hours of the night to researching and writing. Karim Salem, Arthur Maury, Ángela Posada, and Valentina Abril for constructive discussions. My father, for guiding me through life, and my mother, for showing me how to live with joy. Lastly, I dedicate this entire adventure to my daughters with all my love, Martina and Olivia. Thank you for keeping the secret, thank you for listening, thank you for believing. May curiosity, awe, passion, and magic guide the pursuit of your dreams and always inspire your wonderful life journeys. ✶

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Skyward

Stunning Aurorae and Olbers's Comet

by David Levy, Kingston & Montréal Centre

For the last few nights, I have been looking in one particular direction of the sky: the northeast. Over a period of four nights, I have noticed a faint glow in that direction. It wasn't bright, certainly nothing about which to write home, but it was the aurora borealis. It is a direct message from the Sun to us, a cosmic "Hello!" to us, the people, here on Earth. I also was aware that this aurora was a direct result of a gigantic group of at least 60 sunspots that had been rowing across the surface of the Sun.

The northern lights and I have been good friends since my first view of a small display, back in 1961 when I was just beginning my teenage years. I duly informed Louis Duchow, the person in charge of aurora reports at The Royal Astronomical Society of Canada's Montréal Centre.

"Did you write up a report on it?" he asked. When I answered in the negative, he said, "Then you really haven't seen it." It was a silly answer, but there was a morsel of truth in it. I began filling out aurora reports pretty religiously after that.

The night of 1966 July 8, was the night without a dusk. The Sun set, and as I watched the darkening sky…the sky just didn't get dark. Instead, the post-sunset glow slowly shifted from the northwest to the north, and then just stayed there. The sky also gradually turned a bright green as the auroral glow grew brighter. Then the first bright ray appeared, and within an hour, rays were growing all over the sky. Two months later, an even better display lit up the whole sky from Montréal. I was waiting for a bus to go to the observatory for their typical Saturday night meeting when I saw a giant coronal arc at the zenith of the sky. I just turned around and walked home to watch this mighty show.

Over the years I have seen other displays of the northern lights, some from the northeast, and several from my current home in southern Arizona. Possibly the nicest one took place from the great auroral arc around the Arctic Circle. Our airplane took off from Whitehorse, and the instant our plane rose above the clouds, the sky was covered with aurorae.

Figure 1 — The light curve of a flare on V371 Ori observed visually by Lewis (Lew) Cook on 1982 January 8. It plots visual magnitude against Julian Date. Source: AAVSO.

Figure 2 — A photo the author took of the spectacular display of the May 2024 aurora.

The northern nights are best seen without any optical aid at all—without binoculars, without a telescope. When the display appears, just open your eyes and relish the sight. Next to a total eclipse of the Sun, the aurora is one of nature's grandest spectacles.

The Wonderful Visit of Olbers's Comet

On Tuesday, 2024 June 4, David Rossetter and I headed out for our monthly observing session at the Chiricahua astronomy complex, the dark site of the Tucson Amateur Astronomy Association. In addition to the normal two hours of comet searching I did that evening, David located Comet Tsuchinshan–ATLAS, a bright 10th-magnitude comet with a pretty dust tail. I wish I had paid more attention that evening to the other comets that would be visible that night.

If I had been more careful, I would have noticed that Comet Olbers was returning for the first time since 1956. There is no way I would have seen this comet then since I was only eight years old at the time. Since it was already quite bright, I tried to locate it from my observatory on the following Friday evening. But the comet's position low in the northwest made that impossible. On Saturday evening I tried it again from my front porch which does have an excellent view to the northwest but is looking over Tucson. I used a new telescope, a 6-inch telescope from Sky-Watcher. This new telescope, presented to me by Dean Koenig of Starizona, was destined to go to Robin Chapell. Robin has been cleaning my home for many years, first for Wendee and me, and more recently just me, and a few weeks ago she expressed an interest in getting a telescope. To test the new telescope, I tried to use it to find Comet Olbers. I didn't catch it Saturday or Sunday evening, although I might have gone right over it Sunday without spotting it.

On Monday, June 10, I drove to David and Pamela Rossetter's home to find him setting up Archimedes, his 12–inch reflector, in his driveway, which had an excellent view to the northwest except for a Palo Verde tree. After carefully aligning

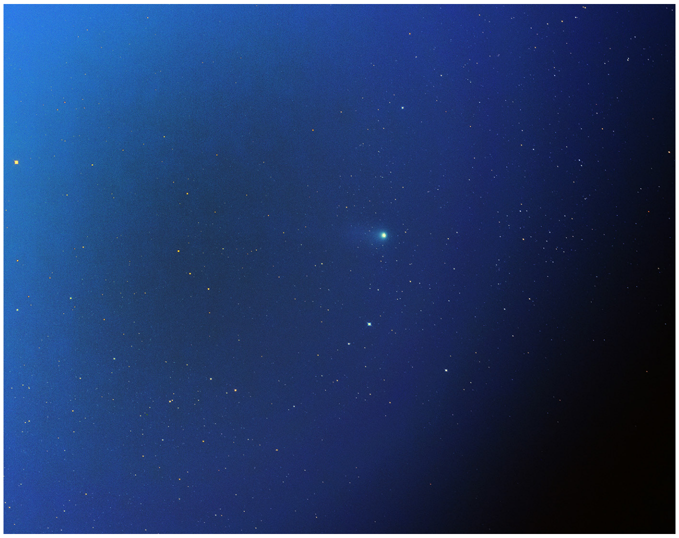

Figure 3 — Olbers's Comet. Credit: Dr. Tim Hunter

the 12-inch telescope on Polaris, then Spica, then Pollux, and finally Castor, he put in the comet's position and moved the telescope. Lo, the comet was in the middle of the tree! David looked anyway and saw two faint stars in the telescope's field.

Toward the left of one of the stars, he detected a faint fuzzy spot. Then it was my turn. Immediately I also detected the fuzzy spot. It was real. For the first time in both our lives, we saw Comet Olbers. Pam joined us for a brief visit.

Heinrich Olbers discovered this comet on 1815 March 6. The comet is named for him as 13P/Olbers. But the comet is not what he is famous for. His magnum opus is Olbers's Paradox. In 1823 he proposed that, with stars spread out to infinity in the sky, there should be no point in the sky that does not fall upon the surface of a distant star. Olbers then suggested that because of this, every inch of sky should be as bright as the Sun. The Nobel prize-winning physicist George Wald went further a few decades ago, adding that the sky should be so bright that life on Earth would be impossible.

"But the night sky is dark," he said. "Therefore, life here is possible."

One would expect that some famous scientist was the first person to resolve Olbers's Paradox. Not quite. An American writer famous for his poetry and short stories, Edgar Allan Poe is one of the truly great American writers. His poem "The Raven," written in 1845, is one of the world's most famous pieces of literature, brought to life when two ravens adopted Gene and Carolyn Shoemaker, who dutifully named them Never and More:

> Presently my soul grew stronger; hesitating then no longer,
> "Sir," said I, "or Madam, truly your forgiveness I implore;
> But the fact is I was napping, and so gently you came rapping,
> And so faintly you came tapping, tapping at my chamber door,
> That I scarce was sure I heard you"—here I opened wide the door;—
> Darkness there, and nothing more.
>
> Deep into that darkness peering, long I stood there wondering, fearing,
> Doubting, dreaming dreams no mortal ever dared to dream before;
> But the silence was unbroken, and the darkness gave no token,
> And the only word there spoken was the whispered word, "Lenore!"
> This I whispered, and an echo murmured back the word, "Lenore!"
> Merely this and nothing more.
> …
> Then this ebony bird beguiling my sad fancy into smiling,
> By the grave and stern decorum of the countenance it wore,
> "Though thy crest be shorn and shaven, thou," I said, "art sure no craven,
> Ghastly grim and ancient Raven wandering from the Nightly shore,
> Tell me what thy lordly name is on the Night's Plutonian shore!"
> Quoth the Raven, "Nevermore."

As delightful as "The Raven" is, and as often as the word darkness appears in it, the poem does not explain why the night sky is dark. But three years later, Poe's final major piece of writing, "Eureka," solves the paradox perfectly:

> "Were the succession of stars endless, then the background of the sky would present us a uniform luminosity, like that displayed by the Galaxy—since there could be absolutely no point, in all that background, at which would not exist a star. The only mode, therefore, in which, under such a state of affairs, we could comprehend the voids which our telescopes find in innumerable directions, would be by supposing the distance of the invisible background so immense that no ray from it has yet been able to reach us at all."

That this is correct was not really confirmed until Edwin Hubble described the expanding Universe around 1929, and these observations were confirmed by modern work by the Hubble and James Webb Space Telescopes.

It is a simple, beautiful, and even loving sentence. "The night sky is dark; therefore life is possible on Earth." And on one lovely evening during that life, I got to enjoy the little comet he found, and which was paying us a welcoming visit from the outer reaches of the solar system where our lives transpire. ✶

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* 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.*

John Percy's Universe

Flare Stars

by John R. Percy, FRASC
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Variable stars are those stars that change in brightness. They come in all different varieties: They may eclipse, rotate, pulsate, flare, erupt, or explode—or any or all of the above. Variable stars have been my research passion for more than half a century.

What is the nearest variable star? The Sun! Viewed from the distance of other stars, its brightness would vary (slightly) on many timescales, for many reasons. It is a very low-level complex pulsating variable star, with periods of about half an hour. If there were a large sunspot on the disk of the Sun, it would be a low-level rotating variable star with a period equal to its rotation period—about a month. If one of its planets transited—crossed in front of it as seen from our location—it would dim slightly as a sort of eclipsing variable star. And it would be a flare star as magnetically driven eruptions occurred in its outer layers.

And what is the nearest variable star to the Sun? Proxima Centauri, the nearest star of any kind. It's a flare star, too. It also has a transiting Earth-like planet, suggesting that Earth-like planets are very common in the Universe. There is one next door! I wonder if there are any organisms on that planet to feel the effects of the flares.

Flare stars are common, too. Almost all stars flare—especially the cool, red ones that make up the bulk of the stars in our galaxy. Many of "The Nearest Stars" in the RASC annual Observer's Handbook are known to be flare stars. But they don't get much attention and respect. So, here's a brief review.

Flare stars are a type of eruptive variable star, along with novae and supernovae. Officially, they are called UV Ceti stars, after a bright, nearby, prototypical example. By the way: If you are not familiar with the esoteric naming and classification systems for variable stars, you can find it here[1]. A list of interesting flare stars is given in a review by Dzombeta and Percy[2]. A few others are highlighted in the Wikipedia entry on flare stars. Proxima Centauri's variable-star name is V645 Cen.

Solar flares have been known since the "Carrington Event" in 1859, observed by Richard Carrington (and independently by Richard Hodgson, who rarely gets credit). UV Ceti stars were discovered in the 1920s, but their study blossomed in the 1940s with the discovery that UV Ceti itself brightened by four magnitudes when it erupted—easily visible to visual observers. The flaring also has a noticeable effect on the spectrum of the star, producing hot emission lines, and violet and ultraviolet emission in an otherwise-cool spectrum. So, they can be detected in that way.

Flares are not easy to observe, because they are infrequent, brief, and random. Human observers require patience. We assume that robotic telescopes do not get bored, but who knows? Nevertheless, some AAVSO (American Association of Variable Star Observers: www.aavso.org) visual observers have been successful in observing flares in these stars, as early as 1950. See Templeton's brief review[3] for a flare light curve for UV Ceti in 1959 by Thomas Cragg. So, it can be done. Figure 1 shows a flare on V371 Ori observed by Lewis (Lew) Cook on 1982 January 8, as described in Templeton's review.

Solar Flares

The causal mechanism in flare stars is the same as in solar flares: an intense, localized release of electromagnetic radiation in the star's atmosphere. A quick glance at the Wikipedia entry will convince you that this is a very complex process, powered by the reconnection of magnetic fields around active regions of the Sun, producing super-hot plasma. As with the Sun, the activity also produces a hot corona (the Sun's coronal temperature is 2,000,000 K) which can make up a significant fraction of a typical flare star's lower-than-solar luminosity.

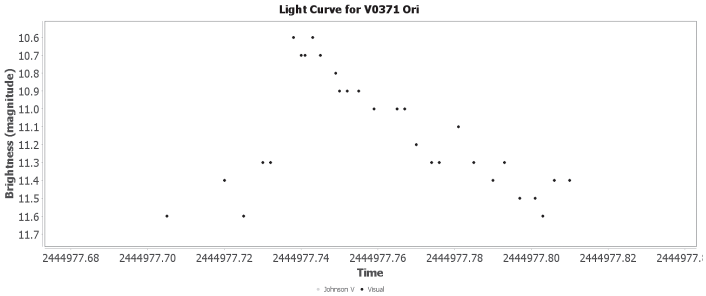

Figure 1 — The light curve of a flare on V371 Ori observed visually by Lewis (Lew) Cook on 1982 January 8. It plots visual magnitude against Julian Date. Source: AAVSO.

These processes produce radiation across the electromagnetic spectrum so, as with many other types of variable stars, our knowledge and understanding was significantly increased by multi-wavelength observations—especially X-ray—that became possible in the space age, along with ground-based visual, infrared, and radio observation.

Observations of thousands of Sun-like stars allows us to put the Sun in context. Young stars, by and large, rotate rapidly, and are very active. The rotation ultimately drives the activity through the production of the star's magnetic field. Old stars rotate slowly and are less active (I can relate to that!). The rotation is slowed down by "braking" by the stars' winds. The Sun is a middle-aged star, 4.5 billion years old. Cooler stars have much longer lives than the Sun—tens of billions of years—so it follows that these cool flare stars are at a much earlier relative stage of life than the Sun, even though they are billions of years old.

Understanding of flare stars has been revolutionized by satellite missions *Kepler*, its successor K2, TESS, (*Transiting Exoplanet Survey Satellite*) and *Gaia*. *Kepler* and TESS were designed to observe large numbers of main-sequence stars, like the Sun and cooler ones, for evidence of transits by exoplanets. This is the part of their mission that attracted the most media attention. But these are also the types of stars that may flare, and may also undergo low-level but easily observable rotational variability—an indication of stellar activity. This gives a clue as to whether the stars are likely to flare. Incidentally, this is a good example of how an astronomical survey for one purpose can yield useful data for totally different ones.

Because these satellites observe so many stars, over such a wide range of temperature, they provide excellent information about the statistics of active stars. Kepler and K2 observed about 200,000 stars, and the Kepler Catalog of Stellar Flares lists almost a million flares. Most of these were observed at one-minute intervals, so the shape and amplitude of the flares could be measured. These have led to exceptionally good information about the flares, and which types of stars they occur on. The *Gaia* satellite has discovered and measured rotational variability periods and amplitudes in almost 150,000 cool stars, the brightest being ϵ Eri at $V = 3.73$.

"Superflares," with energies of 10^{36} to 10^{38} ergs, have also been observed, though they are rare. Have they occurred on the Sun, recently or in the past? Have they affected Earth? Geological studies may tell.

The RS CVn Bandwagon

By definition, RS CVn variable stars are close binary star systems with periods of 1 to 14 days and components of spectral type F or cooler. So, they are slightly hotter, more massive, and more Sun-like than most flare stars. Tidal forces exerted by one binary component on the other have "spun up" one or both of these stars so they have strong rotation and activity, including flares. They also have large star-spots that create rotational variability with periods of a week or two.

They became of scientific interest at the very same time that off-the-shelf photoelectric photometers made such photometry interesting and accessible to skilled amateurs. These volunteer observers were motivated by, among other things, the fact that the results could be published at the end of each observing season—with them as co-authors. Professional astronomers such as Douglas Hall organized, supervised, published, and championed their work.

At the same time, Janet Mattei, Howard Landis, and I were creating the AAVSO photoelectric photometry program, and we decided to concentrate on small-amplitude red-giant variables, which fitted in well with the AAVSO's long-standing visual observing program. Not as sexy, but equally productive, scientifically, I can assure you. And we did put a few RS CVn stars on the program to be trendy (Percy et al. 2001).

Flare Stars and Life

Our Sun is very modest as flare stars go, but we are aware of some of its effects on life on Earth: magnetic storms in our atmosphere, occasional disruption of our delicate power grid, and the beautiful aurora, as we had in May 2024. Whether these effects were harmful or beneficial to the origin and development of early life on Earth is not clear, but certainly of interest—to both biologists and astronomers.

We now know that Earth-like planets are common around red dwarfs. There's one around the nearest star to the Sun. On a much more energetic flare star than the Sun, the effects of the flares would certainly be more severe—especially if that life was on a planet around a cool red star, where the so-called "habitable zone" is much closer to the star and its activity. Perhaps the flares would strip the atmosphere of the forming planets, unless they had already developed a protective magnetosphere. Perhaps they would strip the planet's ozone layer, which would be harmful to both the origin and development of life. But maybe a bit of flare activity would be useful in creating genetic diversity, which would help lead to "the survival of the fittest."

It's always interesting to contemplate life around a different star (or star system) than our own. We can then appreciate our location around a relatively boring star.

Acknowledgements

This short article was inspired by a much more detailed review[2] prepared by Krstinja Dzombeta as a senior thesis, with me as advisor, in the Astronomy Major Program at the University of Toronto. ✶

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Endnotes

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2. tspace.library.utoronto.ca/handle/1807/97060
3. www.aavso.org/vsots_uvcet

John Percy FRASC is a very active Professor Emeritus in Astronomy & Astrophysics, and Science Education, at the University of Toronto. He is a former President (1978–80) and Honorary President (2013–17) of the RASC. He has been a variable-star astronomer for six decades.

Dish on the Cosmos

Using Isotopic Clues to Learn the History of Io

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

One of the constant themes in the astrophysical history of the Universe describes the origin of heavy elements through the nuclear fusion reactions in stars. A Big Bang start to the Universe only leads to very light elements including hydrogen, helium, and traces of heavier elements like lithium, beryllium, and boron. Everything else on the periodic table comes from nuclear processes associated with stars. The elemental composition of objects gives direct insights into the origins of the objects we see. Because most nuclei are long-lived, chemical studies give us deep insight into the depths of time. In one recent example of this, astronomers have used the Atacama Large Millimeter/submillimeter Array (ALMA) to observe the chemical composition of one of Jupiter's many moons, Io. By finding an anomalous amount of heavy sulphur atoms, they argue that Io has been volcanic for as long as it has been around.

Io is one of the first astronomical objects a novice telescope user gets to see. Of the four Galilean moons, Io is the closest to Jupiter, with an orbital period of 1.8 days: so fast that the motion is visible even in a single night of observing. Io is known for its extensive volcanic activity, which is odd because Io is so small. Most moons in the Solar System have cooled off and solidified since Solar System formation. However, Io, and to a lesser extent Europa, have surprisingly warm interiors. Io's volcanism is driven by being so close to Jupiter. There, Io experiences tidal heating from being tugged back and forth by Jupiter's strong gravity and the collective gravitation of the other three moons: Europa, Ganymede, and Calisto. Like working a ball of clay, the constant stretching heats the interior of Io, which is what drives the constant eruptions.

While we see the volcanism now, it is not clear how long Io has been in the middle of this gravitational tug-of-war between Jupiter and the other moons. Our theory for Solar System formation predicts that the Galilean moons formed like a miniature Solar System with Jupiter at the centre. Material that gravity was pulling into Jupiter formed into an accretion disk and the individual moons gravitationally condensed out of that disk, just like the planets formed around the young Sun. We don't know how far out the moons originally formed and whether they locked into their current patterns early in the Solar System or drifted there gradually over time.

Figure 1 — Image of a volcanic plume above Io captured by the instruments on the Galileo mission. The ALMA observations are able to measure the chemical composition of these plumes. Credit: TK

The chemical composition of Io gives some insights into the origin. The basic idea for this measurement is that volcanoes on Io blow material into the atmosphere and most of that material then settles onto the surface. Based on observations from missions like Voyager and Galileo, we can estimate that volcanos dump their ash onto the surface of the moon at a rate of 0.1 to 1 cm/year. That material settles and eventually gets packed back into the interior of the moon, where it can get launched in a volcano again. If Io's volcanism has persisted since the origin of the Solar System, it should have recycled the entire moon through volcanoes 10 to 100 times. But, with each eruption, some of the material is lost into the atmosphere and ultimately into space. The material that is lost into space tends to be the lighter material, since light atoms escape the gravity of the moon most easily. Hence, if we measure the excess of heavy material on Io relative to some standard, that gives an estimate of how many times material has been blown out through volcanoes, since each passage loses some of the lighter material.

The last tool that is needed is to establish the chemical benchmark, against which an excess of heavy elements can be measured. This is more complicated since the astrophysical processes shape the relative abundance of elements.

For example, the Universe is mostly hydrogen and helium, but Earth is mostly iron, nickel, plus carbon, nitrogen, and oxygen. While we do have some of the light gases that are so common in the Universe, the early solar wind pushed most of these atoms into the outer Solar System, warping Earth's chemistry relative to the cosmic standard. Similarly, the heat from Jupiter's formation and the weak gravity of the Galilean moons means that they formed with some unknown chemical composition. How then can we measure whether volcanoes have made the chemistry in Io enriched in heavy elements?

Here, we rely on the different isotopes of individual atoms. The different isotopes of elements have the same number of protons and electrons but different numbers of neutrons from the "common" isotopes. The relative abundances of isotopes are set by nuclear processes in stars, but after that different isotopes tend to follow each other since they behave almost identically in chemical reactions. However, when launched in volcanic plumes the difference in masses for the isotopes means that the lighter elements tend to escape.

The astronomical measurement that measured the duration of Io's volcanism came from studying the isotopes of sulphur and chlorine in SO, SO_2, and NaCl. These observations needed ALMA because of its excellent resolution, which could see the gas being blown out of Io's volcanoes. ALMA also has a sensitive spectrometer, which could distinguish between light from isotopes. These focused on the differences between the molecules with the most common form of sulphur (16 protons, 16 neutrons) and its heavier isotope (16 protons, 18 neutrons). By finding that the heavy isotopes for all these molecules were enhanced relative to the standard abundance ratio in the Solar System, the astronomers were able to measure the excess heavy elements. The excess was sufficiently large that volcanism on Io is likely to have persisted for the entire age of the Solar System. In other words, Io was born into the tidal tug-of-war and the Galilean moons have stablized in their current configuration since they were formed.

Read more: https://arxiv.org/abs/2405.18595 ✶

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.

Blast from the Past!

Compiled by James Edgar
james@jamesedgar.ca

ASTRONOMICAL NOTES.

[This article first appeared in the *Journal* of 1908, Vol. 2, p. 43]

The Lick Observatory party which went to Flint Island, Southern Pacific Ocean, to observe the total eclipse of the Sun on January 3, returned to Mt. Hamilton on January 25. Rain fell during a part of the total phase, but the sky cleared and some excellent photographs were obtained, the instruments though wet working perfectly.

For many years Professor Lewis Boss, director of the Dudley Observatory, Albany, N.Y., has been engaged in the observation and reduction of a large and accurate fundamental catalogue of stars, and two years or more ago the proposal was made to extend this work to the southern hemisphere. The Carnegie Institution has offered to bear the expense of the proposed observatory, and Professor R.H. Tucker, of the Lick Observatory, will be placed in charge of it. It is expected that three years will be required to carry out the project and the station will be either in New Zealand, South America or South Africa. Professor Tucker, Mr. R.F. Sandford his assistant at Mt. Wilson, two from the staff of the Dudley Observatory and three others not yet chosen will leave in August for the new work. The large Pistor and Martins Meridian Circle of the Dudley Observatory will be used in the new work, and it is worthy of notice that it was with this instrument that Professor Tucker began his professional career, while his nine years of Service at the Argentine National Observatory at Cordoba will be of the highest advantage to him in carrying out the southern plan. Professor Tucker will retain his position at the Lick Observatory, being given leave of absence for the necessary time.

In the Lick Observatory Bulletin No. 126 J. C. Duncan, describing his observations of Comet d1907, remarks that "On the nights of August 8, 9, and 10, it was noted that, as the Nicol was rotated, the light of that part of the tail near the head, and that of the coma, underwent marked changes of intensity. The maximum intensity was reached when the plane of separation of the ordinary and extraordinary rays in the Nicol was perpendicular to the apparent direction of the tail; showing that the light of the tail and coma was polarized in a plane containing the axis of the tail. No such effect was noticed in the light of the nucleus.

"On the night of August 12, Professor Campbell observed the comet's light with the same polarizing eye-piece applied to the finder of the 36-inch telescope, and found only a feeble variation of intensity; and on the night of August 13, I again observed a feeble variation. On all succeeding nights when the Nicol was used, no effects of polarization were observed in any part of the comet.

"The observations indicate that, from August 8 to August 13, and probably for some time preceding the former date, the light of the coma and tail consisted largely of diffused sunlight; that the proportion of proper to borrowed light increased about August 12 and 13; and that, after the latter date, the comet's own luminosity was sufficient to mask any polarization effects that may have been produced in diffused sunlight."

S.J. Corrigan is contributing a series of interesting articles to Popular Astronomy on "An Astronomical Theory of the Molecule and an Electrical Theory of Matter." The first of these series appeared in the December number of that journal.

Observations of the "knots" observed on Saturn's ring are described by R.H. Tucker in Lick Observatory Bulletin No. 127. "On the first of the two nights," he says, "the observing conditions were very bad, and the measures were made with difficulty. The light was condensed in four knots, and none of them appeared to be double. The measures are given in the order corresponding to that used above.

"On the last night, the sky was covered with cloud for the greater part of the night. During the short intervals of partially clear sky, the definition was good. Four condensations were seen, and these appeared much flattened. The shadow of the ring upon the planet was black, and sharply defined.

"Bad weather, since the end of November, has interfered with any further measures.

* * *

"The appearance of these knots and their development are evidently similar to those described by W.C. Bond, at the time the earth passed through the plane of the ring in 1848, and published in Volume 2, Part I, of the *Harvard Observatory Annals*. The knots at that epoch, however, appear to have been distributed with perfect symmetry, with respect to the planet; while the present series of measures place the Eastern ones closer to the planet."

Astronomische Nachrichten No. 4213 describes three series of observations of Professor Bohlin, of Stockholm, carried on since 1902, from which a first approximation to a measurable parallax of condensations in the Great Nebula in Andromeda was arrived at. The mean of the results is stated to be 0″.17. This would indicate the nebula to be about 17 light years from us. The diameter of the major axis of the nebula as seen from the earth, 2⅓° as given by Roberts, would indicate at that distance, a diameter in extent approximately 800 times greater than the Solar System, or 4½ million million miles. Twenty-two of such systems as the Great Nebula, from its present position in space, placed edge to edge would on this basis about reach the Solar System.

In the *Astrophysical Journal,* Vol. XXVI, No. 5, F.H. Loud of Colorado College advances a theory explanatory of short-period variability. He says:

"The best-known and most representative stars of the class under discussion, are then, stars of advanced development, and at the same time binaries of short period, in which as a rule one component only of the pair is luminous, for the spectral lines undergo no periodic duplication. According to the hypothesis to be tested, this component owes its light to the resistance of a diffused medium, to which the other must be assumed to be relatively at rest. The visible star, then, is the satellite; and at so short a distance from the primary, the tides necessarily induced tend to impose upon it a rotation of equal rate with its revolution. The orbital movement, however, in parting with the energy which becomes the source of the star's visibility, is continually drawn into narrower compass, and thus accelerated in speed. The tidal action tends to restore the equality of the periods, with the result that the rotation is always a little—but only a little—slower than the revolution. The effect of this lag is that the area on the satellite, heated to brilliant incandescence, is of an unsymmetrical form. The point of greatest heating, since it occupies the momentary center of the advancing front, moves in consequence slowly around the equator, always entering upon regions comparatively cool, and drawing behind it regions glowing from their recent exposure to heat. Thus, as the revolution brings these regions successively into the line of sight, there appears first, to our view, a sudden rise of brightness, then, after the maximum, a long and gradual decline. The degree of cohesion in the surface, implied in this account, might well be too great for a star of Sirian tenuity, but not for the class of bodies actually concerned; especially if it be considered that both primary and satellite are presumed to have advanced far in condensation, with accompanying loss of light, the latter body being probably as dark as the former, save for the surface action of the resistance.

J. R. C. ✶

[J.R. Collins was Society Secretary, one of the signatories in 1903 requesting from King Edward VII the privilege of prefixing the word Royal to the name Astronomical Society of Canada.]

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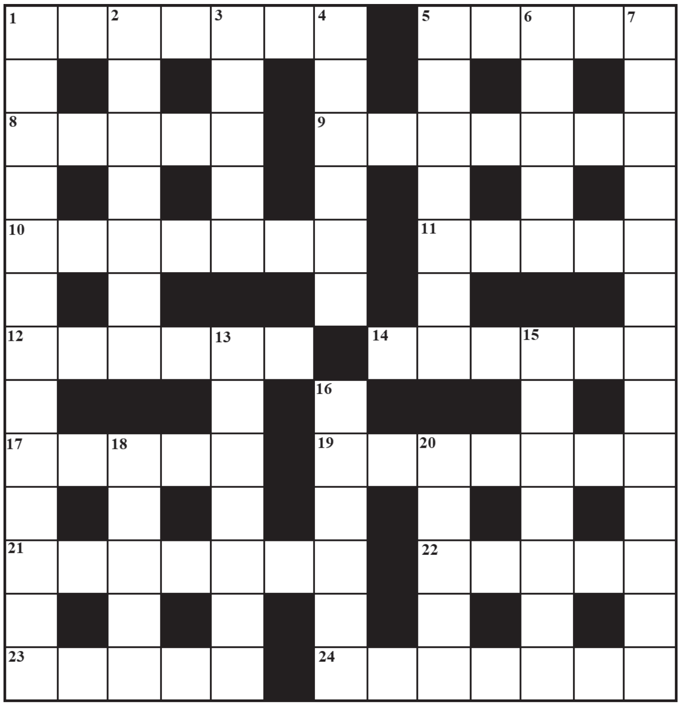
Astrocryptic

by Curt Nason



ACROSS

1. A star rotates to each little asteroid (7)
5. Solar eruption heard with panache (5)
8. Just a bit remains of disrupted crater with no end (5)
9. Altair's neighbour has nail problems (7)
10. No help with AI back around Uranus (7)
11. Sun-up to sunset with no Sun. Troubled? (5)
12. Halley started Earth spinning from an outer-belt asteroid (6)
14. Twins have long dash in GI tract (6)
17. Explosive prominence has impact on Handbook author (5)
19. Speaking of the Handbook, can Alma revise it? (7)
21. As king, he leads us to follow the initial central eclipse path (7)
22. Toronto had double time loss to U of Maine town (5)
23. Handbook observing aids for those lean times (5)
25. Seven Sisters dancing but one is not tempted (7)

DOWN

1. Astronomers' Journal of Pascal history (13)
2. Note to reach around a prime target for EPO Committee (7)
3. He catalogued galaxy clusters with a ringer (5)
4. Maraca shaken in the river (6)
5. Many a sound caster on Europa (7)
6. Neptune seeker was mad as a silly kook (5)
7. General relativity prediction made him angry (8,5)
13. Despite the cheap ocular he found Titan (7)
15. Confused genius puts hole in magmatic rock (7)
16. Cosmologist Nick calculated CMB polarization but did not rule Germany (6)
18. Lunar cliff seen in Peru, turning to the south (5)
19. Moose turns east to north, scrambles satellites (5)

Answers to previous puzzle

Across: **1** EXELIGMOS (2 def); **6** CSA (hid); **8** ROUND (2 def); **9** NUCLEUS (re(anag)v); **10** HANDSET (2 def); **11** NAIAD (anag); **12** LEXELL (Lex+Tell-T); **14** ASTROS (2 def); **17** AZTEC (az+anag); **19** PEGASUS (PE+gas+us); **22** HUNDRED (def); **23** THEBE (hid); **24** RCA (anag) **25** AUSTRALIA (Au+anag+rev)

Down: **1** EARTH (anag); **2** EQUINOX (Equine(-e)+ox); **3** INDUS (hid); **4** MINUTE (2 def); **5** SECONDS (2 def); **6** CAELI (C(AE)LI); **7** APSIDES (AP+sides); **12** LEATHER (anag); **13** LACERTA (La+anag); **15** RUSSELL (hom); **16** APODIS (APOD+is); **18** TENMA (Manet anag); **20** G STAR (anag-NE); **21** SHE-RA (anag)

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- Discovery through the scientific method

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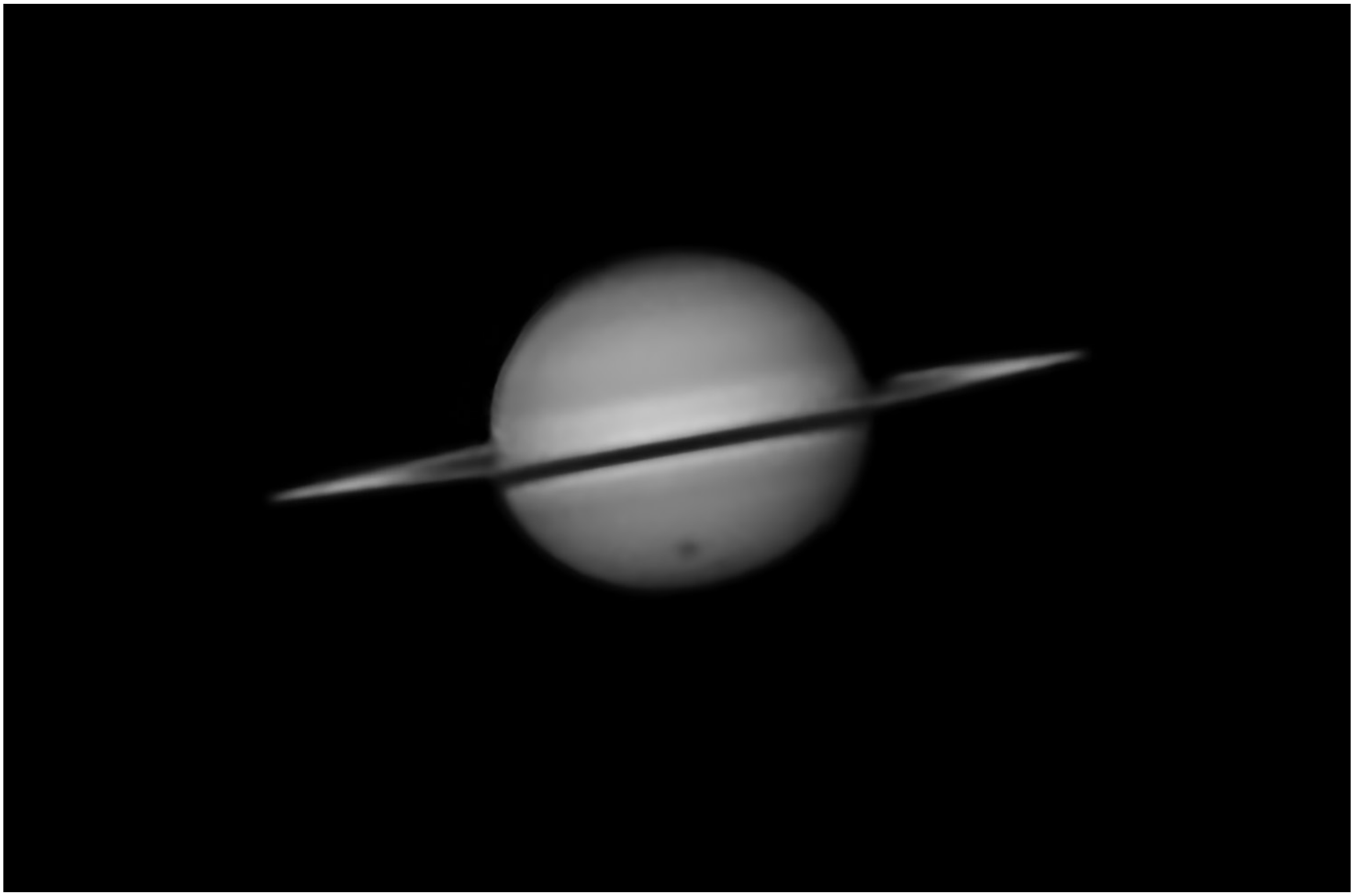
Great Images

by Mike Karakas



This image of Saturn and the transit of its largest moon, Titan, was taken by Mike Karakas from Winnipeg Centre. Mike says that Saturn was just 29 degrees above the horizon, with seeing conditions 2-3 out of 10, and average transparency and it was taken at 6 a.m. CST. He used a Celestron C11 on a Sky-Watcher NEQ6, with a ZWO ASI462MM camera and a 742nm IR filter.

He used FireCapture, Autostakkert!4, Registax (wavelets), Winjupos, and Photoshop. A total of 6 videos stacked and derotated. Total image acquisition time was 20 minutes.

Journal

Scott Johnstone took this beautiful image of the Rho Ophiuchi Cloud Complex, what he calls "the Neapolitan of nebulae." He goes on to say, "I've dreamed of imaging this magical area of the sky since I began my astrophotography journey and saw a picture of this hanging in the Hume Cronyn Memorial Observatory at Western University. It has a little bit of everything in it."

He said it's one of the toughest images he's shot so far. For this two-panel mosaic, he used a William Optics ZenithStar 61II with a Flat61R 0.85 reducer on a Sky-Watcher HEQ5 Pro, and a Canon T3i modified camera, with no filters. 72x180 lights, calibrated with darks, flats, and biases and processed in PixInsight and Photoshop.