The Journal of The Royal Astronomical Society of Canada

Journal

Le Journal de la Société royale d'astronomie du Canada

PROMOTING ASTRONOMY IN CANADA

February/février 2025
Volume/volume 119
Number/numéro 1 [830]

Inside this issue:

NGC 6888 Emission Nebula associated with the Wolf-Rayet star HD 192163 (WR 136)

Matching Galactic Rotation Curves without Dark Matter or MOND

Accuracy of the "Shadow Stick" Method for Determining North

Elephant Trunk

Great Images

By Malcolm Park

LBN 863, also known as Lower's Nebula, Sh2-261 or Sharpless 261, is a faint emission nebula found in Orion. It is named after Harold and Charles Lower who discovered it in 1939. Malcolm Park captured this stunning image of the nebula from his remote telescope in San Pedro, Atacama, using a Celestron 11″ Edge HD with a .7 reducer, an ASI2600MM PRO on a 10 Micron GM 200 HPS II mount. He used Antlia 3-nm filters (SII, Hα, OIII), 20 × 10 minutes each. Final image was processed using PixInsight.

Journal

February / février 2025 | Vol. 119, No. 1 | Whole Number 830

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

contents / table des matières

Research Articles / Articles de recherche

Feature Articles / Articles de fond

Pen & Pixel / Stylo et pixel

Columns / Rubriques

Departments / Départements

Great Images / Superbes images

Tammy Foley captured the Elephant Trunk Nebula (IC 1396) from her home in North County, Ontario. "This target has so much depth and character. It's popular and shot by countless people and loved by many more, myself included," she said. She used a Redcat51(250mm), ZWO 183MC Pro, ZWO EAF, ZWO 5-slot filter wheel using both an L-pro and L-Extreme filters, on a CEM70, UPBv2, guided by PhD2 and 30-mm/f4 w/ASI120-mm mini. All pre- and post-processing was done within PixInsight. Integration was 26.53 hours.

Journal

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

Editor-in-Chief
Nicole Mortillaro
editor@rasc.ca
www.rasc.ca
416-924-7973

Associate Editor
Michael Attas
attasm1@mymts.net

Assistant Editors
Michael Allen
Dave Chapman
Ralph Chou
Ralph Croning
Patrick Kelly

Production Manager
James Edgar
james@jamesedgar.ca

Advertising
Michelle Bass
mempub@rasc.ca

Contributing Editors
Jay Anderson (News Notes)
Mary Beth Laychak (CFHT Chronicles)
David Levy (Skyward)
Blair MacDonald (Imager's Corner)
Curt Nason (Astrocryptic)
John R. Percy (John Percy's Universe)
Randall Rosenfeld (Art & Artifact)
Eric Rosolowsky (Dish on the Cosmos)

Proofreaders
Michael Attas
Margaret Brons
Angelika Hackett
Michelle Johns
Barry Jowett
Alida MacLeod

Design/Production
Michael Gatto
mgatto0501@gmail.com
Grant Tomchuk
grant.tomchuk@gmail.com

Printing
Cansel
www.cansel.ca

The Journal of The Royal Astronomical Society of Canada is published at an annual subscription rate of $125 (plus Canadian tax), $140 USD for US subscriptions, $150 USD for International subscriptions. Membership, which includes the publications (for personal use), is open to anyone interested in astronomy. Applications for subscriptions to the *Journal* or membership in the RASC and information on how to acquire back issues of the *Journal* can be obtained from:

The Royal Astronomical Society of Canada
203-489 College St
Toronto ON M6G 1A5

nationaloffice@rasc.ca
www.rasc.ca
Tel: 416-924-7973
Fax: 416-924-2911

Canadian Publications Mail Registration No. 09818
Canada Post: Send address changes to 203–489 College St, Toronto ON M6G 1A5

Canada Post Publication Agreement No. 40069313

ISSN 0035-872X

Funded by the Government of Canada
Financé par le gouvernement du Canada
Canada

Mixed Sources
Product group from well-managed forests and other controlled sources
www.fsc.org Cert no. SW-COC-005174
© 1996 Forest Stewardship Council
FSC

President's Corner

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

Since I learned, more than half a century ago, that the Moon's distance from Earth varies significantly—resulting sometimes in total solar eclipses and other times in annular eclipses—I have been both fascinated and puzzled by the inconstancy of the second-most prominent body in our sky. Perhaps I should say, by the inconstancy of the *orbital motion* of that body. I have also been intrigued by obscure facts about the Earth–Moon system that make me realize how little I really understand about our home planet's natural satellite. Please let me share a few of these facts and my interest in them.

What exactly does the Moon orbit?

Any two bodies in space that are bound together can be said to be "in orbit." But around what exactly are they in orbit? It's common for us to speak of the Moon, which is only 1.23 percent the mass of Earth, as orbiting an Earth that follows a perfectly and smoothly elliptical orbit around the Sun, unaffected by the proximity of its Moon. But in a two-body system, such as Earth and the Moon, neither orbits around the other; rather, they both orbit—or revolve—around a common centre of mass. The location of that common orbital centre is the "barycentre" (from the Greek "barus," meaning heavy). If Earth and the Moon were of equal mass (such as are some binary stars), the barycentre would lie halfway between them and they would have identical orbits around, and 180 degrees on either side of, that midpoint. Owing to Earth's much greater mass than the Moon's, however, the barycentre of the Earth–Moon system is actually located within our home planet, about 4,670 km from Earth's centre, or about 1,707 km below Earth's surface. This means that while the Moon appears to orbit Earth, both Earth and the Moon orbit around the barycentre, and Earth is sometimes described as "wobbling" around that common centre of mass once per month.

The Moon's distance from Earth

This is a phenomenon that is quite widely known, I think. Throughout its 4-billion-year existence, the Moon has been constantly moving further away from Earth, as a consequence of tidal action slowing Earth's rotation period, and the principle of conservation of angular momentum, by which Earth's rotational angular momentum is gradually being transferred to the Moon's orbit. Eventually Earth and the Moon would become tidally locked, with the same hemisphere of Earth facing the same hemisphere of the Moon. Current estimates suggest that this would occur about 50 billion years from now, and at that point Earth and the Moon would revolve around their barycentre in about 47 current Earth days, with the same hemisphere of each body perpetually facing the other. I say "would" rather than "will" because the Earth-Moon system will never reach that tidally locked stage. Why? Because in about 5 billion years the Sun will exhaust its supply of hydrogen, turn into a red giant, and expand in size dramatically and swallow Mercury, Venus, Earth (including the RASC's head office) and the Moon.

Some terminology—"eclipses" and "occultations"

Before I consider the end of total solar eclipses in the next section, it's worth noting here that the expression "eclipse of the Sun" is a misnomer. An eclipse occurs when one body falls into the shadow cast by another body, such as when the Moon passes through Earth's (Sun) shadow. When one body passes *in front of* another body, either partially or totally obscuring or hiding the other body, the first body is said to "occult"—not to eclipse—the second body ("occult," from the Latin "occultus," meaning clandestine, hidden, secret).

Eclipses and occultations occur at the same time, when three bodies, one of which is light emitting such as our Sun, line up. Take the example of an eclipse of the Moon. Earth lies exactly, or almost exactly, between the Sun and the Moon. Earth casts its (Sun) shadow into space, and the Moon glides through the shadow to produce an eclipse, as seen from Earth. Now let's place a hypothetical observer on the surface of the Moon. Looking toward the Sun, that observer would see the black disk of Earth either partially or totally obscuring, or *occulting*, the Sun.

The same effect, and terminology, apply to the situation where the Moon lies exactly, or almost exactly, between the Sun and Earth. As seen from Earth, the Moon either partially or totally *occults* the Sun. A hypothetical observer on the Moon, however, would see Moon's shadow crossing Earth's surface from west to east, in a partial *eclipse* of Earth.

So, we can see that each time the Sun, the Moon, and Earth line up, at least twice per year during the "eclipse seasons," both an eclipse and an occultation are occurring, and the event is either an occultation or an eclipse, depending on one's observing location and the direction in which the observer is looking.

Nonetheless, the convention was adopted long ago to use the term "eclipse" to denote the partial or total disappearance of the Sun when the Moon passes over it, so I'll use that term in the rest of this column, even though it's actually an occultation!

The end of total "eclipses" of the Sun

Most astronomers know that one of the most remarkable coincidences in nature is that in this epoch the Sun is approximately 400 times the diameter of the Moon, and also, on average, is about 400 times as far away from Earth as is the Moon. The result is that the Moon and the Sun appear to be approximately the same size as seen from the surface of Earth. Of course, owing to the elliptical orbits of the Earth–Moon system around the Sun, and of Earth and the Moon around their barycentre, sometimes the Sun appears a little larger and sometimes a little smaller in the sky than does the Moon.

The apparent diameter of the Sun as seen from Earth varies about 3.4 percent during the year, from 31.46 arcminutes at aphelion between July 3 and 6 (depending on the year), to 32.53 arcminutes at perihelion between January 2 and 5 (again depending on the year). The changes in the Moon's apparent angular diameter as seen from Earth are much greater. According to the celebrated Belgian astronomical mathematician, Jean Meeus (*Mathematical Astronomy Morsels*, 1997, p. 15), the extreme distances between the centres of the Moon and Earth in the 1,000 years between 1500 and 2500 CE are 406,720 km on 2266 January 7 and 356,371 km on 2257 January 1. At these extremes, the Moon's diameter as seen from Earth varies from 29.38 arcminutes to 33.52 arcminutes, a difference of 14.1%. In most years, the difference in the Moon's distance is a little smaller. In 2025, for example, the extremes will be 406,692 km on November 20 (Moon diameter 29.38′) and 356,961 km on December 4 (Moon diameter 33.47′), for a difference of 13.9 percent.

These varying apparent sizes of the Sun and Moon as seen from Earth determine the type of solar eclipse that occurs at new Moon during the two eclipse seasons every year. When the Moon passes centrally across the disk of the Sun, as seen from inside a path that crosses from west to east across Earth, the result will be either an annular or a total eclipse of the Sun, depending on the apparent angular sizes of the Sun and the Moon at the time of the eclipse.

At some future point, the Moon will have moved so far from Earth that even at its closest perigee, it will be so distant and will appear too small ever to be able to cover the Sun's photosphere completely. The result will be only annular and partial "eclipses" (i.e. occultations) of the Sun by the Moon, and no total eclipses, from that point on. When will that be? No one knows for sure, because current thinking is that the rate by which the Moon retreats from Earth has always varied, that the current rate of ~3.8 cm per year is anomalously high, and that the rate is likely to continue increasing. But Jean Meeus has estimated that this may occur in about 1.2 billion years, so there is still the opportunity for all celestial observers alive today to see some total solar eclipses during their lifetimes!

The Perigee Moon

That brings me to the subject of what has—annoyingly to me—come to be referred to as a "supermoon" or "Super Moon." This term was coined and first used in *Dell Horoscope* magazine by astrologer Richard Nolle in 1979. He decided to define it as "a new or full Moon which occurs with the Moon at or near (within 90 percent of) its closest approach to Earth in a given orbit (perigee)." In the decades since, it has been used to describe only a *full* Moon at or near perigee, because at perigee, the new Moon is unobservable except from within the path of totality of a total solar eclipse.

What is "super" about such a Moon? Well, supposedly its size as seen from Earth. But as we have seen, the difference between the apparent angular size of the Moon between apogee and perigee is only about 14 percent, or one-seventh of its diameter. How noticeable is that? Well-known American astrophysicist and astronomy popularizer, Neil deGrasse Tyson, has said that "a 'supermoon' is just a 16-inch pizza pretending to be special next to a 15-inch one," and "the very concept of a supermoon is an embarrassment to everything else we call super." With the average difference between the size of a perigee and an apogee Moon being ~14 percent, the more accurate metaphor is a 16-inch pizza compared to a 14-inch one, so let's use that. For a graphic comparison of the differences in size of an apogee and a perigee full (or nearly full) Moon, see Figure 1, which is a composite image that I made in 2014 using the same telescope.

The silliness and futility of the term "supermoon" to this amateur astronomer—and the way in which it misleads the public—goes further than merely the 16- to 14-inch pizza analogy, for two reasons. First, in order to make the pizza comparison, a valid comparison to the appearance of the Moon in the sky, our 16- and 14-inch pizzas would have to be observed from about 42 metres away, or about the distance between the goal line and midfield of a football field or soccer pitch. Could anyone readily, or at all, discern the difference between two pizzas of those sizes at that distance, even if they were side by side?

Second, on average, extreme apogee and perigee full Moons occur about six months apart. So discerning the difference in appearance between an apogee full Moon and a perigee "supermoon" would be like looking at a 14-inch pizza from a distance of 42 metres, and then six months later looking at a 16-inch pizza from the same distance, and trying to compare how the 16-pizza looks now to how you remember the 14-inch pizza appearing half a year earlier. That's why in my own view—I suspect that many of my fellow RASC members may disagree—this concept of a "supermoon" is misleading hype to the non-astronomical public and should not be used by astronomers generally, and the RASC in particular. Let's use the terms "apogee Moon" and "perigee Moon," and use the opportunity of these full Moons to teach something really useful and interesting about Earth's natural satellite. ✶

Figure 1 — Across different full Moons, the Moon's angular diameter can vary from 29.43 arcminutes at apogee to 33.5 arcminutes at perigee—a variation of around 14% in apparent diameter or 30% in apparent area.

News Notes / En manchette

Compiled by Jay Anderson

Lucy skips past the Earth

On the morning of December 12, NASA's *Lucy* spacecraft skimmed across the top of the Earth's atmosphere, only 360 km above the surface. The maneuver gave the spacecraft a gravity assist that increased its velocity by 7.3 km/s and set it on a new trajectory to through the asteroid belt to Jupiter's trojan moons. This is the second gravity assist for *Lucy*; the first was on 2022 October 16.

Because *Lucy* passed below the orbit of the *International Space Station*, it had the potential to collide with one of the hundreds of satellites orbiting the Earth. NASA's CARA (Conjunction Assessment Risk Analysis) operators determined that no spacecraft maneuvers were necessary to avoid a collision with any satellites or other debris. By mid-morning on the 12th, *Lucy* successfully reconnected with Earth after a short blackout. Arrival at Jupiter's orbit is planned for 2027, but its first target is the main-belt asteroid Donaldjohansen for later this year. *Lucy* has already had one encounter, with the small asteroid Dinkinesh and its even tinier satellite Selam.

The Jupiter trojans are a large group of asteroids that share the planet Jupiter's orbit around the Sun, distributed in two elongated, curved regions around two of the planet's Lagrangian points. Relative to Jupiter, each trojan librates around one of the Lagrange points that exist both 60° ahead of the planet in its orbit (the "Greek" asteroids) and 60° behind (the "Trojan" asteroids). Jupiter is not the only planet favoured by diminutive companions: trojan-type asteroids also co-orbit with Mars, Uranus, and Neptune.

While *Lucy* is now heading toward the Jupiter trojan asteroids, it will be heading away from Jupiter itself. Although the trojan asteroids share an orbit with Jupiter, they are, on average, as far away from that planet as it is from the Sun. On December 14, *Lucy* will pass as "close" as 612 million km, or 4.1 au from Jupiter. *Lucy* will then begin travelling away from that planet, so that the spacecraft will be between 848 and 1071 million km, or 5.7 to 7.2 au from Jupiter during its 2027–2028 trojan asteroid encounters. The first target, expected on 2027 August 12, is the Greek trojan Eurybates, a 64-km asteroid with a 1-km moon.

Compiled in part with material provided by NASA.

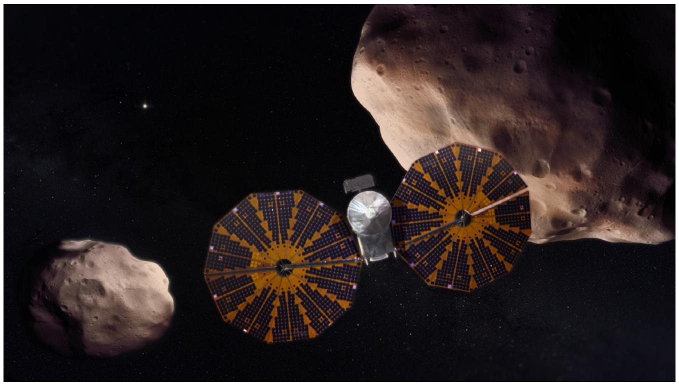


Figure 1 — This artist's concept depicts the Lucy *spacecraft flying past the Trojan asteroid (617) Patroclus and its binary companion Menoetius. Image: NASA's Goddard Space Flight Center/Conceptual Image Lab/Adriana Gutierrez*

Hubble tension tightens up

New observations from the *James Webb Space Telescope* suggest that a new feature in the Universe—not a flaw in telescope measurements—may be behind the decade-long mystery of why the Universe is expanding faster today than it did in its infancy billions of years ago.

The new data confirms *Hubble Space Telescope* measurements of distances between nearby stars and galaxies, offering a crucial cross-check to address the mismatch between observations and modelling in separate measurements of the Universe's mysterious expansion. Known as the Hubble tension, the discrepancy remains unexplained even by the best cosmology models.

"The discrepancy between the observed expansion rate of the Universe and the predictions of the standard model suggests that our understanding of the Universe may be incomplete. With two NASA flagship telescopes now confirming each other's findings, we must take this [Hubble tension] problem very seriously—it's a challenge but also an incredible opportunity to learn more about our Universe," said Nobel laureate and lead author Adam Riess, a Bloomberg Distinguished Professor and Thomas J. Barber Professor of Physics and Astronomy at Johns Hopkins University.

Published in *The Astrophysical Journal*, the research builds on Riess's Nobel Prize-winning discovery that the Universe's expansion is accelerating owing to a mysterious "dark energy" permeating vast stretches of space between stars and galaxies. Riess's team used the largest sample of Webb data collected over its first two years in space to verify the Hubble telescope's measure of the expansion rate of the Universe, a number known as the Hubble constant.

They used three different methods to measure distances to galaxies that hosted supernovae, focusing on distances previously gauged by the Hubble telescope and known to produce the most precise "local" measurements of this number. Observations from both telescopes aligned closely, revealing that Hubble's measurements are accurate and ruling out an inaccuracy large enough to attribute the tension to an error by Hubble.

Still, the Hubble constant remains a puzzle because measurements based on telescope observations of the present Universe produce higher values compared to projections made using the "standard model of cosmology," a widely accepted framework

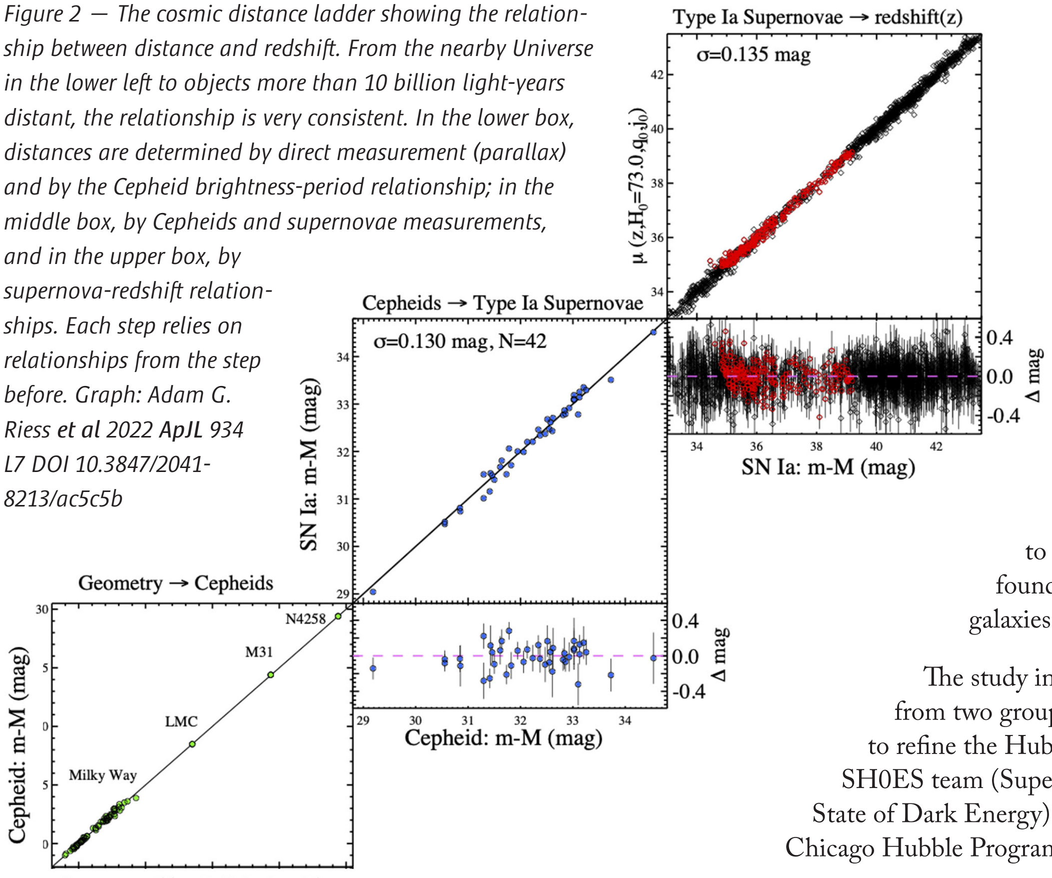


Figure 2 — The cosmic distance ladder showing the relationship between distance and redshift. From the nearby Universe in the lower left to objects more than 10 billion light-years distant, the relationship is very consistent. In the lower box, distances are determined by direct measurement (parallax) and by the Cepheid brightness-period relationship; in the middle box, by Cepheids and supernovae measurements, and in the upper box, by supernova-redshift relationships. Each step relies on relationships from the step before. Graph: Adam G. Riess et al *2022 ApJL 934 L7 DOI 10.3847/2041-8213/ac5c5b*

of how the Universe works calibrated with data of the cosmic microwave background, the faint radiation left over from the Big Bang.

While the standard model yields a Hubble constant of about 67-68 kilometres per second per megaparsec, measurements based on telescope observations regularly give a higher value of 70 to 76, with a mean of 73 km/s/Mpc. This mismatch has perplexed cosmologists for over a decade because a 5-6 km/s/Mpc difference is too large to be explained simply by flaws in measurement or observational techniques. (Megaparsecs are huge distances: 3.26 million light-years).

Since Webb's new data rules out significant biases in Hubble's measurements, the Hubble tension may stem from unknown factors or gaps in cosmologists' understanding of physics yet to be discovered, Riess's team reports.

"The Webb data is like looking at the Universe in high definition for the first time and really improves the signal-to-noise of the measurements," said Siyang Li, a graduate student working at Johns Hopkins University on the study.

The new study covered roughly a third of Hubble's full galaxy sample, using the known distance to a galaxy called NGC 4258 as a reference point. Despite the smaller dataset, the team achieved impressive precision, showing differences between measurements of under 2 percent—far smaller than the approximately 8-9-percent size of the Hubble tension discrepancy.

In addition to their analysis of pulsating stars called Cepheid variables, the gold standard for measuring cosmic distances, the team cross-checked measurements based on carbon-rich stars and the brightest red giants across the same galaxies. All galaxies observed by Webb, together with their supernovae, yielded a Hubble constant of 72.6 km/s/Mpc, nearly identical to the value of 72.8 km/s/Mpc found by Hubble for the very same galaxies.

The study included samples of Webb data from two groups that work independently to refine the Hubble constant, one from Riess's SH0ES team (Supernova, H_0, for the Equation of State of Dark Energy) and one from the Carnegie-Chicago Hubble Program, as well as from other teams.

The combined measurements make for the most precise determination yet about the accuracy of the distances measured using the Hubble Telescope Cepheid stars, which are fundamental for determining the Hubble constant.

Although the Hubble constant does not have a practical effect on the Solar System, Earth, or daily life, it reveals the evolution of the Universe at extremely large scales, with vast areas of space itself stretching and pushing distant galaxies away from one another like raisins in rising dough.

It is a key value scientists use to map the structure of the Universe, deepen their understanding of its state 13-14 billion years after the Big Bang, and calculate other fundamental aspects of the cosmos.

"Resolving the Hubble tension could reveal new insights into more discrepancies with the standard cosmological model that have come to light in recent years," said Marc Kamionkowski, a Johns Hopkins cosmologist who helped calculate the Hubble constant and has recently helped develop a possible new explanation for the tension.

The standard model explains the evolution of galaxies, cosmic microwave background from the Big Bang, the abundances of chemical elements in the Universe, and many other key observations based on the known laws of physics. However, it does not fully explain the nature of dark matter and dark energy, mysterious components of the Universe estimated to be responsible for 96% of its makeup and accelerated expansion.

"One possible explanation for the Hubble tension would be if there was something missing in our understanding of the early Universe, such as a new component of matter—early dark energy—that gave the Universe an unexpected kick after the Big Bang," said Kamionkowski, who was not involved in the new study. "And there are other ideas, like funny dark matter properties, exotic particles, changing electron mass, or primordial magnetic fields that may do the trick. Theorists have licence to get pretty creative."

Compiled with material provided by Johns Hopkins University

More dark stuff: comets

The first dark comet—a celestial object that looks like an asteroid but moves through space like a comet—was reported less than two years ago. Soon after, another six were found. Now, researchers have announced the discovery of seven more, doubling the number of known dark comets, and find that they fall into two distinct populations: larger ones that reside in the outer Solar System and smaller ones in the inner Solar System, with various other traits that set them apart.

Scientists got their first inkling that dark comets exist when they noted in a March 2016 study that the trajectory of "asteroid" 2003 RM had moved ever so slightly from its expected orbit. That deviation couldn't be explained by the typical accelerations of asteroids, like the small acceleration known as the Yarkovsky effect.

The Yarkovsky effect is a force acting on a rotating body in space caused by the daily heating of the object and the subsequent uneven emission of infrared radiation, which carries away momentum. It is usually considered in relation to meteoroids or small asteroids (about 10 cm to 10 km in diameter), as its influence is most significant for these bodies. Depending on whether an orbit is prograde or retrograde, the emitted radiation can cause the affected body to slowly spiral away from the Sun, or toward it. In effect, a tiny, low-powered rocket engine.

"When you see that kind of perturbation on a celestial object, it usually means it's a comet, with volatile material outgassing from its surface giving it a little thrust," said study co-author Davide Farnocchia of NASA's Jet Propulsion Laboratory in Southern California. "But try as we might, we couldn't find any signs of a comet's tail. It looked like any other asteroid—just a pinpoint of light. So, for a short while, we had this one weird celestial object that we couldn't fully figure out."

Farnocchia and the astronomical community didn't have to wait long for another piece of the puzzle. The next year, in 2017, a NASA-sponsored telescope discovered history's first documented celestial object that originated outside our Solar System. Not only did 1I/2017 U1 ('Oumuamua) appear as a single point of light, like an asteroid, its trajectory changed as if it were outgassing volatile material from its surface, like a comet. However, the strength of the added propulsion from such outgassing defied that of typical asteroids and matched a comet's pace. The problem? 'Oumuamua was missing the signature, bright dust tail of a comet. Thus, it could not be classified easily as an asteroid or a comet.

"'Oumuamua was surprising in several ways," said Farnocchia. "The fact that the first object we discovered from interstellar space exhibited similar behaviours to 2003 RM made 2003 RM even more intriguing."

By 2023, researchers had identified seven Solar System objects that looked like asteroids but acted like comets. That was enough for the astronomical community to bestow upon them their own celestial object category: "dark comets." Now, with the finding of seven more of these objects, researchers could start on a new set of questions.

"We had a big enough number of dark comets that we could begin asking if there was anything that would differentiate them," said Darryl Seligman, a postdoctoral fellow in the department of Physics at Michigan State University, East Lansing, and lead author of the new paper. "By analyzing the reflectivity," or albedo, "and the orbits, we found that our Solar System contains two different types of dark comets."

One kind, which they call outer dark comets, have similar characteristics to Jupiter-family comets: They have highly eccentric (or elliptical) orbits and are on the larger side (hundreds of metres or more across). The second group, inner dark comets,

reside in the inner Solar System, travel in nearly circular orbits, and are on the smaller side (tens of metres or less).

Like so many astronomical discoveries, Seligman and Farnocchia's research not only expands on our knowledge of dark comets, but it also raises several additional questions: Where did dark comets originate? What causes their anomalous acceleration? Could they contain ice?

"Dark comets are a new potential source for having delivered the materials to Earth that were necessary for the development of life," said Seligman. "The more we can learn about them, the better we can understand their role in our planet's origin."

Compiled with material provided by NASA and Michigan State University.

Firefly shines across the Universe

The *James Webb Space Telescope* has detected and "weighed" a galaxy that not only existed about 600 million years after the Big Bang, but also has a mass that is similar to what our Milky Way Galaxy's mass might have been at the same stage of development.

Other galaxies Webb has detected at this period in the history of the Universe are significantly more massive. Nicknamed the Firefly Sparkle, this galaxy is gleaming with star clusters—10 in all—each of which researchers examined in great detail.

"I didn't think it would be possible to resolve a galaxy that existed so early in the Universe into so many distinct components, let alone find that its mass is similar to our own galaxy's when it was in the process of forming," said Lamiya Mowla, co-lead author of the paper and an assistant professor at Wellesley College in Massachusetts. "There is so much going on inside this tiny galaxy, including so many different phases of star formation."

Webb was able to image the galaxy in sufficient detail for two reasons. One is a benefit of the cosmos: A massive foreground galaxy cluster radically enhanced the distant galaxy's appearance through a natural effect known as gravitational lensing. And when combined with the telescope's specialization in high-resolution imaging of infrared light, Webb delivered unprecedented new data about the galaxy's contents.

Figure 3 — Possible shape of asteroid 'Oumuamua. Image: William Hartmann

"Without the benefit of this gravitational lens, we would not be able to resolve this galaxy," said Kartheik Iyer, co-lead author and NASA Hubble Fellow at Columbia University in New York. "We knew to expect it based on current physics, but it's surprising that we actually saw it."

Mowla, who spotted the galaxy in Webb's image, was drawn to its gleaming star clusters, because objects that sparkle typically indicate they are extremely clumpy and complicated. Since the galaxy looks like a "sparkle" or swarm of fireflies on a warm summer night, they named it the Firefly Sparkle Galaxy.

The research team modelled what the galaxy might have looked like if its image weren't stretched by gravitational lensing and discovered that it resembled an elongated raindrop. Suspended within it are two star clusters toward the top and eight toward the bottom. "Our reconstruction shows that clumps of actively forming stars are surrounded by diffuse light from other unresolved stars," said Iyer. "This galaxy is literally in the process of assembling."

Webb's data show the Firefly Sparkle Galaxy is on the smaller side, falling into the category of a low-mass galaxy. Billions of years will pass before it builds its full heft and a distinct shape. "Most of the other galaxies Webb has shown us aren't magnified or stretched, and we are not able to see their 'building blocks' separately. With Firefly Sparkle, we are witnessing a galaxy being assembled brick by brick," Mowla said.

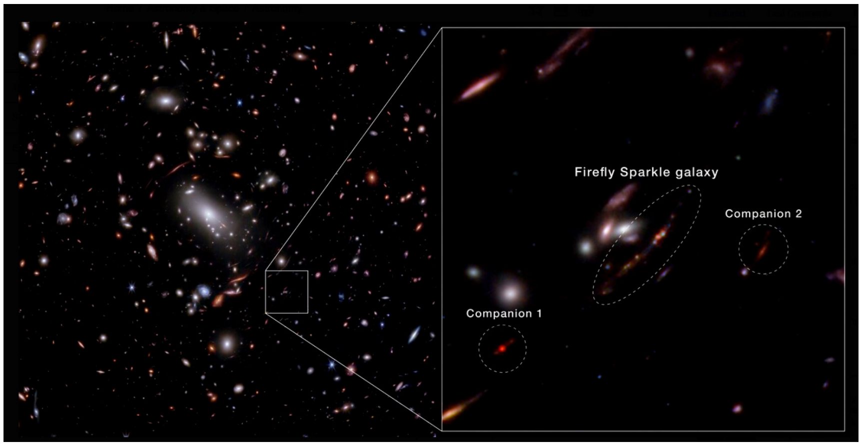


Figure 4 — At left, thousands of overlapping objects at various distances are spread across this galaxy cluster. A box at bottom right is enlarged on the right half. A central oval identifies the Firefly Sparkle Galaxy, a line with 10 dots in various colours. Credit: NASA, ESA, CSA, STScI, C. Willott (NRC-Canada), L. Mowla (Wellesley College), K. Iyer (Columbia)

Since the image of the galaxy is warped into a long arc, the researchers easily picked out 10 distinct star clusters, which are emitting the bulk of the galaxy's light. In Webb's images, they are represented in shades of pink, purple, and blue. Those colours, along with supporting spectra, confirmed that star formation didn't happen all at once in this galaxy, but was staggered in time.

"This galaxy has a diverse population of star clusters, and it is remarkable that we can see them separately at such an early age of the Universe," said Chris Willott of the National Research Council Canada, a co-author and the observation program's principal investigator. "Each clump of stars is undergoing a different phase of formation or evolution."

The galaxy's projected shape shows that its stars haven't settled into a central bulge or a thin, flattened disk, another piece of evidence that the galaxy is still forming.

Researchers can't predict how this disorganized galaxy will build up and take shape over billions of years, but there are two galaxies that the team confirmed are "hanging out" within a tight perimeter and may influence how it builds mass over billions of years. Firefly Sparkle is only 6,500 light-years away from its first companion, and 42,000 light-years from its second companion. For context, the fully formed Milky Way is about 100,000 light-years across—all three would fit inside it. Not only are its companions very close, the researchers also think that they are orbiting one another.

Each time one galaxy passes another, gas condenses and cools, allowing new stars to form in clumps, adding to the galaxies' masses. "It has long been predicted that galaxies in the early Universe form through successive interactions and mergers with other tinier galaxies," said Yoshihisa Asada, a co-author and doctoral student at Kyoto University in Japan. "We might be witnessing this process in action".

The team's research relied on data from Webb's CAnadian NIRISS Unbiased Cluster Survey (CANUCS), which include near-infrared images from NIRCam (Near-InfraRed Camera) and spectra from the microshutter array aboard NIRSpec (Near-Infrared Spectrograph). The CANUCS data intentionally covered a field that NASA's *Hubble Space Telescope* imaged as part of its Cluster Lensing And Supernova survey with Hubble program. ✶

Compiled with material provided by the European Space Agency.

Research Article / Article de Recherche

NGC 6888 emission nebula associated with the Wolf-Rayet star HD 192163 (WR 136) shows its hidden profile

by Gilbert St-Onge (RASC, CDADFS, SAM, FAAQ)
gilberts311@gmail.com

Abstract

Observations of the nebula NGC 6888 (the Crescent Nebula) have allowed a description of its general morphology. It is an emission nebula whose progenitor star is the massive Wolf-Rayet WR 136. WR stars have dominant stellar winds whose velocity varies according to the different stages of stellar evolution. These winds therefore contribute to the ejection of materials from the star toward its circumstellar environment at high velocities throughout the life cycle of the star, reaching the WR-star stage and beyond.

These observations attempt to detect and describe the traces of different bubbles of material produced by stellar winds over time, based on the detectable morphology of the visible-light nebula. For this study, the use of different filters and two specific sensors has allowed, among other things, a description and measurements of the angles of positions of filaments whose detected light seems to come from elements ionized by the star WR 136, which seem to present a common pattern. Another point of interest (mainly in the conclusion section) is the detection of a line of material whose light seems to come from ionized Hα. This line of material is of a significant length and is on a perpendicular plane to all the other filaments observed on the major axis of the nebula. The presence of this latter phenomenon can be difficult to locate on images available on the web.

Resumé

Des observations de la nébuleuse NGC 6888 (la nébuleuse du Croissant) ont permis de décrire sa morphologie générale. Il s'agit d'une nébuleuse à émission dont l'étoile progénitrice est la Wolf-Rayet WR 136, une étoile massive. Les étoiles WR ont des vents stellaires dominants dont la vélocité varie selon les différentes étapes correspondant au stade de l'évolution de l'étoile. Ces vents contribuent donc à l'évacuation de matériaux de l'étoile vers son environnement circumstellaire à de grandes vélocités tout au long du parcours de l'étoile pour atteindre le stade d'étoile de type WR.

Ces observations permettent de détecter et décrire les traces de différentes bulles de matériaux produites par les vents stellaires avec le temps, en se basant sur la morphologie de la nébuleuse

en lumière visible. Pour ce dossier, l'utilisation de différents filtres et de deux détecteurs a permis entre autres une description et des mesures d'angles de positions sur des filaments en émission qui semblent présenter un patron commun. Un autre point d'intérêt (voir la conclusion) est la détection d'une ligne de matériel lumineux en émission d'une taille importante qui se trouve sur un plan perpendiculaire à l'ensemble des filaments qui sont aussi en émission. Ces derniers se trouvent sur le grand axe de la nébuleuse. La présence de cette ligne de matériel lumineux peut être difficile à localiser sur des images disponibles sur le web.

Introduction

The Wolf-Rayet (WR) star HD 192163, also known as WR 136, is associated with the emission nebula NGC 6888. It is in the constellation of Cygnus, the Swan, at coordinates RA: 20h 12m 06.5418s and Dec: +38° 21′ 17.7841″ (ICRS (ep=J2000) Simbad, 2024)[16]. It is at a distance of 5650 light-years (GAIA EDR3)[7]. The star WR 136 is very hot, with a temperature estimated at ~70 000 K (J. Reyes-Pérez et al. 2015)[10].

WR stars have strong stellar winds that make them lose their outer shell. The WR 136 star ejects the equivalent of a solar mass (1 $M_\odot$) of materials in its high-velocity circumstellar environment over a period of ~10,000 years (APOD, NASA 2021 June 17)[1], so the nebula is expanding. It is currently a bubble of about 25 ly in diameter (Ciel des Hommes, 2021 & Photon Millenium)[3,14]. The model seems to indicate that the fast winds of today's WR 136 cause an interaction with slower materials ejected previously by the star, when it was at the red supergiant stage (Wikipedia/ bubble shape)[19]. This may contribute to the filamentous morphology, which presents several more intense local knots (compact, in shockwave form), that are observed on the surface of this emission nebula. In addition, large intense regions that have the shape of large bow shocks, are observed all around the nebula on more than half of its circumference. NGC 6888 is in the more general form of a crescent, which can come from the interaction between materials ejected by winds of different velocities, forming gas bubbles in emission (Wikipedia/ bubble shape)[19]. WR 136 should eventually explode into a supernova (APOD, 2021 June 17)[1].

The morphology in the images (Hα and OIII) of the emission nebula will highlight the significance of filamentous pattern structures, with a better understanding of their distribution on the observable surface in the visible nebula NGC 6888.

Observation

The first observations were made from Dorval in the western suburb of Montréal, on 2023 September 3 and 4. The quality of the sky was at an average FWHM of 3.66″, using a Celestron 8-inch EDGE-HD telescope at f/10, for a sampling of ~0.8″ and 1.4″/pixel. The sensor was a ZWO 1600 (CMOS) colour camera, coupled with certain filters.

Other observations were made with an ST-10XME camera on the same telescope with filters L (no filter), OIII, Hα for those of 2023 November 1 and 4; here the images have an average FWHM of 3.12″. Lastly, other images were taken in Hα with the C8 telescope at FL=1400mm between 2024 May 18 and June 15. The ST-10XME CCD sensor was binned 2×2 for 13.6 microns per pixel, a scale of 2″/pixel.

Table 1 – Filters used for this project

1. Optolong L-eNhance Dual Narrowband Filter
   (H-Alpha and H-Beta/OIII)
   telescopescanada.ca/products/optolong-l-enhance-dual-bandpass-filter-h-alpha-o2-2-inch

2. Optolong L pro (for nebulae and galaxies) Optolong L-Pro Light Pollution Filter,
   telescopescanada.ca/products/optolong-l-pro-light-pollution-filter

3. ZWO Duo Band, Bandwidths: Hα (15 nm), OIII (35 nm)
   telescopescanada.ca/products/zwo-duo-band-filter

4. Astronomic UHC-E. For deep-sky observation of emission nebulae and comets under light polluted skies.
   typ. 97% transmission at 486nm (Hα)
   typ. 97% transmission at 496nm (OIII)
   typ. 97% transmission at 501nm (OIII)
   typ. 97% transmission at 656nm (Hα)
   www.astronomik.com/en/visual-filters/uhc-e-filter.html

5. No filter (Transmission ~ 400 nm to ~1000 nm), 1600 colour (CMOS)

6. Filters used with the CCD ST-10XME camera:
   6.1 = (L), no filter
   6.2 = Filter OIII (7 nm)
   6.3 = Filter Hα (10nm)

Image processing

Images taken between 2023 August 6 and September 6.

The first approach was to produce images including all the data from the filters in the 1 to 5 configurations described in Table 1. As we are in a lower-quality sky in the suburbs, it seemed interesting to see what could be captured on images of NGC 6888 with all these filter configurations. Figures 1 and 2 present our first results.

Description Figure 1 and Figure 2

Figure 1 is the result of integrating the five configurations used for these images; refer to Table 1 for details of these (configurations 1 to 5). Figure 2 is the result of integrating only the four configurations with emission filters from Table 1; unfiltered images are not integrated into Figure 2.

Figure 1 — NGC 6888 (The four filters in emission + no filter (L))

Figure 2 — NGC 6888 (Four filters, emission filters only)

Refer to Figure 3 for the position measurements on the surface (morphology) of NGC 6888:

Consider the position angle on the sky of the major axis of N6888 as follows; ~45° (NE) by ~225° (SW). At both ends of this major axis we observe what seem to be large, curved shockwaves, "ends of bubbles." The position of WR 136 is the point of origin for the measurements of position angles.

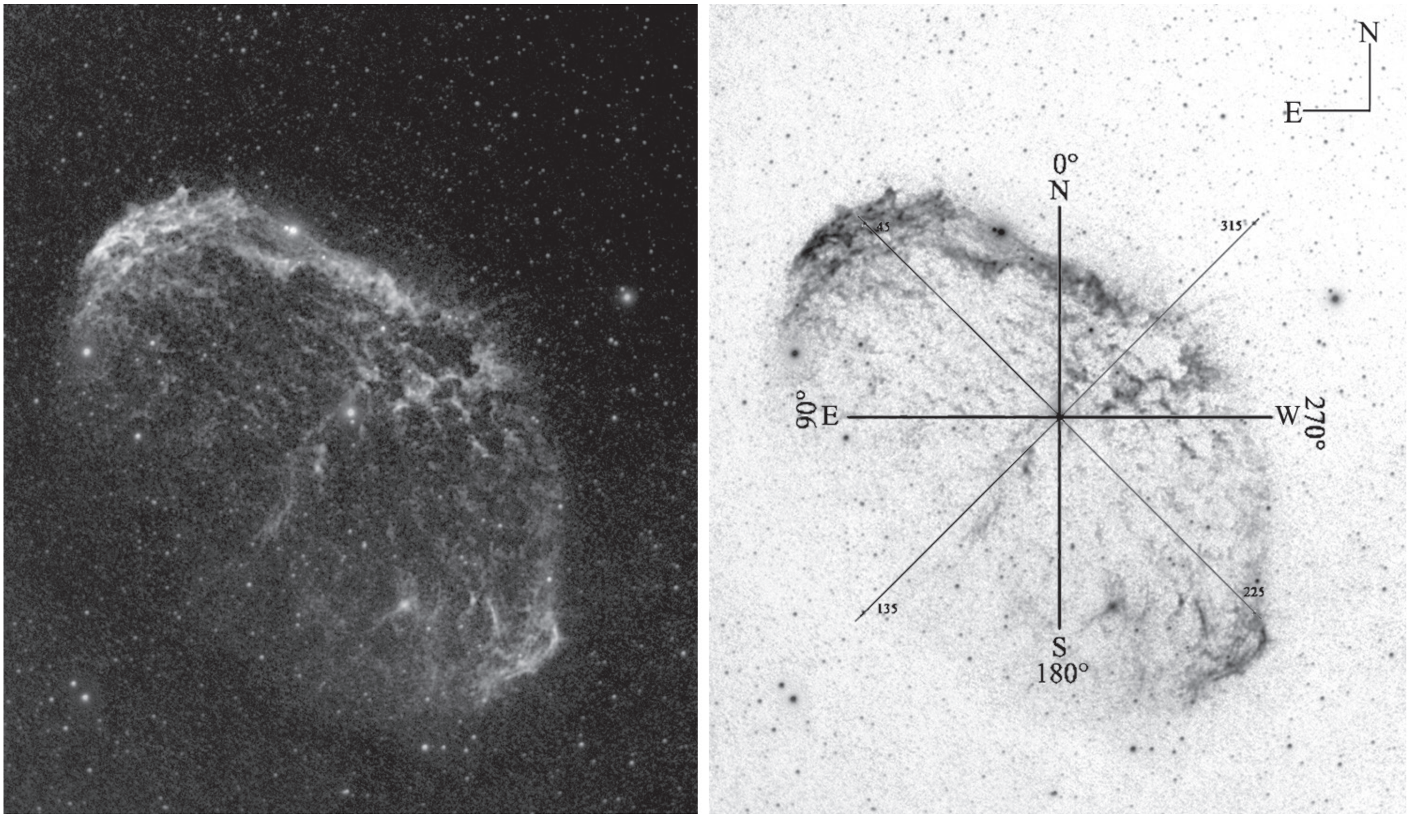
In this paper the focus is on certain structures, particularly a large rather dark region "DR", (like a big darker hole in the emission nebula) of an irregular shape, it is observed to the northwest of the star just inside the limit of the nebula on this side. This extends ~285° farther west to ~320° farther northwest, and it is reasonable to assume that the central region is at ~305°. A large luminous filiform structure cuts the contour of this dark region from the south lengthening just south of the star WR 136. Some secondary luminous, long filiform structures define the northern contour of the dark region farther inside the nebula. Refer to Figure 8 on the left image to identify the dark region, indicated there by "DR."

It is also detected on the opposite side, south-east of the star position, as another luminous filiform structure (transverse oriented luminous line) that moves away from it at ~140°, it crosses the entire nebula on this side, even though it is fainter in the sky outside the SE nebula, in some images.

Description of Figure 4

On the left image in Figure 4, the stars have been removed; only the position of WR 136, from which the nebula NGC 6888 originated, is indicated by a white point near the centre of the nebula.

On the right image of Figure 4 is a luminous filament network that is distributed in a fairly parallel pattern of intense lines at rather regular intervals, which also follows the plane of the major axis of the nebula quite well at the interface with the sky on the north side. We also detect the transverse oriented luminous line, NW by SE, that moves away from the star at ~140° SE, this structure is used to separate in two the patterns of parallel intense lines. A series of lines is aligned on the NE plane of the transverse luminous line, and another series is aligned on the SW plane; on this side we observe a slightly more inclined pattern.



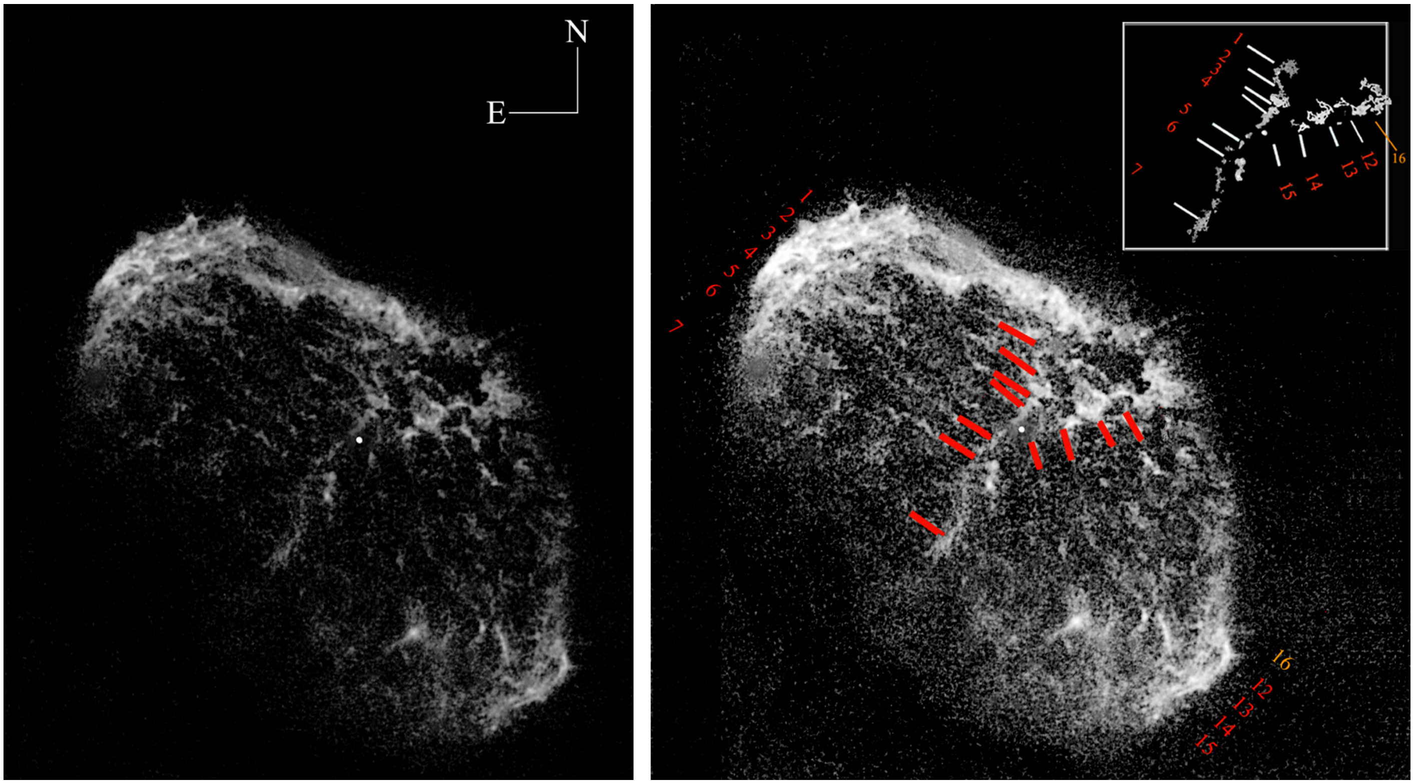


Figure 3 (top), Figure 4 (bottom)

But what mechanism can create a luminous filament network aligned on the same plane in NGC 6888?

Also in Figure 4, the right image shows the results of the position angle estimates of the intense filament network observed on both sides of the transverse luminous line. The red lines indicate the angle of filament position at their closest point to the transverse luminous line. Most of these filaments are also observed farther in the nebula, some of them are lost in the large shockwaves at the ends of the nebula.

From the NE side of the transverse luminous line, there are seven luminous filaments identified and from the SW side of the transverse luminous line there are four identified. These

NE Of the Transverse emission line	**Segments** (NE)	**Angle**
	1 (NE)	63.7°
	2 (NE)	58.8°
	3 (NE)	45.6°
	4 (NE)	45°
	5 (NE)	50.2°
	6 (NE)	55°
	7 (NE)	49.2°
Average Angle		(NE) 52.5° ±6.96
SW Of the Transverse emission line	Segments (SW)	Angle
	12 (SW)	209.05°
	13 (SW)	202.1°
	14 (SW)	191.82°
	15 (SW)	195.29°
Average Angle		(SW) 199.56 ±7.63

Table 2

latter ones are perhaps a little more inclined toward the south and they are less straight and seem to present more deformations. See Table 2 for a summary of the line segments and their respective angles.

Discussion of Table 2

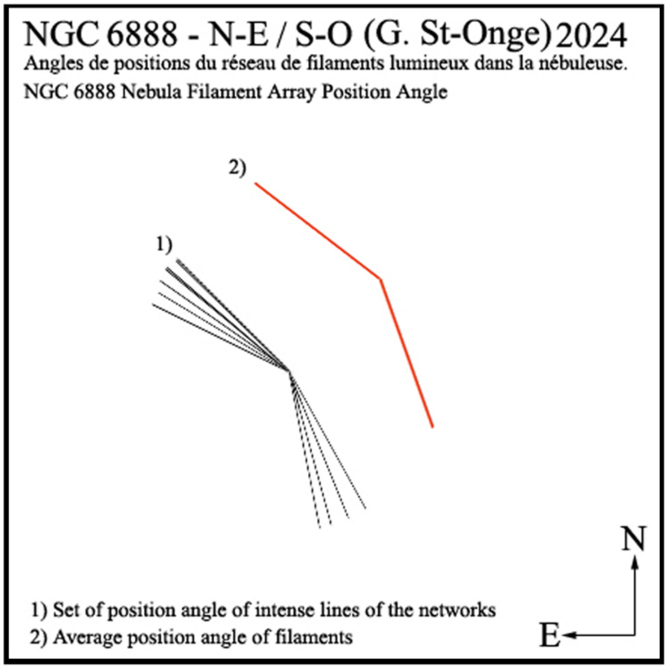
It can be assumed that the use of filters as described in Table 1, with the ZWO1600 colour camera, allows highlighting these large luminous filaments on the plane of the major axis of the nebula. In summary, these are distributed as follows: for the NE section, the angles of positions of the luminous filaments are observed from 63.7° to 45°, with the average angle being 52.5° ± 6.96°; filaments in the SW section are observed from 191.82° to 209°, with the average angle being 199.56 ° ±7.63°. This SW region shows more curved and often discontinuous filamentary lines in a series of light shock waves.

A second set of images from NGC 6888

These observations took place on 2023 November 1 and 4, also from Dorval.

This was achieved with the SBIG ST-10XME CCD camera binned 2×2 for a sampling of 1.4″/pixel.

Narrowband filters, Hα (10nm) and OIII (7nm), were used, in addition to images without filter, which allows transmission from ~400nm to ~1000nm. The quality of the sky for these two evenings was an average FWHM of 3.12″. Also used was the IR 72 Is filter (Near IR continuum), on 2024 May 10, to complete the images necessary for this project (See Table 3, for the transmission of this filter).



Graph 1 — Position angle of the luminous filament array of NGC 6888. This graph shows in point 1) the angles of positions of all the luminous filaments of both sides of the star, at NE and SW.

In point 2), in red, the average angle for both series of filaments is shown, NE and SW. These lines indicate that it seems quite possible that the observed position angles of the two patterns of the filament networks on each side of the star are of similar values, so there might be some symmetry.

Figure 5: NGC 6888 - Hα (10nm)

The use of the Hα filter (10nm), and the CCD ST-10XME allows us to see that all morphological elements discussed in the previous section, which were detected on images with the other camera, the CMOS ZWO 1600 colour coupled to the filters 1 to 5 mentioned in Table 1, are quite real.

- The ST-10XME CCD coupled to the Hα ±5nm even shows additional detail of the large pattern of filamentous structures in the nebula.
- We also see that the network of feathery filaments escaping on the sky at the NE interface of the larger darker region “DR”, seems more intense in Hα with the CCD.
- The transverse luminous line that moves away from the star at ~140° SE is also seen on the sky further outside the nebula.

Description of Figure 5b

Several images show a small darker region just south of the star WR 136, very close to two important intense and wide diffused knots grouped together.

Figure 5a

The arrow on the Hα image, on the left-side of Figure 5b, indicates the position of this dark region on one of the Hα images of the nebula with the ST-10XME CCD sensor. The morphology of this one in Hα is a dark bow on its eastern side and it becomes progressively paler on its western side. It is a little like a half moon. So, in Hα it is detected mainly on its eastern side, which is the darkest side; on its western side it gets lost in the nebula.

The right-side image of Figure 5b comes from Figure 1. This image is a compilation of the results with the colour camera using the filters 1 to 5 as mentioned in Table 1. You can see the easternmost section of this dark structure. On the OIII filter images, this region seems rather uniformly dark: see Figure 6.

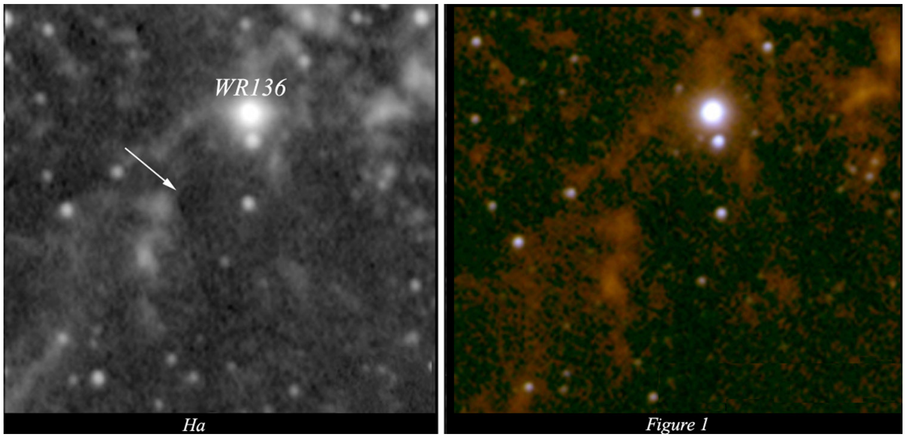


Figure 5b

Description of Figure 6

Using no filter (Figure 6 left), the nebula is pale; we see mainly that the most intense regions are at the ends (interface of the nebula and the sky) north and NE of the nebula, then some luminous bowing at SW. One can also detect the luminous linear structure line just south of the larger darker region "DR" that can be seen at ~300°. This image is dominated by a background of numerous stars.

With the OIII 7nm filter (Figure 6 right), the nebula is generally quite pale, but its surface can be seen quite fully in the sky. Some more intense regions emerge from the nebula, mainly the large luminous linear structure that extends over the interface (nebula and sky), just north of the "DR" at ~300°. We also observe the structure that runs along the south side of "DR" (~west by ~east). The large bow at the NE end of the nebula is less intense in OIII 7nm. There is also an intense compact region in the nebula: it is detected farther south in the nebula at the position angle of ~195° (For this one, refer to Figure 8 on the left at the bottom of the image); this region is also detected on the images with the Hα filter, but it's less intense.

Name	Wavelength range	Content
IR 72 Is	≈ 793 nm to ≈ 1,000 nm	Near IR continuum
Hα	656.3 ± 5 nm	Hα and [NII] λ654.8 and λ658.3
OIII	496 nm to 504 nm	[OIII] λ4959 and λ5007
No filter (L)	≈ 400 nm to ≈ 1000 nm	Continuum and spectral lines

Table 3: All filters used with the ST-10XME CCD sensor are described more precisely.

Results and Conclusion

The aim of this paper is to describe observable aspects in the visible and near-IR range (~400 nm to 1000 nm) of the emission nebula NGC 6888, as detected with the instruments at our disposal. The main thrust of this paper is limited to commenting on some aspects of the observations, presented by describing the two arrays of luminous filaments on the great axis of the nebula, which are observed on both sides NE and SW of the position of WR 136 in the nebula. These filaments seem to be aligned with fairly regular patterns that may suggest a periodic situation. Perhaps rings (or shells) of material are periodically ejected by the star on almost the same plane in the nebula. These rings (or shells) could then have been formed by discharges of various quantities of materials ejected by WR 136, thus contributing to the formation of the nebula NGC 6888.

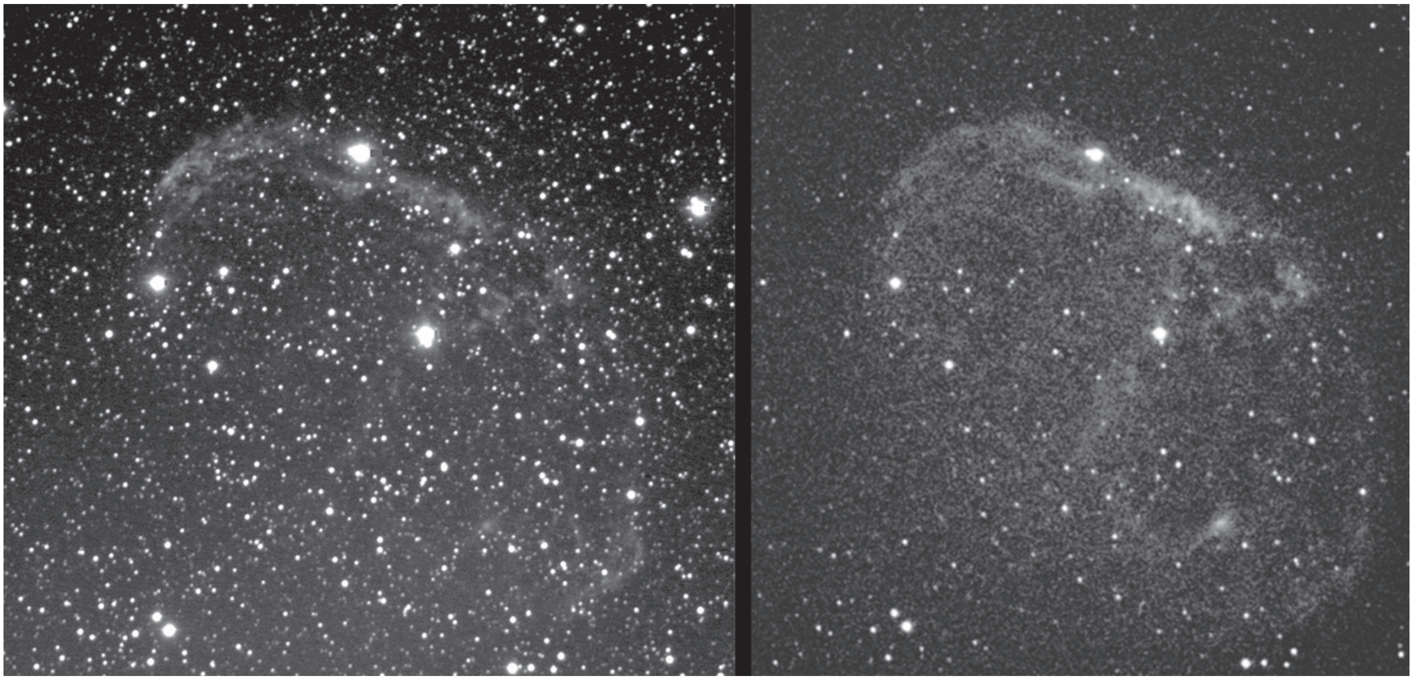


Figure 6 – No filter (left) OIII 9 (7nm (right)

In the literature we have found the study of Peter Tuthill, University of Sydney Australia, Les spirales paradoxales des étoiles Wolf-Rayet [13]. He studied the star WR 140, which is composed of an environment of darker dust shells at regular intervals. This is a system of double massive stars whose rotation period corresponds to the rate of appearance of the dust shells. The star WR 136 that is targeted by this paper does not seem to be a star that has a massive companion; some think rather that it can have a much less massive companion star, type K or M (Rustamov, D.N. & Cherepashchuk, A.M. 2011)[15]. The comparison leads us to question the patterns of the associated nebula NGC 6888 that also seems to have a pattern of structures aligned on a plane, but these are composed of luminous materials.

Are these patterns of luminous filaments of the nebula NGC 6888 mainly ionized Hα, or are they rather a component made up of the continuum very close to the Hα? The filter that was used has a 10nm bandwidth of transmission. Figure 7 gives some answers to this question.

Hα – IR 72 Is ≈ Hα Exclusive

Refer to Table 3 to know the parameters of the Hα filter and the IR 72 Is filter.

Figure 7 is the result of the extraction of the image continuum into Hα at wavelength range 656.3 ±5 nm. Using the IR 72 Is filter as a continuum, we can perform the extraction of most of the continuum from the image made with the Hα filter. This results in an image focused on the wavelengths of Hα and the two emission lines of ionized nitrogen [NII] at 654.8 nm and 658.4 nm. The rest of this image is just continuum in the nebula, it darkens in the final image.

You can see in Figure 7 the regions with intense emissions in Hα. There are few stars that show emission on the image, most are dark spots with an approach this focused. Here the objective was to isolate in the image the main regions of intense light that come from ionized chemical elements whose signature corresponds to the Hα spectrum.

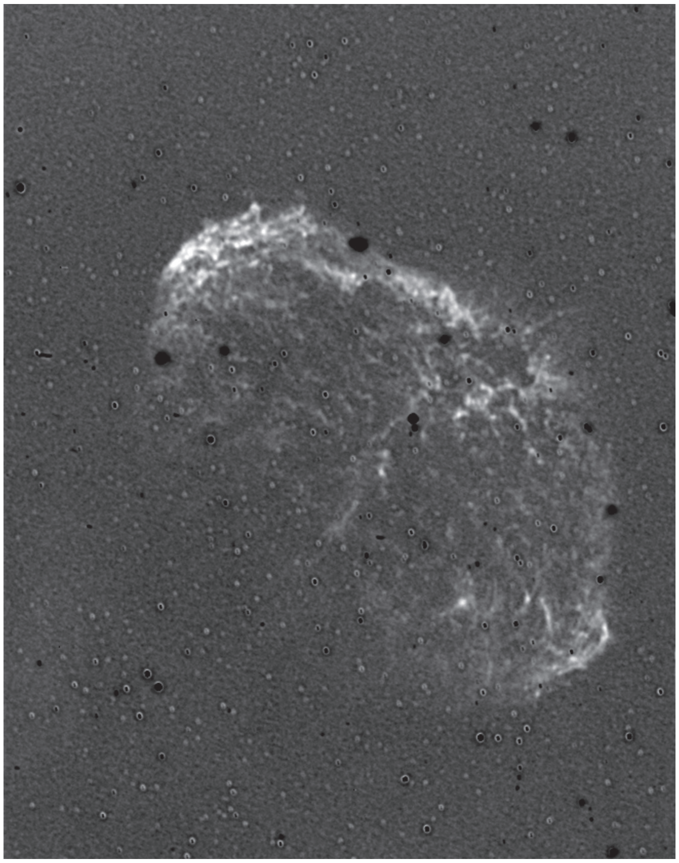


Figure 7 – Hα emission exclusively.

We see that the remaining Hα is in a state of emission and we can still see the luminous filaments that were measured on Graph 1.

We conclude that the luminous filaments are in part ionized gases that are bright in Hα environment and they are aligned at fairly regular intervals in the nebula.

On this image of the Hα exclusive, we also see that the transverse luminous line oriented (NW to SE), which moves away from the star position by SE, also seems to extend towards the large "DR," which is at the opposite at NW. It even expands and passes in front of the large "DR" at (~300°), then it seems to move away from it quite far on the sky outside of the nebula at the NW.

In Figure 7, we can assume that the transverse emission line that passes in front of the dark region "DR," seems to be in front of the nebula, possibly between us and the nebula. It can be followed on a long, curved line of knots and more diffuse regions of inter-knots. It is almost perpendicular to the plane of all the luminous filaments observed on the major axis of the nebula.

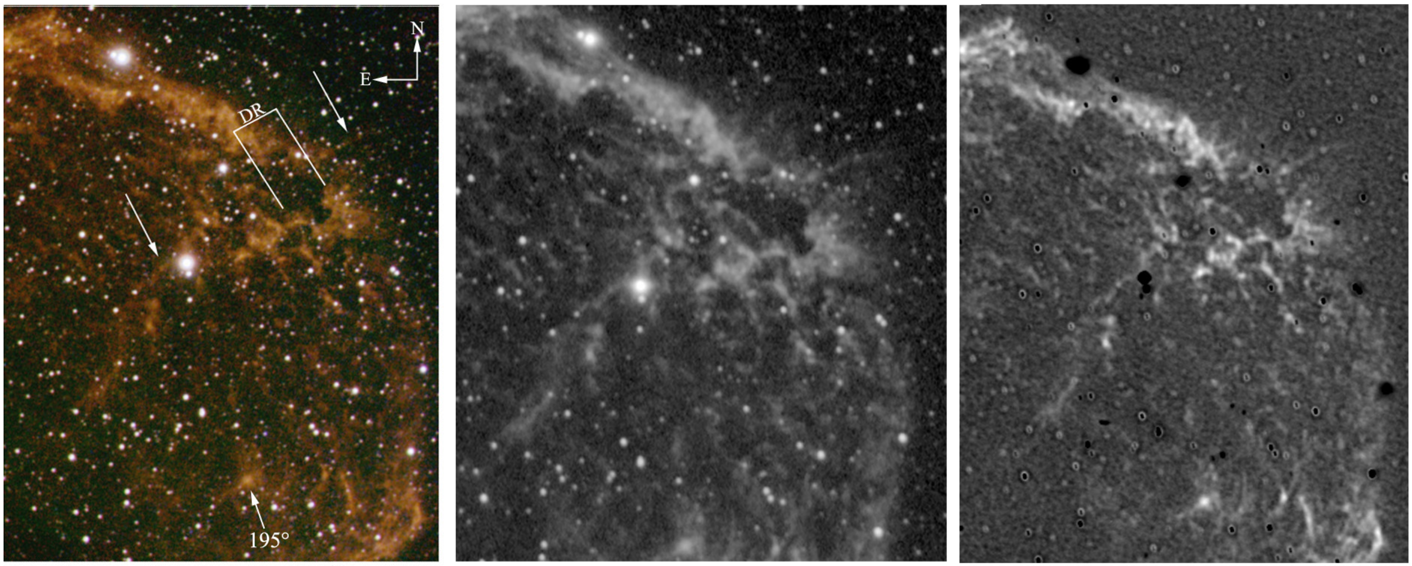
If we consider that the transverse luminous line is well associated with the star WR 136, one can question its position angle, which is practically perpendicular to the general angle pattern of the luminous filaments in the rest of the nebula. In addition, the transverse luminous line has a morphology that is a curve that seems to follow the contour of the main nebula quite well for most of its path, so the possible axis of propagation from which it could come is perhaps centred on the position of WR 136, but on a different plane from the other filaments. Could it be material ejected by WR 136 before the formation of the large network of the nebula?

In Figure 7, one can also detect the intense compact region to the south which is at ~195°. From it a luminous curved "feather" stands out. Near the more intense compact region, this feather extends towards the SE, then it curves towards the NE widening, becoming paler and eventually disappearing. It is detected as an emission region of Hα. Figure 8 on the left at the bottom shows the intense compact region at ~195°.

Figure 8 shows the image slices centred on the position of the transverse luminous line. On our images presented from the left, this one comes from Figure 1, using filters 1 through 5, and the one in the centre comes from Figure 5 (Hα 10nm), this transverse luminous line remains diffuse and virtually undetectable with certainty in front of the large dark region "DR" at (~300°). On the opposite side (~140°), which may be an extension of this luminous line, it also overflows over the sky, it widens and then just disappears.

Discussion, Figure 8

- On the left image, using filters 1 to 5 of Table 1, the arrows present two sections of the transverse luminous line on either side of the large "DR"; in this image no trace of the transverse luminous line is detected on the surface of the "DR."
- The central image Hα (10nm): on this one no significant trace of the transverse luminous line in front of the "DR" is detected.
- The right image (Hα – IR 72 Is): it is found that this transverse luminous line is detected even in front of the large dark region "DR" and crosses to the sky outside the nebula. In this image, we can follow the path of the transverse luminous line through the nebula and even over the sky on opposite sides of the main nebula. The



4 Filtres en émission + aucun filtre (L)

Ha (10nm)

Ha - IR 72 Is

Figure 8 – Filters 1 through 5.

morphology of this luminous line is sometimes more diffuse (nebula and inter-knots), and sometimes consists of more punctual knots.

By examining some of our individual Hα images trying to detect traces of this transverse luminous line in front of the large “DR,” it was possible to produce Table 4. It was found that several images show traces of this luminous transverse line in front of the large “DR,” and that these are images with an average FWHM of ~3 pixels and better.

FWHM / NGC 6888 Hα (2024)

Dates Images	Domain Hα	“Transverse emission line” detection in emission in dark region	FWHM Average Pixels
May 18	Hα	* Yes (pale)	3.18 ±0.05
May 19	Hα	* Yes (more intense)	3.04 ±0.05
May 31	Hα	No	3.938 ±0.15
June 03	Hα	* Yes (paler)	3.12 ±0.08
June 15	Hα	* Yes (pale)	2.982 ±0.06

Table 4

Some aspects of this paper are confirmed by images from professionals. On the SIMBAD[16] site, one can see that the DSS2 Red (F+R) image shows traces of this faint filiform structure that passes in front of the large “DR” observed at ~300° in the nebula. This image shows some distinct structures spread out at the position of the large transverse filiform structure, a bit like in our images in Hα (10nm), which are not the product of continuum extraction (IR 72 Is filter).

Also refer to the paper of Marianne Ruest et al. (2022)[12], *The Crescent Nebula and its hundreds of line-of-sight stars as seen with the imaging FTS SITELLE*: their paper seems to confirm some aspects of the nebula NGC 6888 that were described in this document. The team (Marianne Ruest et al.) used the Canada-France-Hawaii (CFHT) telescope facility located on the summit of Mauna Kea in Hawaii and the SITELLE imaging spectrometer sensor. Their study, which was consulted for this paper, focuses on the southern section of the nebula NGC 6888. Their work made it possible to ensure that several aspects of the structures studied in our paper are found in their images. We can therefore be confident that our results are correct.

NGC 6888 is a fascinating nebula, in visible light it bears its name well, the Crescent Nebula. But by limiting observations in an urban sky using a narrowband Hα filter, we can see the whole nebula with a dimmer input from the stars and the surrounding sky. Under these conditions, it resembles a transparent jellyfish: such a filter allows a better isolation of the luminous filament network and several more diffused structures, and others in the form of knots in the emission nebula. ✶

Software used in data processing:

- Images were reduced with the *PRiSM* software version 6.00.133. © C. Cavadore & B. Gaillard.
- Some figures were processed with *Irfan-View* software, version 4.60, Irfan Skilijan, Graduate of Vienna University of Technology.
- *Microsoft Excel* was used as a calculator.
- Final image produced in an outdated version of *Adobe Photoshop* for Windows.
- *StarNet* software, Mikita (Nikita) Misiura, was used to remove stars in images www.starnetastro.com

Thanks to reviewer and translation—Gerald MacKenzie and Dominique, (RASC Montréal Centre)

References

1 Astronomy Picture of the Day / 2021 June 17 NGC 6888: The Crescent Nebula Copyright: Joe Navara, Glenn Clouder, & Russell Discombe https://apod.nasa.gov/apod/ap210617.html

2 Branko Petrov, Faculté des sciences, Département de Physique, Université de Sherbrooke, 14 avril 2009 Dans le cadre du cours PHQ 662, Initiation à la recherche, sous la supervision d’Yves Grosdidier

3 Ciel des Hommes, NGC 6888, la nébuleuse du Croissant, 17 juin 2021 http://www.cidehom.com/apod.php?_date=210617

4 D.J. Stock & M.J. Barlow, *MNRAS, Vol. 409, Issue 4*, December 2010, Pages 1429–1440, https://doi.org/10.1111/j.1365-2966.2010.17124.x

5 Dufour, Reginald J., The Wolf-Rayet Star HD 192163 And its Surroundings, FUSE Proposal ID C097. https://ui.adsabs.harvard.edu/abs/2002fuse.prop.C097D/abstract

6 ESA/Hubble / NGC 6888· Crescent Nebula / Hubble Space Telescope· WFPC2 https://esahubble.org/images/opo0023a/

7 (GAIA EDR3) HD 192163 – Wolf-Rayet [archive] https://www.cosmos.esa.int/web/gaia/earlydr3

* https://gea.esac.esa.int/archive/ GAIA EDR3; Parallax WR 136 ≈ 0.5772389031203671 (mas)

* https://vizier.cds.unistra.fr/viz-bin/VizieR-S?Gaia%20DR3%20 2061690233159124352

8 G Rubio, J A Toalá, P Jiménez-Hernández, G Ramos-Larios et M A Guerrero, « Unveiling the stellar origin of the Wolf–Rayet nebula NGC 6888 through infrared observations », *MNRAS, vol. 499, nº 1*, septembre 2020, p. 415–427 (DOI 10.1093/mnras/staa2837, lire en ligne [archive] [html]) https://academic.oup.com/mnras/article/499/1/415/5908399?login=false

9 HST
https://hubblesite.org/contents/news-releases/2000/news-2000-23.html

10 J. Reyes-Pérez, C. Morisset, M. Peña, & A. Mesa-Delgado
A consistent spectral model of WR 136 and its associated bubble NGC 6888
MNRAS, Vol. 452, Issue 2, 2015 11 September, Pages 1764–1778,
https://doi.org/10.1093/mnras/stv1423
https://academic.oup.com/mnras/article/452/2/1764/1069321

11 Lacroix Marc, The Crescent Nebula: A Cosmic Masterpiece, *Skyward* - RASC Montréal Centre, March–April 2024, p. 35–37.

12 Marianne Ruest, Camille Poitras, Laurent Drissen, & Nicole St-Louis, 2022,The Crescent Nebula and its hundreds of line-of-sight stars as seen with the imaging FTS SITELLE
Université Laval, Université de Montréal, Centre de Recherche en Astrophysique du Québec
https://astro.phy.ulaval.ca/fileadmin/user_upload/SPIE2022-Marianne-NGC6888.pdf

13 Peter Tuthill, Les spirales paradoxales des étoiles Wolf-Rayet, Université de Sydney Australie
https://www.pourlascience.fr/sd/astrophysique/les-spirales-paradoxales-des-etoiles-wolf-rayet-25843.php

14 Photon Millenium, NGC 6888 – NÉBULEUSE DU CROISSANT
https://millenniumphoton.com/portfolios/ngc6888/#:~:text=Cette%20bulle%20est%20de%20dimension,25%20ann%C3%A9es%2Dlumi%C3%A8re%20de%20longueur%20!

15 Rustamov, D.N. & Cherepashchuk, A.M. (2011). The Wolf-Rayet star HD 192163 as a possible evolutionary progenitor of a low-mass X-ray binary. *Astronomy Reports 55 (4)*, 347–358.
https://ui.adsabs.harvard.edu/#abs/2011ARep...55..347R/abstract.
Retrieved 2013 July 17.

16 Simbad, HD 192163, NGC 6888, https://simbad.cds.unistra.fr/simbad/sim-basic?Ident=20+12+06.5418877464+%2B38+21+17.784181008&submit=SIMBAD+search
Images DSS Coloured, DSS2 Red (F+R), DSS2 Blue (XJ+S)

17 Spectroscopy http://www.astrosurf.com/heidemann/spectroscopie/spectroscopic_atlas_walker_4.pdf

18 Techno-Science.net https://www.techno-science.net/glossaire-definition/Etoile-Wolf-Rayet.html

19 Wikipedia / facteurs peuvent affecter la forme des bulles de vent stellaire https://fr.wikipedia.org/wiki/Bulle_de_vent_stellaire

20 Wikipedia / https://en.wikipedia.org/wiki/WR_136

Matching Galactic Rotation Curves without Dark Matter or MOND

Simon Brissenden
Sunshine Coast Centre
sbrissenden@hotmail.com

Abstract

Standard cosmology requires either dark matter or modified Newtonian dynamics (MOND) to reproduce the observed rotational velocities of stars in spiral galaxies. A recent JRASC paper (Brissenden 2024) describes a *Big Bubble* cosmological model where the Universe is a self-inflating bubble in four-dimensional space. This model provides a new way to explain observed galactic rotation curves, with minimal-surface physics acting to keep stars on the hyper-surface of the bubble Universe. The restoring force manifests as Newtonian torque-induced precession superposed on conventional stellar orbital mechanics, and results in a quadratic equation for galactic rotation curves. This is a solution to the long-standing problem of understanding the origins of bimodal galaxy types, with rotation curves being either faster (spiral galaxies) or slower (elliptical galaxies) than would be expected from gravitational effects alone.

Introduction

One of the most perplexing mysteries in science is why the equations and concepts that predict the motion of planets and satellites in the Solar System so accurately, are unable to explain the motion of stars in galaxy clusters and spiral galaxies. The first recognition of this problem appears to have been by Knut Lundmark, professor of astronomy at Lund University, Sweden (Lundmark, 1930). This effect was also noticed by Fritz Zwicky, when he observed that small galaxy clusters move much faster than might be expected from the amount of mass that appeared to be present (Zwicky, 1933). He speculated that this might be due to the presence of invisible *dark matter*.

In the 1970s, Vera Rubin et al. found that spiral galaxy rotation curves had similar anomalies (Rubin, Thonnard & Ford, 1978). The rotational velocity of stars, as indicated by the Doppler shift of their spectral lines, while matching theory near to the galactic centre, is faster at larger radii than would be expected from standard gravitational theory.

Figure 1 is an illustration of this galactic rotation curve problem for the M33 spiral galaxy (de Leo/Wikipedia 2018).

Today, the leading theories to explain these observations are dark matter and modified Newtonian dynamics or MOND (Milgrom, 1983), with most cosmologists favouring a dark matter explanation (de Swart, 2024).

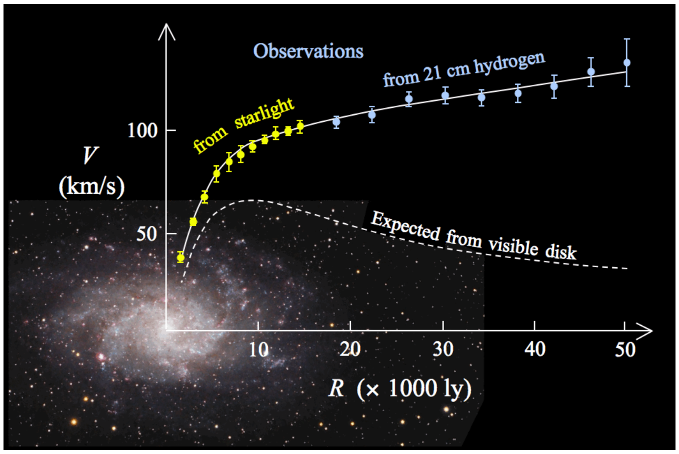


Figure 1 — M33 Galaxy Rotation Curve (de Leo/Wikipedia 2018).

Dark matter is an unknown type of matter that has gravitational effects but doesn't interact with electromagnetic radiation. To match the observed rotation curves of spiral galaxies with Newtonian gravity requires halos of dark matter around, but not at, the galactic centre, with the total amount of dark matter modelled in a spiral galaxy typically five to six times larger than the amount of normal matter. The quantity of dark matter and the position of the halo is adjusted to give the best fit for individual spiral galaxies.

Stars in most elliptical galaxies do not appear to rotate quickly or in an organized fashion around the galactic centre and significant quantities of dark matter are not required to explain their galactic dynamics. With standard cosmology, the observed dynamics of elliptical galaxies is believed to be due to stars behaving as a collisionless Boltzmann-type fluid, rather than the conventional Kepler-type orbits of Newtonian gravity.

MOND is an empirically derived theory which reproduces the behaviour of stars in spiral galaxies by modelling a change in Newtonian gravity from $\frac{1}{R^2}$ to $\frac{1}{R}$ when the local acceleration due to gravity falls below a_0, which was estimated by Milgrom to be 1.2 x 10^{-10} m s^{-2}. A strength of MOND is its ability to reproduce observed rotation curves for a wide range of spiral galaxies quite well from these simple empirical rules. A weakness is that it does not have a supporting cosmological model that is consistent with it. MOND does not provide any additional insight into the dynamics of elliptical galaxies.

Dark matter and MOND are both flawed concepts. Scientists have been looking for dark matter particles for decades without success. MOND is more than forty years old and remains an incomplete and unpopular theory. Recent binary star observations have been interpreted as being consistent with Newtonian gravity and inconsistent with MOND (Banik, et al., 2023). A new theory that can account for observed galactic rotation curves without requiring new particles beyond the standard model, or modifying Newtonian dynamics, ought to be of interest to cosmologists.

A recent JRASC paper (Brissenden, 2024) described a novel *Big Bubble* cosmological model, where the Universe is a self-inflating bubble in four-dimensional space, expanding due to internal radiation pressure, and held together by minimal-surface physics, with gravity acting like surface tension in a soap bubble. It was claimed in (Brissenden 2024) that a Big Bubble cosmological model provides a means to account for observed galactic rotation curves without invoking dark matter or MOND, but no details of this mechanism were given. This paper provides those details.

Galaxies are Big

"Space is big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist's, but that's just peanuts to space."

— Douglas Adams, The Hitchhiker's Guide to the Galaxy

The Milky Way galaxy is much bigger than the Solar System. The two *Voyager* spacecraft measured the distance from the Sun to the heliopause to be about 120 astronomical units or 1.8 x 10^{13} m, while the diameter of the Milky Way is about 100,000 light-years or 10 x 10^{20} m. To put this difference in a Canadian context, if the diameter of the Milky Way were equivalent to the length of Lake Superior (from Thunder Bay to Sault Ste Marie is about 430 km) then the equivalent diameter of our Solar System would be 1.5 cm, smaller than a glass of water.

We would normally expect the laws of physics to apply equally to Lake Superior and a glass of water. But there is one aspect of Lake Superior that is not obvious in a glass of water - the curvature of its surface. A laser beam projected from Thunder Bay one metre above, and parallel to the lake surface, would be detected at Sault Ste Marie 14.2 km up in the air due to the curvature of the Earth. A mathematical model of a glass of water that assumes its surface to be a flat two-dimensional surface would give accurate results. A similar model of Lake Superior would not.

It is the hypothesis of this paper that a comparable effect is behind seemingly anomalous galactic rotation curves. A galaxy is so big that the curvature of the Universe is apparent in galactic dynamics, but this effect is not detectable in the movement of objects in the Solar System.

The Shape of the Universe

With a Big Bubble cosmological model, the Universe is a bubble in four-dimensional space, expanding due to internal radiation pressure from starlight, and held together by minimal-surface physics. Gravity plays the role of maintaining structure and shape that surface tension does in a soap bubble.

The metric for this cosmological model is given by the equation:

$$ds^2 = -dr^2 + r^2[d\varphi^2 + sin^2\varphi(d\theta^2 + sin^2\theta d\psi^2)] \qquad (1)$$

This metric uses spherical coordinates (r, ϕ, θ, ψ) to represent the shape of a bubble in four-dimensional space, but a bubble shape can also be represented in cartesian coordinates (with an origin at its centre of mass) by the equation:

$$R^2 = W^2 + X^2 + Y^2 + Z^2 \qquad (2)$$

Einstein was the first person to use general relativity to model the entire Universe. In (Einstein 1917) as interpreted by (O'Raifeartaigh et al. 2017) he wrote:

It remains now to determine those components of the gravitational potential which define the purely spatial-geometrical relations of our continuum (g11,g12 …g33). From our assumption as to the uniformity of distribution of the masses generating the field, it follows that the curvature of the required space must be constant. With this distribution of mass, therefore, the required finite continuum of the x1, x2, x3 with constant x4 will be a spherical space.

We arrive at such a space, for example, in the following way. We start from a Euclidean space of four dimensions, ξ_1,ξ_2,ξ_3,ξ_4, *with a linear element* dσ *; let, therefore,*

$$d\sigma^2 = d\xi_1^2 + d\xi_2^2 + d\xi_3^2 + d\xi_4^2 \qquad \text{(E9)}$$

In this space we consider the hyper-surface

$$R^2 = \xi_1^2 + \xi_2^2 + \xi_3^2 + \xi_4^2 \qquad \text{(E0)}$$

where R denotes a constant. The points of this hyper-surface form a three-dimensional continuum, a spherical space of radius of curvature R.

While there are significant differences between the physics and dynamics of (Einstein 1917) and (Brissenden 2024), such as the assumption of a fixed versus increasing radius, the geometry of the Universe assumed by Einstein, and the geometry of Big Bubble cosmology are compatible. Einstein's equation E10 is effectively the same as equation 2.

Rotation on a Curved Hyper-Surface

Attempting to describe the motion of stars on a bubble in four-dimensional space presents a challenge for the English language. The words *flat* and *curved* are familiar concepts in three-dimensional space, but general relativity complicates matters by using the same words to describe the curvature of spacetime. A bubble Universe may have a curved shape in space, but if it is gravitationally stable, with no unbalanced forces moving test particles about its surface, it can also be called flat in a GR sense.

Terminology is even more complex with a fourth dimension of space. With Big Bubble cosmology, the three-dimensional classical world is the hyper-surface of a bubble in four-dimensional space, while the quantum world is the full four-dimensional volume.

Small children have an intuitive understanding of how bubbles form and are structured, but describing this mathematically with minimal-surface physics is challenging. This paper will present its arguments using simplified mathematics and analogy, which will require the use of clear terminology. The adjectives *flat* and *curved* will be reserved for the physical shape of surfaces in familiar three-dimensional space. The terms *3flat* and *3curved* will be used to describe the analogous physical shape of hyper-surfaces in four-dimensional space. The terms *GRflat* and *GRcurved* describe the shape of spacetime that manifests as gravitation.

In standard ΛCDM cosmology, the shape of a spiral galaxy can be approximated as a flat two-dimensional disk in three-dimensional space. All stars in a spiral galaxy should experience the same coordinate time t, which increases at a consistent rate.

With Big Bubble cosmology, radius r replaces coordinate time t, and all stars should experience the same radius when they form part of the cosmic bubble. Radius reflects the current curvature of the Universe and increases as the Universe expands.

If a spiral galaxy could be isolated from the rest of the Universe, its disk would be 3flat. However, when it is part of the Universe's bubble structure, it must be 3curved to share a common radius r, with the rest of the Universe.

Minimal-surface physics will therefore exert a force on a star in a spiral galaxy to cause it to deviate from a 3flat hyper-surface and conform to the overall 3curved bubble shape of the Universe. The direction of this force will be aligned with the radius of the Universe and will be either in the $R+$ direction if the star is lagging behind the cosmic bubble, or in the $R-$ direction if it is ahead and needs to be held back.

The magnitude of this force will be defined as g_u, where g_u is the acceleration applied to a test particle in m s^{-2}. It will be assumed for the purpose of this analysis that the magnitude of this restoring force is the same in the $R+$ and $R-$ directions, but this may not be an accurate assumption.

If a test particle is at a greater radius than the rest of the Universe and needs to be held back, the restoring force in the $R-$ direction could be regarded by classical Newtonian shell theory as being equivalent to the gravitational effect of the mass of the entire Universe, located at the Universe's centre of mass. However, Newtonian shell theory does not suggest that a test particle inside the bubble surface would experience a comparable force in the $R+$ direction, while minimal-surface physics of bubble dynamics (and our experience of bubbles in the real world) suggests it should.

Newtonian Torque-Induced Precession

Newtonian torque-induced precession is a somewhat counter-intuitive mechanism where a force applied to a rotating body causes precession at 90° to the direction in which the force is applied. This can be seen in a slowing gyroscope, which precesses faster as it starts to topple over. Gravity exerts a downward force on the gyroscope as it leans over, causing it to precess horizontally rather than fall.

The restoring force exerted on a star by bubble physics, acting at right angles to the galactic plane of rotation, causes Newtonian torque-induced precession to affect stellar motion. This force is proportional to the distance of the star from the galactic centre and is superposed on the forces associated with its conventional orbital mechanics due to gravity.

Big Bubble cosmology substitutes radius r, for coordinate time t, and this becomes the fourth dimension of space. If the terminology of standard cosmology is used instead, it is like applying a force in the coordinate time dimension and having its effects appear at 90° in the three dimensions of space. Given this mechanism, it is perhaps unsurprising that the problem of apparently anomalous galactic rotation curves has been so challenging for the scientific community to solve.

The Newtonian formula for torque-induced precession is:

$$\omega_p = \frac{m\,g_u r_s}{I_s \omega_s} \tag{3}$$

where ω_p is the precessional angular velocity, ω_s is the total angular velocity of a star around the galactic centre, r_s is the radius of the star's orbit from the galactic centre, m is its mass and g_u is the restoring acceleration of the Universe acting in the R direction (i.e. normal to its orbital plane). It is hypothesised that g_u should be comparable to, but less than, the value a_0 in MOND which marks the transition from Newtonian to modified Newtonian dynamics.

The moment of inertia of the star, I_s is given by;

$$I_s = m{r_s}^2 \tag{4}$$

The total angular spin velocity of the orbiting star ω_s is the sum of its Keplerian orbital angular velocity ω_g and precessional angular velocity ω_p;

$$\omega_s = \omega_g + \omega_p \tag{5}$$

ω_g can be approximated by the standard Kepler equation;

$$\omega_g = \frac{1}{r_s}\sqrt{\frac{GM(r_s)}{r_s}} \tag{6}$$

where G is the gravitational constant, and $M(r_s)$ is the sum of baryonic mass in the galaxy with radius less than r_s.

Substituting and rearranging gives a quadratic equation for ω_p;

$$r_s{\omega_p}^2 + \omega_p\sqrt{\frac{GM(r_s)}{r_s}} - g_u = 0 \tag{7}$$

Solving for ωp with the quadratic formula gives;

$$\omega_p = \frac{1}{2r_s}\left[-\sqrt{\frac{GM(r_s)}{r_s}} \pm \sqrt{\frac{GM(r_s)}{r_s} + 4r_s g_u}\right] \tag{8}$$

This equation has two solutions; an ω_p-plus solution, which is positive, starts small and increases with r_s, and an ω_p-minus solution that has a negative sign, starts big and decreases with increasing r_s.

Adding the ω_p-plus solution to the theoretical ω_g angular velocity for a given mass distribution gives a rotation curve that is faster than a purely Kepler calculation would predict. It is possible to get flat or rising rotation curves at large distances from the galactic centre.

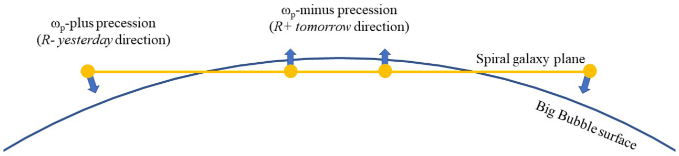


Figure 2 — Cross-section of Newtonian torque-induced precession directions for a spiral galaxy.

When the ω_p-minus solution is added to the ω_g angular velocity, they nearly cancel each other out, and it gives a rotation curve much less than a purely Kepler calculation would predict.

This is an interesting result. An attempt to find a Newtonian mechanism that would explain the flat or rising rotation curves of spiral galaxies has led to an equation with two solutions; one which predicts faster rotation curves than Kepler (like spiral galaxies) and one which predicts much slower rotation curves. The solution with slower rotation curves is consistent with Illingworth's observation that most elliptical galaxies show little or no internal rotation (Illingworth, 1977).

Figure 2 is a diagram of how the directionality of torque-induced precession could affect a spiral galaxy that wants to rotate in a 3flat surface but is forced to adopt the 3curved shape of the Big Bubble Universe. At the centre of the galaxy, stars lag behind the 3curved surface and there is a torque-induced precession force in the R+ direction, similar to that experienced by an elliptical galaxy. This is the mechanism that can cause bulges at the centre of spiral galaxies. At the edge of the galaxy, the force is in the R– direction, causing stars to rotate at anomalously high speed compared to standard Kepler orbital predictions.

Galactic Meteorology

While the anomalously fast speed of stars in spiral galaxies is perhaps the most obvious problem with ΛCDM cosmology's understanding of galactic behaviour, it is not the only one. (Peebles, 2022) provides a summary of other cosmological anomalies, including the bimodal galaxy problem. It has been more than a hundred years since spiral and elliptical galaxy types were first observed, but it is still not clear why galaxies have this bimodal grouping. He comments "*what is the separatrix in galaxy formation that determines the evolution of a protogalaxy to a spiral or elliptical morphology? It cannot simply be the mass… It might be some combination of mass, angular momentum and environment, or maybe something completely different… It is a fascinating opportunity for research, provided you bear in mind that people have been trying to solve the puzzle of the early–late bimodality for a long time.*"

The two solutions to equation 8 would seem to be a solution to this problem.

Figure 3 — The similar spiral structure in Hurricane Alberto and NGC 6814 (Cao, Liu, & Zheng, 2018).

When Peebles refers to “early-late bimodality,” he is reflecting Hubble’s original galaxy classification, which implied that elliptical galaxies form first, and evolve into spiral galaxies as they age. This concept is challenged by JWST observations of an abundance of spiral galaxies at high redshifts (Melia, 2023).

In contrast, the mechanism described in section 5, where rotation due to torque-induced precession cancels out gravitational rotation, is a lower energy solution, suggesting that spiral galaxies can evolve into elliptical galaxies (e.g. by growth of the central bulge) as individual stars flip from a higher energy state to a lower state. This hypothesis is consistent with the observation that stars in elliptical galaxies are, on average, older than stars in spiral galaxies, and is compatible with JWST’s observations of abundant early spiral galaxies.

It has long been remarked that the appearance of spiral galaxies is similar to hurricanes, which are low-pressure weather systems—a recent example is (Cao, Liu, & Zheng, 2018). With the new approach to galactic rotation curves proposed in this paper, both spiral galaxies and hurricanes are manifestations of fluids rotating on a curved surface, experiencing the effects of (different) Newtonian mechanisms, which would contribute to their similar appearance.

The analogy with weather systems can be extended, as although there is less similarity of appearance, elliptical galaxies could be seen as the equivalent of high-pressure weather systems.

Astrophysics currently models elliptical and spiral galaxies using different equations and concepts. Spiral galaxies are modelled as Kepler orbits, usually with dark matter halos to match observed rotation curves, while elliptical galaxies are modelled as a collisionless Boltzmann-type fluid that requires little or no dark matter. The textbook “Galactic Dynamics” (Binney & Tremaine, 2008) has separate chapters on the dynamics of spiral and elliptical galaxies, with very little commonality between them.

Meteorology, in contrast, models the behaviour of low-pressure and high-pressure weather systems using a single approach. Meteorologists do not use different computer systems to model the weather on sunny days and rainy days. With the concepts described in this paper, it is hoped that a similar unified approach to modelling galactic dynamics will become possible.

M33 Example

Incorporating Newtonian torque-induced precession through equation 8 can generate galactic rotation curves that show flat or rising profiles, without requiring dark matter or MOND. As an example, this methodology has been applied to the M33 spiral galaxy. (M33 is the galaxy in figure 1 that Wikipedia uses to illustrate the concept of anomalous galactic rotation curves.)

There are many parameters that affect the shape of a spiral galaxy rotation curve, including total visible and non-visible mass and its distribution, the presence and size of a massive black hole at its centre, the size and mass of a central bulge, the presence and size of spiral arms, and the amount of surrounding gas. These parameters are often poorly defined, giving scope to optimize the fit. The intention of the example plot for M33 is not to provide a perfect match, but to demonstrate that the concept does reproduce the overall shape of observed rotation curves.

The values used for M33 are given in Table 1. The value for g_u that was used is 2.0 x 10^{-11} m s^{-2}, which is reasonably near to the value a_0 =1.2 x 10^{-10} m s^{-2} used for the transition from Newtonian to non-Newtonian dynamics by Milgrom.

M33 galaxy	Units	Values
Black Hole mass	M⊙	-
Bulge radius	pc	-
Bulge density	M⊙/pc^3	-
Disk radius	pc	3000
Disk thickness	pc	500
Disk density	M⊙/pc^3	0.3
g_u	m s^{-2}	2.0E-11

Table 1. M33 rotation curve calculation values

The resulting rotation curve is shown in Figure 4, plotted against measurements taken from (Kam, et al., 2017). The quality of the match is not perfect and could be improved with a more detailed model of mass versus radius, but it exhibits the classic character of flat/rising spiral galaxy rotation curves that was so difficult to explain previously without invoking dark matter or MOND.

Conclusions

The inability of standard cosmology to explain the rotation curves of spiral galaxies is not a subtle problem. The discrepancy between theory and observation is large and the scientific community’s inability to resolve this problem has persisted for decades. A heroic effort is being spent on the search for dark matter, with the cost of some experiments, such as the

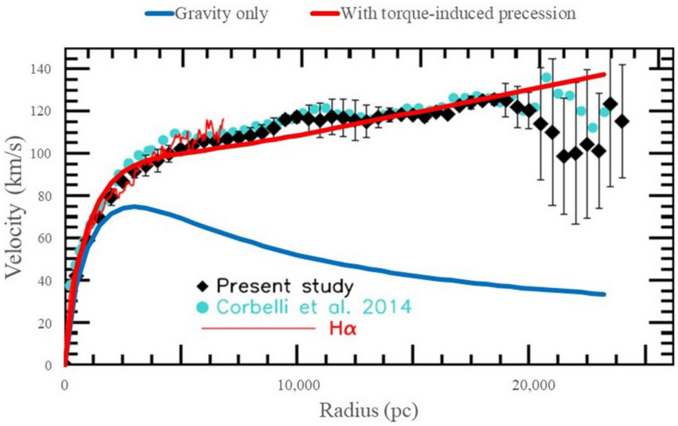


Figure 4 — M33 rotation curve calculations plotted against observations (Kam et al. June 2017, Fig. 14.)

proposed Cern FCC, now approaching $15 billion (Ghosh, 2024), but to date there is no evidence for the existence of particles beyond the standard model that would behave as astrophysicists require to match astronomical observation. The main alternative theory, MOND, is no nearer to being a viable theory, accepted by most scientists.

Big Bubble cosmology is a new concept that can resolve these long-standing problems. It requires no new dark matter particles, no modification to Newtonian dynamics, no dark energy, no inflation, no expanding space, and can explain much that standard cosmology cannot (Brissenden 2024). It has accommodated without modification the JWST revelations about the early Universe that have challenged standard cosmology. From a Bayesian information criteria perspective, its ability to address a wide range of problems is unmatched. It does require a revised perspective on the shape and characteristics of the Universe, including the (largely semantic) redefinition of coordinate time as the fourth dimension of space.

This paper shows that Big Bubble cosmology can reproduce the shape and magnitude of galactic rotation curves in spiral galaxies and has given insight into the bimodal split of spiral and elliptical galaxy types. Further study is required to refine these ideas, including modelling more galaxies and applying the (complex) mathematics of minimal-surface physics to the problem.

Acknowledgements

The concepts in this paper were originally documented in (Brissenden, 2019), which is unpublished. Publication of this paper would not have been possible without the prior publication of (Brissenden, 2024), which is a major departure from standard cosmology. I am grateful to The Royal Astronomical Society of Canada and the *Journal*'s editorial staff, who provide the opportunity for Canadian scientists, amateur and professional, to have their work brought to a wider audience. ✶

References

Banik, I., Pittordis, C., Sutherland, W., Famaey, B., Ibata, R., Mieske, S., & Zhao, H. (2023). *"Strong constraints on the gravitational law from Gaia DR3 wide binaries."* [astro-ph.SR] arXiv:2311.03436v1.

Binney, J., & Tremaine, S. (2008). *"Galactic Dynamics."* Princeton University Press.

Brissenden, S.J. (2019, October). *"Big Bubble Theory."* www.researchers.one/article/2019-09-21

Brissenden, S.J. (2024, April). "Cosmological Redshift without Expanding Space." *JRASC, 118(2)*, 57–63.

Cao, Z., Liu, L., & Zheng, T. (2018, Feb). *"Is the Spiral Galaxy a Cosmic Hurricane?"* arXiv:1802.02734 [astro-ph.GA].

Einstein, A. (1917). *"Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie."* Sitzungs. König. Preuss. Akad., 142–152.

Ghosh, P. (2024, March 24). *"Cern: Scientists search for mysterious ghost particles."* BBC News: www.bbc.com/news/science-environment-68631692

Illingworth, G. (1977, December 1). "*Rotation (?) in 13 elliptical galaxies*". *ApJ, Part 2 - Letter to the Editor, 218*, L43–L47.

Kam, S.Z., Carignan, C., Chemin, L., Foster, T., Elson, E., & Jarrett, T.H. (2017, June). *"HI Kinematics and Mass Distribution of Messier 33."* arXiv:1706.04248 [astro-ph.GA].

Lundmark, K. (1930). *"Über die Bestimmung der Entfernungen, Dimensionen, Massen und Dichtigkeit fur die nächstgelegenen anagalacktischen Sternsysteme."* Meddelanden Fran Lunds Astronomiska Observatorium Serie I. 125: Bibcode:1930MeLuF.125....1L, 1-13.

Melia, F. (2023). *"The Cosmic Timeline Implied by the JWST High-redshift Galaxies."* MNRAS Letters, 521, L85.

Milgrom, M. (1983). *"A modification of the Newtonian dynamics as a possible alternative to the hidden mass hypothesis." ApJ, 270,* 365–370.

O'Raifeartaigh, C., O'Keeffe, M., Nahm, W., & Mitton, S. (2017). *"Einstein's 1917 static model of the universe: a centennial review."* Eur. Phys. J. H. arXiv:1701.07261, 42(3), 431–474. doi:Bibcode:2017EPJH...42..431O.

Peebles, J. (2022). *"Anomalies in Physical Cosmology."* arXiv:2208.05018v1 [astro-ph.CO] .

Rubin, V., Thonnard, N., & Ford, W.J. (1978). *"Extended rotation curves of high-luminosity spiral galaxies. IV – Systematic dynamical properties, SA through SC." ApJ Letters, 225*, L107–L111. doi:Bibcode:1978ApJ...225L.107R. doi:10.1

Swart, J.d. (2024). *"Five decades of missing matter."* Physics Today, 77(8), 34–43.

Zwicky, F. (1933). *"Die Rotverschiebung von extragalaktischen Nebeln"* [The redshift of extragalactic nebulae]. Helvetica Physica Acta. 6: Bibcode:1933AcHPh...6..110Z, 110–127.

The April 2025 *Journal* deadline for submissions is 2025 February 1.
See the published schedule at rasc.ca/sites/default/files/jrascschedule2025.pdf

Pen & Pixel

Figure 1 – Steve Leonard captured this beautiful image of the Omega Nebula (M17) and says, "The nebula was framed so that the beautiful open star cluster M18 (NGC 6613) would be included in the image in the top right corner for a balanced composition." He shot this with only 5 hours of narrowband data in Markham, Ontario, under Bortle 9 skies and says the image "was processed to bring out the complex and undulating waves within the Omega Nebula without blowing out the core." He used an AT115EDT 4.5" triplet refractor at f/5.6, on an EQ6-R mount, using NINA, an ASI 1600MM Pro camera, with Chroma 3-nm SHO filters, and Astrodon RGB filters. 3 hours of Hα, 2 hours of OIII, and 1.5 hours of RGB. Processing was done in PixInsight and Topaz Denoise.

Figure 2 – This image of the Pacman Nebula, found in Cassiopeia, was taken by Rob Lyons from Vancouver under Bortle 9 skies. "In case you were wondering, yes, there is a Ghost Nebula nearby as well," he says, a throwback to the popular 1980's arcade game. "The gas and dust in this region forms new stars, which in turn bombard the remaining gas with UV radiation causing it to emit light. Here we see sulphur in red, hydrogen in green, and oxygen in blue," he says. "This is known as the classic Hubble colour palette." He used a Celestron Edge HD 8 with a 0.7× reducer, an ASI294MC Pro camera, with an Altair 4-nm dual-band set and a ZWO AM5. Total integration was 27 hours of 300-second subs.

Continues on page 29

What's Up in the Sky?

February/March 2025

Compiled by James Edgar

February Skies

The Moon is joined by Saturn, Venus, and Neptune on February 1, while at the same time it reaches perigee of 367,457 km. On the 5th, the Moon reaches first quarter, close by the Pleiades (M45), only 0.5 degrees away on the 6th. Jupiter is 5 degrees south on the early morning of the 7th. By the 9th, Mars is 0.8 degrees south of our satellite. The Moon is full on the 12th. On the 17th, Spica, the bright star in Virgo, The Maiden, is 0.3 degrees north of the waning crescent Moon. On that same day, the Moon reaches apogee of 404, 882 km. Antares is 0.4 degrees north of the last-quarter Moon on February 21. New Moon is on the 27th.

Mercury is in superior conjunction, meaning it is on the far side of its orbit, behind the Sun. By month-end, the speedy planet is just starting to appear after twilight.

Venus, the Evening Star, continues to blaze in the southwest, visible even in early twilight. The bright planet is among the stars of Pisces, The Fish. Venus achieves greatest illuminated extent on the 14th. Even though the planet appears as a crescent, the square degrees of the visible portion are at their greatest amount.

Mars rises in the east in mid-afternoon, becoming visible as darkness falls in the stars of Gemini, The Twins. The waxing gibbous Moon joins the crowd on the 9th, to the east of Orion, The Hunter. The Red Planet makes a nice triangle with Castor and Pollux during the month.

Jupiter, in Taurus, The Bull, has been retrograding and is stationary on the 4th, then slowly resuming eastward, prograde motion, just a few degrees north of Aldebaran. The end of the month sees double shadow transits across the face of the gas giant.

Saturn, at the beginning of the month, is barely visible in the southwestern evening sky, fading fast as it nears conjunction with the Sun. Watch for Mercury 1.7 degrees away on the 25th.

Uranus is in Aries, The Ram, visible in the evening sky after sundown. The blue-green planet falls into a long line of celestial objects on the 2nd, with Saturn near the Sun, Venus to its northeast, then the Moon, Uranus, and Jupiter.

Neptune, though barely visible even in a telescope, is clustered with the waxing crescent Moon and Venus in the southwestern evening twilight.

The **zodiacal light** is visible in the western evening twilight for two weeks during the end of February and into March. This phenomenon is caused by dust in space along the ecliptic being backlit by the Sun. It's subtle, but fun to catch a glimpse.

Figure 1 — On February 2, all the planets but one are lined up across the evening sky (Earth is included, Mercury is too close to the Sun) Photo credit: Starry Night Pro Plus 8

Continues on page 28

The Sky February/March 2025

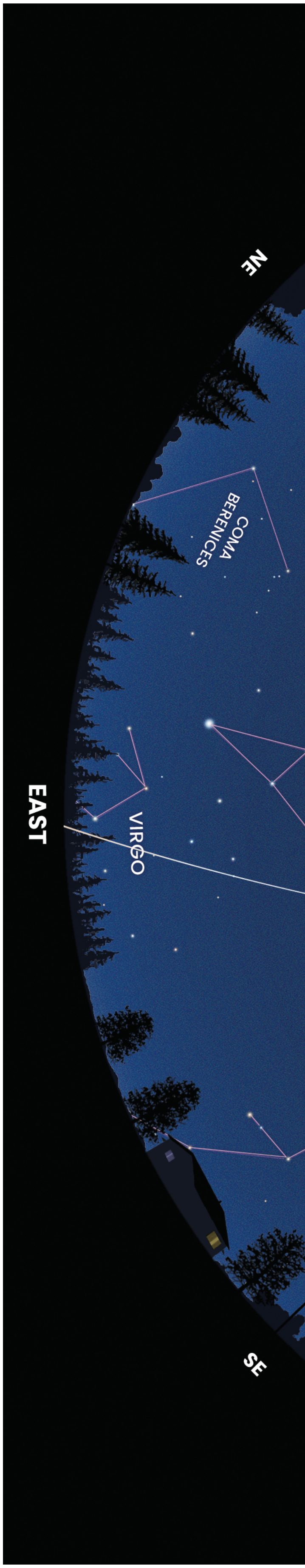
Compiled by James Edgar with cartography by Glenn LeDrew

Celestial Calendar (bold=impressive or rare)

Feb. 1	**Saturn 1.1° south of crescent Moon**
Feb. 1	**Venus 2° north of crescent Moon**
Feb. 1	Moon at perigee (367,457 km)
Feb. 1	Neptune 1.4° south of crescent Moon
Feb. 5	Moon at first quarter
Feb. 6	**Moon 0.5° north of Pleiades (M45)**
Feb. 7	Jupiter 5° south of waxing crescent Moon
Feb. 9	**Mars 0.8° south of nearly full Moon; occulted in the north Feb. 12 full Moon 8:53 a.m. EST**
Feb. 14	Zodiacal light visible in west after evening twilight
Feb. 17	**Spica 0.3° north of waning gibbous Moon**
Feb. 17	Moon at apogee (404,882 km)
Feb. 20	Moon at last quarter
Feb. 21	**Antares 0.4° north of last-quarter Moon**
Feb. 25	Pluto 1° north of waning crescent Moon
Feb. 25	**Mercury 1.7° north of Saturn**
Feb. 25	**double shadows on Jupiter**
Feb. 27	new Moon 8:45 p.m. EST (lunation 1264)
Feb. 28	Mercury 0.4° north of one-day-old Moon
Mar. 1	Moon at perigee (361,964 km)
Mar. 1	Venus 6° north of thin crescent Moon
Mar. 4	**double shadows on Jupiter**
Mar. 5	**Moon 0.6° north of Pleiades (M45)**
Mar. 6	Jupiter 6° south of waxing crescent Moon
Mar. 6	Moon at first quarter
Mar. 8	Mercury at greatest elongation east (18°)
Mar. 8	Mars 1.7° south of eight-day-old Moon
Mar. 9	Daylight Saving Time begins
Mar. 9	**Pollux 2° north of waxing gibbous Moon**
Mar. 11	**double shadows on Jupiter**
Mar. 14	full Moon at 2:55 a.m. EDT
Mar. 14	**Total lunar eclipse begins at 2:25 a.m. EDT**
Mar. 16	Zodiacal light visible in west after evening twilight
Mar. 16	**Spica 0.4° north of waning gibbous Moon**
Mar. 17	Moon at apogee (405,754 km)
Mar. 19	**double shadows on Jupiter**
Mar. 20	**Spring Equinox**
Mar. 20	**Antares 0.5° north of last-quarter Moon**
Mar. 22	Moon at last quarter
Mar. 29	new Moon at 6:58 EDT (lunation 1265)
Mar. 29	partial solar eclipse
Mar. 30	Moon at perigee (358,128 km) Large tides

Planets at a Glance

	DATE	MAGNITUDE	DIAMETER (″)	CONSTELLATION	VISIBILITY
Mercury	Feb. 1	—	4.8	Capricornus	—
	Mar. 1	−1.0	6.0	Pisces	Evening
Venus	Feb. 1	−4.8	31.9	Pisces	Evening
	Mar. 1	−4.8	48.7	Pisces	Evening
Mars	Feb. 1	−1.1	13.7	Gemini	Evening
	Mar. 1	−0.3	10.9	Gemini	Evening
Jupiter	Feb. 1	−2.5	43.4	Taurus	Evening
	Mar. 1	−2.3	39.6	Taurus	Evening
Saturn	Feb. 1	1.1	16.0	Aquarius	Evening
	Mar. 1	—	15.7	Aquarius	—
Uranus	Feb. 1	5.7	3.6	Aris	Evening
	Mar. 1	5.8	3.6	Aries	Evening
Neptune	Feb. 1	7.9	2.2	Pisces	Evening
	Mar. 1	8.0	2.2	Pisces	Evening




NORTH
NW
WEST
SW
CYGNUS
Deneb
BOÖTES
DRACO
Little Dipper
URSA MINOR
Polaris
CANES VENATICI
Big Dipper
URSA MAJOR
CEPHEUS
LACERTA
PEGASUS
CASSIOPEIA
CAMELOPARDALIS
Double Cluster
M31
Great Square of Pegasus
ANDROMEDA
LEO MINOR
LYNX
Capella
PERSEUS
TRIANGULUM
ARIES
PISCES
LEO
Castor
Pollux
AURIGA
CANCER
Mars Mar 28
GEMINI
Jupiter Mar 28
TAURUS
Pleiades
Regulus
M44
CANIS MINOR
Aldebaran
CETUS
HYDRA
Procyon
Betelgeuse
ORION
MONOCEROS
Rigel
ERIDANUS
Sirius
CANIS MAJOR
LEPUS
PYXIS
PUPPIS
COLUMBA

Continued from page 25

Figure 2 — March 10 sees the Moon and Mars high above Jupiter and Uranus, while Venus and Mercury hug the horizon. Photo credit: Starry Night Pro Plus 8

March Skies

The Moon is joined by Mercury on the 1st, but it might be a tough observation – the Moon is just a faint, thin sliver in the evening twilight. Plan on using binoculars or a telescope. The Moon is at perigee that day, too, at 361,964 km; Venus is 6 degrees north, as well. By the 5th, Luna has moved over to 0.6 degrees north of the Pleiades, in Taurus, The Bull. Jupiter is 6 degrees south of the first-quarter Moon on March 6. On the 7th, the Moon reaches its maximum northerly declination – a lunar standstill – the most northerly since 2006. On the 8th, Mars sits 1.7 degrees south of our satellite, while Pollux is 2 degrees north – could be a good photo op! The Moon is full on the 14th, and since it is also crossing the ecliptic, a total lunar eclipse occurs as the Moon passes through Earth's shadow. This eclipse, lasting a little over 4 hours, will be visible from North America, with greatest eclipse occurring near midnight. On the 16th, Spica is 0.4 degrees north of the waning crescent Moon. On the following day, the 17th, the Moon is at apogee of 405,754 km. The 20th sees Antares 0.5 degrees north of the Moon. The Moon is new on the 29th, and, as expected, a solar eclipse occurs. This one is partial only and visible from a very small part of northeastern North America. The Moon is at perigee on the 30th at 358,128 km; large tides occur at coastal areas.

Mercury puts on a show for North American viewers, with the best evening apparition of 2025. The angle of the ecliptic is steep, so Mercury is directly north of the Sun at twilight. Greatest elongation is on the 8th, then begins a steep dive to inferior conjunction on the 24th.

Venus appears to move westward as it begins retrograde motion at the beginning of March. The bright planet is prominent in the western evening sky. Like Mercury, Venus is heading to inferior conjunction on the 22nd. For a few days close to conjunction, a northern viewer can spot Venus in the bright sunlight both before sunrise and after sunset!

Mars remains in Gemini all through March, gradually moving eastward. Castor and Pollux join with the Red Planet to create an ever-changing triangle. The Moon passes by on the 8th.

Jupiter starts off the month with double shadow transits on the 4th, 11th, and 19th. The gas giant spends March among the stars of Taurus, with the Moon gliding by on the 6th.

Saturn is behind the Sun, but a major event—a ring plane crossing—occurs on the 23rd, when Earth passes to the south side if the rings. It will remain so for several years.

Uranus gets closer and closer to the Sun throughout the month, from 73 degrees away on the 1st to 43 degrees on the 31st. The viewing window rapidly closes.

Neptune is too close to the Sun to be seen.

The **zodiacal light** is visible in the western evening sky shortly after sunset for the two weeks beginning March 16.

Daylight Saving Time begins on March 9.

The spring equinox is on March 20. ✶

Continued from page 24

Figure 3 – Shraddha Pai of Toronto took this image from the dark skies of the Monte Verde region of Costa Rica in March 2022. At 10°N latitude, Costa Rica sees constellations normally not seen in the Northern Hemisphere. Here you see the four bright stars of the Southern Cross (left), the purple glow of the Carina Nebula (right), and the Southern Pleiades (bottom-right), on a diamond-dust ribbon of stars of the Milky Way.

Unmodified Canon Rebel T2i. 50-mm ƒ/1.8. ISO 1600. 122 lights x 3s, 30 darks. No flats or bias frames. Processed in PixInsight with touchups in Lightroom Classic.

Figure 4 – Like an eye in the sky watching over us, here is the Helix Nebula taken by Frank Sowa. He captured the image over two nights at River Place Campground at the North York Astronomical Association's Starfest, with a Sky-Watcher 80-mm Esprit Refractor and an ASI071 MC pro camera with no filters. He used 65 frames of 420 seconds each.

Feature Article /
Articles de fond

Accuracy of the "Shadow Stick" Method for Determining North

by David M.F. Chapman, FRASC, Halifax Centre
(chapmandav@gmail.com)

Introduction

A classic woodcraft skill is finding north by observing (over several hours) the shadow cast by the Sun of a stick inserted vertically into the ground (see Fig. 1). From time to time, one marks the end of the shadow with a marker such as a stone. In theory, the marked line traces out a west-east line over time, and the north direction is then perpendicular to that line. As the Sun rises roughly eastward and sets roughly westward, this method seems reasonable at first thought, but I have often wondered how accurate it is (never having tried it myself). In this age of precise electronic navigation, this activity seems quaint. However, it is an interesting example of practical astronomy and is an instructive exercise in the use of the "Angular Relations" material found in the RASC *Observer's Handbook*. The following analysis shows that the method is accurate at the equinoxes and less accurate at other times of the year, particularly near the solstices. The error can be reduced by limiting the observations to near solar noon, and there is a trick one can apply to restore accuracy at any time of year. Warning: the analysis involves trigonometric mathematics!

The Angular Relations

The observer's latitude is denoted ϕ (the longitude does not matter). The position of the Sun on the celestial sphere is denoted by its right ascension α and declination δ. Instead of using α directly, it is convenient to use the hour angle $h = \alpha - t$, in which t is the sidereal time, that is, the celestial line of right ascension that lies directly south at the time of observation. The variable h represents the angle of the Sun along its declination line before (negative) or after (positive) its position at solar noon. Although h is an angle, it can represent hours of time simply by replacing h by $h\pi/180$ in the formulas. The other set of coordinates needed are the Sun's azimuth A (angle clockwise from north) and altitude a (angle above the horizon). Computing the position of the end of the shadow on the ground for a stick of height H consists of transforming the coordinates (h, δ) to (A, a) at the date and time of observation, followed by a little geometry.

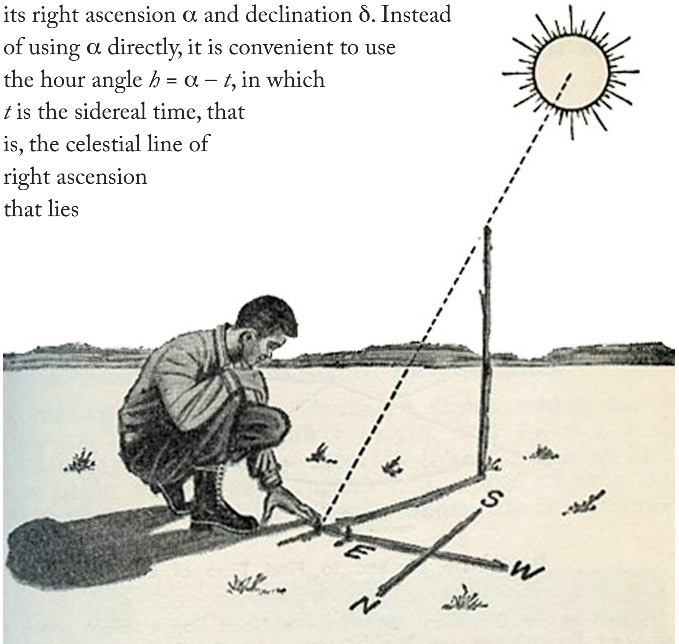


Figure 1 — A typical illustration of the "shadow stick" method of finding north in the wild.

The transformation equations are found on p. 32 of the *Observer's Handbook*.

$$\sin a = \sin\delta \sin\phi + \cos h \cos\delta \cos\phi \tag{1a}$$
$$\sin\delta = \sin a \sin\phi + \cos a \cos A \cos\phi \tag{1b}$$
$$\cos\delta \sin h = -\cos a \sin A \tag{1c}$$

For a given location, the latitude ϕ is constant. For a given date, the declination δ of the Sun is constant (close enough). The above equations then show how the azimuth A and altitude a of the Sun vary with the hour angle h through the day, keeping ϕ and δ fixed.

Equations (1a–c) apply to any celestial object, not just the Sun. For example, to determine the rising and setting circumstances of any object, simply set $a = 0$ (object on the horizon) to get the simplified equations:

$$0 = \sin\delta \sin\phi + \cos h \cos\delta \cos\phi, \text{ and} \tag{2a}$$
$$\sin\delta = \cos A \cos\phi. \tag{2b}$$

The rise/set hour angles and azimuths derive from equations (2a) and (2b), that is

$$h_{rs} = \arccos(-\tan\delta \tan\phi), \text{ and} \tag{3a}$$
$$A_{rs} = \arccos(\sin\delta/\cos\phi). \tag{3b}$$

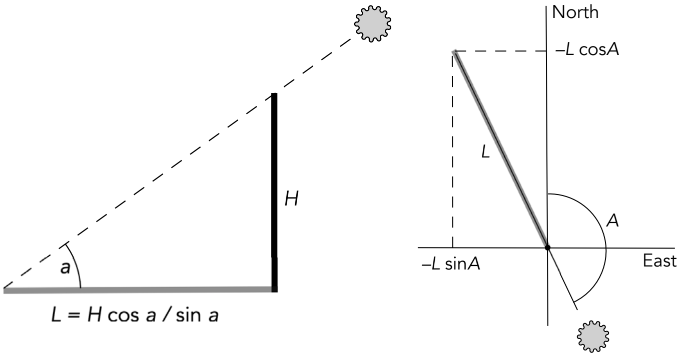


Figure 2 — The side view of the stick and shadow. (left)
Figure 3 – The overhead view of the stick and shadow. (right)

Casting the Shadow

Referring to Figure 2, a vertical stick of height H casts a shadow of length L on the ground, given by a simple function of the Sun's altitude a:

$$L = H \cos a / \sin a. \tag{4}$$

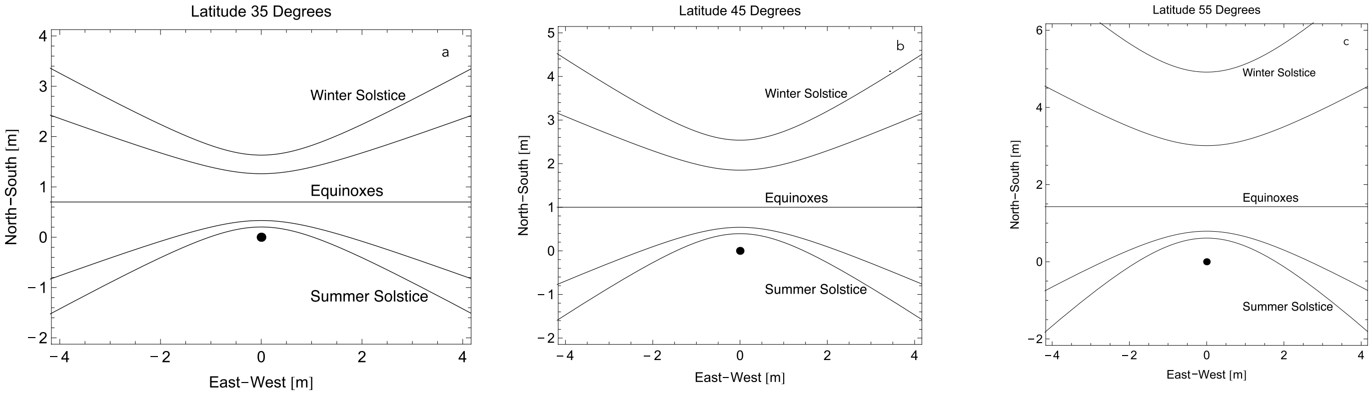


Figure 4 — Shadow-stick curves at eight times of year for three latitudes: (a) 35°, (b) 45°, and (c) 55°.

Referring to the overhead view in Figure 3, The cardinal direction of the shadow is opposite the azimuth angle A, with x (east) and y (north) components

$$x = -H \sin A \cos a / \sin a, \text{ and} \tag{5a}$$

$$y = -H \cos A \cos a / \sin a. \tag{5b}$$

Substituting for a and A using equations (1a–c), and using the identity $\sin^2 a + \cos^2 a = 1$, these become functions of h with parameters ϕ and δ:

$$x = H\,(\sin h/\cos\phi)/(\cos h + \tan\phi \tan\delta), \text{ and} \tag{6a}$$
$$y = H\,(\tan\phi \cos h - \tan\delta)/(\cos h + \tan\phi \tan\delta). \tag{6b}$$

From equations (6a–b) we can compute the position of the shadow end throughout the day for a given latitude ϕ and date (i.e. declination δ of the Sun). Without computing, we note some interesting properties of these results. Firstly, the (x,y) curves are symmetric about the y (north-south) axis, as $x(-h) = -x(h)$ and $y(-h) = y(h)$. This will become helpful later on. Secondly, and most important, note that for $\delta = 0$ we have $y = H \tan\phi$, a constant independent of h—in other words, the end of the shadow traces a perfectly straight west-east line offset from the origin—at the equinoxes, the shadow stick method is exact.

Sample Calculations

In this section we compute shadow curves for three values of latitude ϕ (35°, 45°, and 55°) and five values of solar declination δ (+23.4°, +16.5°, 0°, –16.5°, and –23.4°). The extreme values represent the solstices (summer and winter, respectively, in the Northern Hemisphere) and 0° represents the equinoxes (vernal and autumnal). The intermediate values ±16.5°, represent the cross-quarter days about halfway in time between the solstices and equinoxes, which take place in early May and August (positive) and early November and February (negative). The results are shown in Figures (4a–c), which have similar form but vary in detail.

The curves are symmetric about the north-south direction, as predicted, and the curves for the equinoxes ($\delta = 0°$) are straight, as predicted. Otherwise, the curves do not trace out the east-west direction accurately. The error increases with latitude, with declination north and south, and with time away from solar noon. Best practice for reducing error is to ensure that the shadow marking be near noon; better yet, include time on both sides of noon.

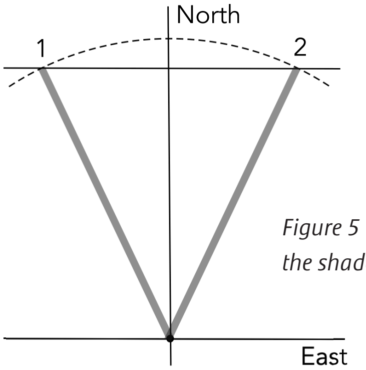


Figure 5 — Restoring accuracy to the shadow stick method.

A Trick to Improve Accuracy

Taking advantage of the east-west symmetry of the curves, here is a neat trick to restore accuracy of the shadow stick method, illustrated in Figure 5: Well before noon, mark the end of the shadow lying to the west (1). Using a piece of cord and a second stick, trace the arc of a circle centred on the shadow stick, over to the east. As the shadow moves eastward through the day, mark the point (2) at which the shadow end next intercepts the circular arc. The line joining points 1 and 2 lies exactly east-west.

Summary

The classic "shadow stick" method of finding north is based on the west to east travel of the stick's shadow over the day; however, it is only accurate at the equinoxes or if one uses the east-west symmetry of the motion over solar noon. Otherwise, the method only gives a general indication of the east-west direction, and only if applied near noon. Accuracy can be restored using the east-west symmetry of the geometry. ✶

David Chapman has been an amateur astronomer and RASC member since the 1960s and became a Fellow of the RASC in 2020. He studied physics at the University of Ottawa (1975, B.Sc.) and the University of British Columbia (1977, M.Sc.). From 1977 to 2008, he worked as a Defence Scientist, performing research in underwater acoustics for the Canadian Navy. He is an Emeritus Editor of the RASC Observer's Handbook *(2012–2016 editions). Consult https://linktr.ee/DaveChapman to learn about his projects.*

Blast from the Past!

Compiled by James Edgar
james@jamesedgar.ca

Work at the Lick Observatory and Improvements in its Equipment.

BY C.A. CHANT

In the following pages an attempt is made to give a general account of the work being carried on at the Lick Observatory and of some recent additions to its equipment.

Improvements in Buildings and Equipment

a. A Photographic House.

The plans for the observatory were made in the late '70s, and executed in the early '80s, at which time astronomers did not realise the important part which photography was destined to play in their researches. Consequently when the institution was opened on June 1, 1888, it did not possess suitable rooms and apparatus for taking celestial photographs or for their study and measurement. The first director, Professor Holden, soon found it necessary to transform the observatory equipment to meet the photographic requirements. Fortunately considerable gifts from outside sources as well as small sums from the maintenance funds allowed the provision of photographic telescopes, spectrographs and measuring microscopes. Space suitable for the manipulation and study of photographs has always been wanting, and the successive annual reports of Directors Holden, Keeler and Campbell have drawn attention to the need of a building in which the rapidly growing collection of photographs could be stored, and which would supply proper facilities for the enlargement and measurement of photographic plates. This pressing need is soon to be satisfied. Plans for a building to cost about $22,000 have been prepared, and the Legislature of the State of California has appropriated $10,000 to begin the work, which, it is hoped, the succeeding Legislature will complete. The building will be of re-enforced concrete, and the portions to be used for storage purposes will be made as nearly fireproof as possible. The structure will be 52 feet long by 31 feet wide. and two stories high. It will contain four storage vaults, an enlarging room 50 feet in length, three dark-rooms, a room for testing new apparatus and two rooms for the measurement of photographs.

b. Electrical Equipment.

The observatory began its work also without any electrical equipment. In 1891 Mr. Thomas A. Edison presented the institution with a complete outfit, consisting of a dynamo of one kilowatt capacity, together with steam engine and boiler, storage battery, switchboard and wiring. This small plant supplied current for the comparison apparatus and temperature-control of the spectrographs, for the illumination of the setting-circles and the micrometer wires of the principal telescopes, that is, for the more pressing scientific needs. The lighting of the observatory buildings has been by oil lamps.

The small Edison plant has long been inadequate even for scientific purposes, and it was felt also that the heterogeneous combination on the mountain of steam, water, wind and gasoline driven engines for various purposes was uneconomical both of time and money, and at last the Legislature of two years ago appropriated the sum of $10,000 to supply an electrical equipment to meet the numerous and varied requirements. A 20 h.p. gasoline engine is directly connected to a dynamo, which is used to charge a storage battery of 128 cells, each having a capacity of 200 ampere-hours. This acts as a reservoir, to be drawn upon as required. The greater part of the installation was made in 1906, but owing to the extraordinary conditions of labor and supplies, following the earthquake and the great fire in San Francisco, it was not completed until the present summer. Apart from the current for purely scientific purposes, it will be used to turn the domes of the great refractor and the Crossley reflector, to wind their clocks, to run the machinery in the instrument and carpenter shops, to work two pumps of the water supply and to saw fuel for the community. Already it illuminates the main building, (with its 36-inch and 12-inch refractors,) the meridian circle house, the Crossley, six-inch and Crocker telescope houses, the workshops, and also ten residences and outbuildings. This electrical plant is perhaps appreciated all the more because of the long time required to get it.

c. The Water Supply.

When it is remembered that the summit of Mt. Hamilton is 4200 feet above the sea and that the entire community live on the observatory property, it will be seen that the task of supplying comfortable accommodation and the ordinary necessities of modern life is not a simple one. At most observatories when funds are available for an assistant's salary the director chooses the best man available and allows him to make his own living arrangements. Not so with the Lick Observatory. Here the Director must first inquire the size of the applicant's family, as there is no other place for him to live but in an observatory house, and the space is very limited.

One of the most important problems is that of the water supply. At first the community had from twelve to twenty inhabitants and the water supply question was found to be difficult enough, but now when the inhabitants number from 55 to 60 it is much more serious.

The source of supply up to the present has been a spring located about one mile from the observatory buildings and 300 feet below their level. This spring could supply more than the amount required in the wet season, but much less than is needed in the long rainless summer. Storage capacity of 160,000 gallons exists on a peak fifty feet higher than the main buildings and half-a-mile distant from them. Careful attention to the piping, in order to prevent leaks, has enabled the system to supply the modest demands, provided the rainfall has been of average amount. In some seasons, however, this has not been the case, and then the domestic and photographic services had to go on short allowance. On two occasions the situation has been difficult. Moreover, the shortage always happens at the end of the long dry season, when fire risks are greatest. The Legislature recently made a small appropriation for the development of another spring, which, though 350 feet lower than that hitherto used, has an output perhaps fifteen-fold greater. It is located on a 30° slope, at a level 680 feet below the reservoir system. It may be of interest to outline the pumping system employed in raising the water. First it is led into small reservoirs placed a few feet below the level of the spring, and from these a pipe leads the water to a point 215 feet lower in level, where an automatic pump is installed. The water-head of 215 feet operates the motor-end of the pump in exactly the same way that steam performs in ordinary pumps. The motor pistons are directly connected to the pumping pistons, the crosssection of the latter being one-sixth that of the former. The supply for the pumping pistons reaches them likewise under a head of 215 feet. Connected to the pumping chamber is the delivery pipe, which runs up the slope to the storage reservoir on the summit. It will thus be seen that of every seven gallons six operate the pump and the seventh is delivered at the summit. On account of the large flow of the spring the available water supply has been multiplied three-fold.

Several improvements are projected as a result of the increased supply, for example, the foresting of several of the slopes leading down from the observatory, involving irrigation during the first few dry seasons.

d. Alterations to the Crossley Reflector.

An addition to the optical system of the Crossley reflector is under way, in order to adapt this powerful instrument to the requirements of parallax and spectrographic work. At present the system consists exclusively of the excellent 36½-inch silver-on-glass mirror, which has a ratio of aperture to focal length of 1:5.8. This ratio is not suitable for the collimator of a spectrograph, and likewise the scale of stellar photographs is too small to admit of the very accurate observations required in parallax determinations. Mr. F. G. Pease, formerly assistant to Professor G. W. Ritchey, and now expert optician to the Scientific Shop in Chicago, is on Mt. Hamilton, constructing a 9¾-inch hyperboloidal secondary mirror in order to convert the telescope into the Cassegrainian form. A third mirror with flat surface will be mounted diagonally, immediately in front of the parabolic mirror, in order to direct the beam of light through the side of the telescope tube near the lower end. The course of the light is thus as follows: Passing down the tube it reaches the great parabolic mirror, by which it is returned along the axis of the tube to the hyperboloidal mirror, which again returns it to the plane reflector placed near the large mirror. By this it is turned at right angles, and emerges through an opening in the side of the tube. Here it will be received on the photographic plate, or in the eye-piece. The equivalent focal length will thus be increased to about 75 feet. Professor Perrine is hoping promptly to utilize the telescope thus modified in the development of stellar parallax methods, and Director Campbell is planning for spectrographic work on certain especially interesting types of stars.

Spectrographic Determination of the Velocity of Stars in the Line of Sight.

The most extensive investigation under way at the observatory is that of determining the radial velocities of the brighter stars by means of the Mills spectrograph attached to the 36-inch refractor, in accordance with the programme entered upon by Professor Campbell in 1896. This programme embraces all the stars, whose photographic magnitudes are equal to or brighter than 6.0, lying north of –25° declination, with the addition of essentially all of the stars brighter than the 5th magnitude between –25° and –30° declination. The number of stars on the list is approximately 750, though a certain number of these are not amenable to accurate observation, for the reason that their spectra do not contain sharply-defined lines. It is of interest to note that the efficient apparatus in use is capable of recording spectra of 60 photographic magnitude stars in good strength with an exposure of 2 1/2' hours, provided the atmospheric conditions are average.

The number of spectrograms secured to date is approximately 4,800, not including several hundred spectrograms, principally of variable stars of the δ Cephei type, obtained with an excellent one-prism spectrograph. All of these plates have been submitted to approximate measurement and reduction, and fully two-thirds have been measured and reduced definitively. Since the year 1896 an average of three nights per week have been devoted to the observations. The labor of measuring and reducing a spectrogram is in general two or three times that of obtaining it. For a year and a half Professor Campbell was alone in the work. For five years he was assisted by Professor W. H. Wright, and during the last three years the Carnegie Institution has given support for the employment of assistants in measuring and reducing the plates.

The degree of accuracy attained is simply astonishing, that for the stars of the 5th or 6th magnitude being little inferior to that for the brighter ones. Early in 1901 the results thus far secured were combined mathematically for the determination of the direction and speed of the motion of the solar system in space. This was the original chief purpose of the undertaking and is so yet. However, the by-products of the work, more or less unexpected. are considered by some to be no less important than the determination of the solar motion. For example, the surprising result was soon reached, confirmed amply by work of later years, that at least one star out of six or seven, on the average, has a variable velocity which, passing rapidly through its cycle of changes, shows that the star is a spectroscopic binary. In no case have the components of such a star been observed directly with the telescope, and it is perhaps too much to hope that any of the systems thus discovered by the spectrograph will permit of telescopic resolution.

The proportion of spectroscopic binaries will probably increase rather than diminish as the work proceeds, for the discoveries thus far made relate only to those whose periods are relatively short and whose range of velocity is great. In recent years a considerable number of stars that were originally supposed to have constant speeds are showing changes, indicating that here we are dealing with systems of long period. As the work progresses the suspicion becomes more pronounced that the solar system may not be an average type of stellar system, but may in fact be near one extreme in a long series of different types.

During the organisation of the programme of work with the Mills spectrograph Director Campbell was impressed with the need of similar observations on the stars not accessible to northern observers before a satisfactory solution of the solar motion could be attained. Let the observations of stars in the northern two-thirds of the sky be as extensive and accurate as it is possible to make them, the solution would be incomplete and unsatisfactory so long as the one-third of the stars about the south pole were not included in the solution. The observations in the northern hemisphere could not have their full strategic value until they were combined with corresponding observations in the south polar region.

From the year 1894 Professor Campbell definitely held in mind the desirability of despatching an expedition to secure these observations. In 1900 the time seemed to have come for undertaking this work, and he was fortunately able to enlist the interest and support of D. O. Mills, Esq., who provided the funds completely to meet the requirements of such an expedition. In that year Professor Campbell was made director of the observatory, and it devolved upon his chief assistant in the spectrographic work, Professor Wright, to go in charge of the expedition. The Mills Observatory was located on the summit of a low mountain near Santiago, Chile; and here was completed the original programme of observations, involving 145 stars south of declination –25°, whose spectra contained well-defined lines. The number of spectrograms secured was 800, and the number of spectroscopic binaries discovered by Professor Wright is, as in the north, one in every six or seven stars. The measurement and reduction of the Chile plates has been the chief work of Messrs. Wright and Albrecht on Mt. Hamilton during the last year, and more than three-fourths of the spectrograms have been completed. The end of this work should be reached in a few months.

The need for many more observations of this kind in the southern hemisphere is very pressing, both to improve our knowledge of the solar motion, and to assist in the solution of other leading problems concerning our sidereal system. The Mills Observatory is equipped especially for this work, and when the subject was brought to the attention of Mr. Mills he was pleased to provide for its continuance for five more years. During this second period the southern work is in charge of Dr. Heber D. Curtis, who assisted with the Mills spectroscope on Mt. Hamilton for three years. The accuracy reached in the Chile work is substantially equal to that on Mt. Hamilton.

One significant fact may be mentioned in connection with the work in the southern hemisphere. For the first time a reflecting telescope, whose arrangements differ in many important respects from those of the conventional instrument, was employed in radial velocity determinations. The spectrograph likewise involved a number of departures that at the time of its construction were new. It was planned definitely to assemble the telescope and spectrograph complete on Mt. Hamilton, to submit them to critical tests, in order that the many unexpected defects and difficulties might be isolated and removed. But an error in figuring the mirrors rendered this assembling and testing on Mt. Hamilton impossible. The unassembled apparatus was shipped to Chile, it was mounted in place at the observing station, far from the services of expert mechanicians and opticians, and there first submitted to test. The significant point is that the programme of observations with the apparatus was carried through substantially as planned, with the accuracy hoped for, without experiencing any serious difficulties and without introducing any single important change in the apparatus. This certainly shows that the elements of the problem of determining the radial velocities of stars with great accuracy have for several years been fully comprehended.

With this great problem of radial determinations the names of Campbell, Lick Observatory and Mills will always be honorably associated, but the Director's greatest satisfaction is not in the fact that the important work is now moving definitely to a conclusion, but that he has trained a considerable number of men who are well qualified to carry on similar researches both in the matter of observation and reduction. In this connection the names should be mentioned of Messrs. Wright, Curtis, Moore, Burns and Albrecht, as well as several who have left the observatory to accept appointments elsewhere.

Eclipse Expedition, January 1908

Since the opening of the Lick Observatory kind friends have provided ways and means for the despatching of expeditions to observe all the observable total solar eclipses, except that of last January which was visible in Turkestan and for which the weather-conditions seemed likely to be so unfavorable that it was not worth while preparing for it. There have been ten expeditions in all, providing for the observations of eight eclipses. All have been successful except the Japanese and the Labrador expeditions, for which the sky was totally obscured by clouds. The greatest value of the many successful observations secured lies in the continuity of the series.

As is well known, a total eclipse will occur on January 3, 1908, visible in the central Pacific Ocean. The shadow-path crosses but two known portions of land, Flint and Hull Islands. The conditions are much more favorable at the former, the eclipse occurring at about 11.18 a.m., local mean time, with the sun at an altitude of 75°, and the duration of totality being approximately four minutes. Flint Island is in longitude west

151° 48′ and latitude south 11° 26′, and is 389 geographical miles N.N.W. of Papeete, Island of Tahiti. While the weather conditions at that time of the year are not especially favorable, yet the great altitude of the Sun, the long duration of totality, and the desire to give continuity to the observations, and if possible to bring certain lines of investigation to a close, led Director Campbell to plan for the sending of an expedition to observe the phenomenon. He was fortunate in enlisting again the interest of Wm. H. Crocker, Esq., of San Francisco, who defrayed the expenses of five previous expeditions.

The problem of transport to and from Flint Island of the observers, apparatus and supplies was unusually difficult. No steamers sail regularly to the island, and it was not found possible to arrange for a steamer passing within a few hundred miles of the island to divert its course in order to land and re-embark the expedition. The matter was brought to the attention of the Navy Department of the U.S. Government, and they most generously undertook to meet Director Campbell's requirements, by providing a war vessel to transport the expedition from Tahiti to Flint Island and return. The ship assigned to this duty is the gun-boat Annapolis. It will be under the personal command of His Excellency Governor Moore, U.S.N., of the Island of Tuituila, Samoa. The accommodation on board the Annapolis is limited, and the number on the expedition must not exceed twelve.

It seemed very desirable to Director Campbell that a bolometric survey of the corona should be undertaken on this occasion, in continuation of Professor Abbot's observations at the eclipse of 1900. As Professor Abbot is the astronomer best fitted to undertake this work the Director suggested to Secretary Walcott, of the Smithsonian Institution, and to Professor Abbot, that they send an expedition for this purpose, the two expeditions to be independent scientifically, but travelling and subsisting together. The Secretary has most fortunately arranged for this expedition, which will consist of Professor Abbot and one assistant. It is expected that Messrs. Campbell, Aitken, Perrine and Albrecht, of the Lick Observatory staff; Professor Lewis, of the Department of Physics, University of California; Professor Abbot and his assistant; and one or two assistants not yet definitely determined upon will sail from San Francisco on November 22 for Tahiti, at which place they will probably arrive on December 4. The Annapolis will at once convey the party to Flint Island. The expedition should re-embark about January 5 for Tahiti, and leave the latter port on January 13 for San Francisco. One or two mechanics and servants and one or two workmen will be secured either at San Francisco or Tahiti. The coronal photographs with the camera of 40 feet focus pointed directly at the Sun will be continued. Likewise the photographs with a camera of aperture 5 inches and focal length 70 inches. The large-scale records will·necessarily be of especial interest for studying the structure of the inner corona, and those on a smaller scale for that of the outer corona. There will be two groups of cameras-four in each group-for photographing the region east and west of the Sun, along the line of the Sun's equator, for the purpose of recording the presence of any bodies such as intra-Mercurial planets which may exist there. Dr. Perrine's work in Sumatra in 1901 and in Spain in 1905, though hindered by light clouds in both cases, has made it probable that no intra-Mercurial planets of considerable size exist. Stars were recorded down to the 8th magnitude in substantially the entire region searched. If planets fainter than the 7th or 8th magnitude exist there would have to be an enormous number of them to provide sufficient mass to account for the anomalies in the motions of Mercury's perihelion. Consequently any small bodies that may be discovered near the Sun would be interesting on their own account rather than in connection with the motion of Mercury. The cameras are capable of recording 9th and 10th magnitude stars with an exposure of three or four minutes, and it is hoped that favorable conditions on Flint Island may enable the record to be carried to this limit. The recent mathematical researches of Professor Seeliger, apparently showing that the material responsible for the Zodiacal Light exists in sufficient quantities to explain the anomalies in Mercury's motion, together with the photographs obtained by previous expeditions from the observatory, practically have brought the famous intra-Mercurial problem to a close.

Objective-prism spectrographs will be used to record the spectrum of the Sun's edge, near the instants of beginning and ending of totality. One of these will have exposures on a fixed plate to record the uneclipsed crescents of the Sun's atmosphere. The other will make the exposure on a continuously moving plate, in order to record the changing spectrum of the Sun's edge as the edge is gradually covered at contact two and uncovered at contact three. The advantage of the moving plate is that it gives a continuous record of the changes which occur, whereas the fixed plate gives an integrated effect for a short interval, while what the spectrum was before and after exposure is unknown. The method was applied by Director Campbell at the eclipses of 1898, 1900 and 1905, and the records obtained show in the most beautiful manner how the dark lines change to bright ones and at what depths in the Sun's atmosphere they begin and end. Indeed one can hardly conceive a more striking method of exploration. In this connection I may say that the study of the eclipse photographs of 1905 is proceeding satisfactorily, and it is hoped that all the results will be published in the near future. There will be a low-dispersion spectrograph for recording the general structure of the corona. The coronal spectrograms obtained in Sumatra and Spain, showing the ordinary Fraunhofer solar type of spectrum for the outer corona, were taken through thin clouds, and it is hoped to eliminate the possible effect of clouds in modifying the apparent type of the spectrum. There will be another spectrograph for the determination of the wave-length of the green coronal line, and still another for studying the form of the incandescent gaseous stratum responsible for that green line.

The polarigraphs used by Dr. Perrine in Spain will be taken to Flint Island. The study of the brightness of the corona as a whole will also be undertaken. Professor Lewis has a large quartz spectrograph, with which he will attempt to record the ultra-violet spectrum of the corona. The expedition will be supplied with auxiliary instruments for determining the time,·and latitude and longitude for the adjustment of the spectrographic apparatus.

Flint Island is approximately half-a-mile wide and 2½ miles long. Its surface is about 14 feet above the sea level. The population consists of an English foreman and twenty or thirty natives, all of whom are engaged in the copra industry.

Observation of Double Stars; Correction to Mr. Espin's Note

In April 1899 Professors R. G. Aitken and W. J. Hussey began a systematic search for new pairs of double stars in that portion of the sky north of declination –22°. During 1899 comparatively little was done, but since then no occasion has been lost in pushing the search. Professor Hussey withdrew from the work on his leaving the observatory in 1905, and since then Professor Aitken has continued the work alone. The great refractor is used on four nights each week for spectrographic work, on Saturday until 10 p.m. for visitors—who come in great numbers—and the other time is devoted to double star observations. In the great catalogue of double stars prepared by Burnham and very recently issued, Burnham gives a list of 1336 discovered by himself. Counting 137 stars just announced in Lick Observatory Bulletin No. 117, Hussey's discoveries amount to 1337. Of these, however, 10 are of southern doubles and have not been properly measured. Professor Aitken has already published more than 1500 new pairs, and has over 100 more ready to publish, and thus he now is decidedly in the lead in this work. His great survey will likely be completed in two years.

Besides this work the measurement of binaries has been kept up-to-date, and Dr. Aitken's card catalogue of these objects is a veritable mine of interesting information.

On account of the great resolving power of the 36-inch telescope-and the keen eye of the observer—many interesting extensions of the labors of other observers have been made. The writer has been given some interesting examples. The star 29 Hydrae was pronounced double by Burnham 20 years ago. It is now found that the principal component, of 6.5 magnitude, is itself a close double; and since all the components have the same proper motion, one can conclude that they form a physical system. Star number 75 in Espin's list in A.N. 3784, with R.A. 1h 15m.9, declination + 46° 29′ (1880) is given by its discoverer as double. It is found to be triple. Star 370 = B. D. + 52°.2963 in Burnham's list is given as a binary, being an eighth magnitude star with a ninth magnitude companion. It is now found to be quadruple.

Professor Aitkin informs me that there is a mistake in Rev. T. E. Espin's "Notes on Double Stars" in the last number of the JOURNAL, and I cannot do better than give here a note of correction prepared by Dr. Aitken:

"The Rev. Mr. Espin is usually correct in his statements relating to double stars, but he is mistaken in thinking that the pair B. D. + 29°.1821, near Cancri is new. It was discovered by me on February 20, 1903, and is included as A 553 in the list printed in the Lick Observatory Bulletin No. 50. Possibly a mistake in bringing forward the star place accounts for the failure to recognize the identity of the two pairs, for the correct position for 1900 is R. A. 8h 39m 53′, decl. + 29° 22′.

"My measures give

1903.16 70°.4 2″.44, 3 nights, 36-inch.

There is no other similar pair in the vicinity."

Beside the work on double stars, micrometric measurements on the comets and satellites too faint for the 12-inch telescope are regularly made with the 36-inch. At present the satellites of Mars and Uranus are being observed. and Kopff's comet 1906 b = 1905 IV has been followed from April 20 to July 3. At the last observation the object was so faint—about the sixteenth magnitude—that when the absence of the Moon allows another observation to be made it will probably be invisible.

The Meridian Circle

The meridian circle belonging to the observatory has an aperture of 6.4 inches, and is one of the fine productions of the Repsolds. It was mounted twenty years ago, and for three quarters of that period has been in active use. It is in charge of Professor R. H. Tucker, who, before joining the observatory staff in 1893, had had much experience in meridian circle work at the Dudley Observatory, Albany, N. Y., and the Cordoba Observatory in the Argentine Republic. A skilful observer may secure good results with an inferior instrument, but the best results can only be obtained with a first class instrument in the hands of an experienced and able observer. This instrument has been investigated in great detail, and the final test, that given by the results obtained in its use, has shown that it is of the highest mechanical design and construction.

There are certain classes of errors that remain constant for one instrument, and the investigation of these can be expected to give data which will be useful for a long period of time, and for the various observers who may use the instrument. The flexure and the division error are included in this class. These have been extensively investigated for the meridian circle. The first is of very small size, certainly less than 10″. The measurement of every division of the graduated circles is a labor too great for any single observer if all his time for a term of years were to be devoted to that alone. The fixed circle of this instrument has been measured completely down to the 10′ divisions; the movable circle down to 3°. Also large numbers of the 2′ divisions have been measured, so that corrections can be applied, either directly for the divisions used, or by interpolation for intermediate divisions. Other classes of instrumental errors are constantly determined, as well as the errors of the investigator, the result perhaps of personal peculiarity in the first place and confirmed by long habit eventually.

The instrument is now being used for work of a fundamental character, in which the greatest refinement of methods is necessary. Few observatories undertake this line of work, but about once in a generation the need becomes somewhat pressing for a revision and adjustment of our fundamental system of star places.

Two volumes of meridian circle measurements have been issued and a third volume is now going through the press. The first volume contains observations of standard stars mainly. The second includes a long list of southern stars, and the stars for Eros which were observed at many other observatories. The present volume, in addition to miscellaneous lists, contains the stars of the Zodiacal Catalogue, which are also to be observed elsewhere. In all about 25,000 observations of star places have been completed and prepared for publication.

The work of this department has naturally included the rating of the fine clocks, of which the observatory has six, including a new Riefler, enclosed in air-tight glass case and wound electrically.

The work at the present time will be a contribution to the knowledge of the positions of the standard stars, just as previous work has contributed to that of the greater mass of less prominent stars. It is hoped to round out consistently a programme that has included a number of detached and a number of closely related schemes.

The Keeler Memorial Volume

James Edward Keeler was appointed director of the observatory in June 1898, and died in August 1900. In the short interval his work with the Crossley Reflector was such a distinguished success that it produced a decided revival in the use of such instruments.

For some time a Memorial Volume has been in preparation, the work being in charge of Professor Perrine, who took over the reflector at the decease of the late director, and completed his programme, of which all but one third had been carried out. The volume, which will be one of the regular publications of the observatory, will contain seventy illustrations, representing the most interesting nebulae and clusters within reach of the instrument at its present latitude. Great difficulty has been experienced in securing proper reproduction of the original negatives, as it is desired to show not only the detail of the denser portions but the fainter parts as well. One fourth of the engraving has been done and the rest will be secured as soon as possible.

The volume will also contain a brief memoir, a reprint of Keeler's well-known paper on the Crossley Reflector and a catalogue of new nebulae discovered on the negatives. On the 103 plates taken 744 new nebulae were found. Each of these plates covers three-fourths of a square degree and as they were well distributed throughout the sky a simple calculation leads to the conclusion that over 500,000 nebulae are within the reach of the Reflector with an exposure of four hours.

Paper photographs, no matter how carefully made, are not suitable for original research, which should be made with glass plates. It is hoped that means will be found to prepare six or eight sets of glass positives of these Crossley photographs of nebulae and star clusters, to be deposited, for the use of investigators, with leading learned societies and institutions throughout the world.

Reference has been made above to alterations made in the optical system of the Reflector. Its mounting was entirely remodelled, according to Dr. Perrine's plans, in 1903. In 1904 Saturn's ninth satellite was photographed and soon after this followed the discovery of Jupiter's sixth and seventh moons.

For some time Dr. Perrine has been investigating the distortions of photographic films, preparatory to undertaking his parallax programme. The discordance between successive photographic plates of an object is many times greater than the errors of measurement. Much of the trouble lies in the structure of the photographic film. If the difficulty can be overcome a great advance in the means of research will be attained.

The above notes, though somewhat extensive, by no means exhaust the activities of the Lick Observatory. Systematic studies of the different classes of variable stars are in progress, an important contribution to this subject by Dr. Albrecht having recently appeared. An investigation is also being made into the Zodiacal Light; while no new object appears in the heavens—such as a nova or a comet—without being promptly attacked. In cases of emergency the entire resources of the observatory are turned to the study of a new phenomenon.

Another matter which strongly impresses the visitor is that the doors of the observatory are never closed, and at almost any hour of the day or night someone can be found busy in observation or investigation. Indeed the energy, enthusiasm and earnestness of purpose of the Director are reflected throughout the entire institution; and the spirit of investigation seems to saturate the rare air about the summit of the mountain.

Lick Observatory,
Mt. Hamilton,
July 20, 1907. ✶

Astronomical Art & Artifact

Encountering Astronomy's Past Through Replications in Museums: Useful, or Not?

by R.A. Rosenfeld, FRASC,
(r.rosenfeld@rasc.ca)

Abstract

This paper examines the roles and status of copies of apparatus and documents in astronomical museums. Can they be effective?

Copies are *Everywhere*

What is an astronomical copy, and for that matter, what is an original?

In common usage, the label "copy" often conveys a neutral or negative value, in contrast with the positive connotations conferred by the label "original"—such as a "mere copy," contrasting with a "genuine original." Astronomical examples could include: i.) the lunar images originally appearing in Galileo's *Sidereus nuncius* (1610), which became progressively degraded in copies published in subsequent 17th-century editions (Galileo 1656 II, 15); ii) original *jetons* from 1667 struck to mark the founding of the Paris Observatory, which could be considered intrinsically more valuable than 19th or 20th-century copies (restrikes) of the coin; and iii), the iconic Questar Standard Maksutov-Cassegrain telescopes (1954–), which are valued much more highly than now defunct manufacturer's optically and mechanically less impressive "copies" introduced in the latter 1990s (Gross 2021, 6.2, 6–10).

Originals do not hold primacy everywhere in astronomy, however. The astronomical images we either analyze or admire invariably come to us as "copies," and we hardly register the fact. It could scarcely be otherwise in the era of digital images. In the world of emulsion astrophotography, which seems an eon ago, an "original" print from an "original" negative possessed a real meaning, which it would not have in the present universe of digital astrophotography, yet even in the former era of film and glass plates most people saw astronomical images through copies. This would only have entailed difficulties if elusive features of astronomical phenomena were lost through the processes used to replicate the images (as occasionally happened). In such cases formally printed and circulated copies could still be imbued with positive associations, for they allowed more people to see an image than if they weren't distributed, however much the prints lacked the resolution of the original negative.

When astrophotographers exchange images, or post them to fora for display and comment, or submit them to the Royal Museum Greenwich Astronomy Photographer of the Year competition, or the NASA Astronomy Picture of the Day (APOD), or for possible inclusion in the *RASC Observer's Calendar*, they are circulating and submitting copies. Modern astronomy seems awash in these images, and many peoples' diet of astronomical phenomena consist almost entirely of these copies. They truly are everywhere. But what do we mean when we label something as either an "original," or a "copy?"

The Difficulties of Definitions

Formulating simple black & white (either/or) definitions of "original" and "copy" to cover all cases in astronomy where they could apply is simply impossible. Readers would be right to even question the appropriateness of the labels in some cases (such as in digital astrophotography).

Reliable popular dictionaries of astronomy don't give over any of their valuable real estate to even the briefest of definitions (and they're none the weaker for it, for their remit is to cover current *astronomical* nomenclature; e.g. Daintith & Gould 2006; Ridpath 2018).

The Oxford English Dictionary gives numerous definitions, several of which are seemingly serviceable for discussing "original" and "copy" in astronomical contexts:

> "**original**, n. & adj….That is the origin or source of something; from which something springs, proceeds, or is derived; primary...designating the thing, as a document, text, picture, etc., from which another is copied or reproduced; that is the original...**copy**, n. & adj...A transcript or reproduction of an original...A writing transcribed from, and reproducing the contents of, another; a transcript...A picture, or other work of art, reproducing the features of another" (OED—bolding added for clarity).

These are fairly close to what dictionaries of art offer:

> "**original** 1. an artist's independent creation. 2. a work of art considered as a PROTOTYPE, as that from which copies and reproductions have been made...3. the person or an object that is represented in an artist's work...**copy** 1. any reproduction or facsimile of an original work of art, done in the same art form although not necessarily in the same size or with the same materials...2. any one of a series of reproductions, especially printed reproductions, of the same original work. 3. in printing, any written or typed text or illustrative material (as a picture, photograph, or drawing) that is to be reproduced..." (Mayer 1991, 100, 286—bolding added for clarity).

Again, apparently useable. What these definitions have in common is that they are black & white, either/or. That may be seen as a desirable quality for establishing clear distinctions between terms (something one appreciates when first striving to achieve an orientation in a subject), but the definitions are wanting in subtlety; they lack gradations of light and shade. This poor applicability of these definitions to astronomical materials, particularly historical artifacts, quickly becomes clear when actual things are investigated.

Instances of Originals, or Copies…

The week after this work was completed, the Cathedral of Notre Dame de Paris (ca. 1163–ca. 1260, with subsequent changes and alterations; burnt 2019) is scheduled to officially reopen, after its restoration following a fire that consumed much of the lead roof, its wooden supports, damaged some of the stone, and generally weakened the structure. The decision was made to reconstruct some version of what was lost, reusing surviving materials to the greatest extent possible, and, when that couldn't be accomplished, using replacement materials as close as possible to the originals, and using traditional techniques. The story has been a dramatic one.

Notre Dame contains little astronomical iconography, but nearly two decades before its conflagration a very similar case enveloped a Canadian structure with UNESCO world-heritage recognition for its astronomical ceiling, St. John's Anglican Church in Lunenburg, Nova Scotia (Figure 1; 1754–1763, with subsequent changes and alterations 1840s, 1870s; burnt 2001; Turner 2005). It too was reconstructed to its pre-fire appearance over a similarly short time frame (reopened in 2005), using surviving materials where possible, sympathetic modern replacements, and traditional techniques. In both cases the rebuilt structures are amalgams of original components and reconstructions, which are so skillful that visual means alone are frequently inadequate to tell which portions are original and which copies.

Figure 1 — Photograph of a portion of the celestial ceiling, ca. 1870(?), in the chancel of St. John's Anglican Church, Lunenburg. Photograph by R.A. Rosenfeld, 2014.

Older telescopes and apparatus that remain in professional use are often amalgams of the new and the old, featuring original parts married to replacement or updated components. The Great Melbourne Telescope, which saw first light in 1869, from the 1950s–ca. 2003 was upgraded as needed for professional research until a bushfire destroyed the Mount Stromlo Observatory, but by then all that dated back to the Victorian era was chiefly the polar axis (Gillespie 2011, 144–167). Continued scientific utility is the driver of those changes, and there is usually no concern to make the new look like the old (but sometimes effort was spent making the old look like the new!). Matters are different with vintage or antique telescopes and apparatus in institutions with mandates to promote the history of science, or education and public outreach; in such settings, instruments are often restored to ensure both usability (or potential usability) and an appearance in accord with an earlier state, in some cases "as new" (which can be ca. 1650, or 1850, or 1950), or as the instrument was in its research heyday. Collectors with an expertise in restoring their own and others' instruments frequently must replace some missing or damaged parts, and the usual course is to reproduce them so that they function and look like the originals. Here too it can be difficult to tell from visual inspection alone what's original, and what's a copy or reconstruction.

What this means is that many "original" astronomical artifacts are not wholly so. It is probably wise to indicate to what extent something is "original," although even that is not always straightforward. Often it comes down to a matter of judgement.

What of the examples of astronomical originals given earlier; the etchings of the Moon in Galileo's *Sidereus nuncius* (1610), Louis XIV's Paris Observatory *jetons* (1667), and the Questar Standard Maksutov-Cassegrain telescopes (1954–present)? These are all original astronomical artifacts, but they can also be considered copies. None of them were meant to be one-offs, but every surviving example was (is) produced as one of many. Galileo's etchings were copies of his ink-wash drawings, the 1667 *jetons* were copies of what was engraved on the dies, and the Questars are all copies of the successful prototype (early 1950s) developed by Lawrence Braymer and colleagues. Examples of the book, the coin, and the telescope are both originals and copies. And, by the same token, the copies of all of these, the 17th-century copies of Galileo's etchings, the 19th- and 20th-century restrikes of the *jeton*, and the Meade ETX are themselves original artifacts of their times. Why should life be easy?

Museums

Copies can be found in many museums. They were included along with originals in Sir John Soane's Museum

(1808/1833–) from the start (Furján 2011), and the copies now on display in the Cast Courts in the Victoria and Albert Museum was amassed in the 19th century for teaching purposes (Lending 2017). Copies allowed museum goers some experience of important artifacts that were not local without the great inconvenience, expense, and sometimes danger of foreign travel. Many other examples could be cited.

Science centres and museums of astronomy, offshoots of the earlier universal museums, often display copies. Some of them have few, but others rely on them a great deal. The twin museums founded by Fuat Sezgin to celebrate the Islamic contribution to science, one in Istanbul and the other in Frankfurt am Main, rely entirely on high-quality reproductions (Sezgin & Neugebauer 2010). This collection strategy makes it possible to present in both locals the best of the the Islamicate tradition of medieval and early-modern astronomical instruments from around the globe. One can quibble with the overly whiggish inspiration of the project, but the presentation is apparently quite effective (Clifton 2024). Nearly every artifact in the galleries devoted to Leonardo da Vinci in the Museo Nazionale della Scienza e della Tecnologia Leonardo da Vinci in Milan is either a copy, or a reconstruction, or a scale model. It could hardly be otherwise, given that many of Leonardo's machines and art works don't survive, or merely existed on the page in a codex belonging to another collection in another country. The quality of the Milan museum's reproductions of the openings from Leonardo's notebooks is quite high—seen from behind their display windows, they look like they really could be more than half a millennium old.

Likewise the Griffith Observatory's copy of one of Galileo's surviving telescopes in the Museo Galileo in Florence is convincing in appearance,[1] as is the copy of Isaac Newton's earliest surviving telescope at the Royal Museums Greenwich. And the 7th Earl of Rosse had his ancestor the 3rd Earl of Rosse's Leviathan of Parsonstown (72-inch reflector, first light 1845) recreated 1996–1999 (Tubridy 1998). Besides copies supplying in some fashion the material presence of the original, "standing in" as it were for originals which may be too valuable or fragile to travel, or be too fragmentary, the process of producing them may supply information about their manufacture which is otherwise inaccessible. They can also be used for the experimental archaeology of astronomy, to provide at a minimum the hands-on experience of what it was like to do science with such instruments.

Copies undoubtedly have their uses. But what should be their status as objects? To ask that question, particularly as regards the relationship of copies to originals, is at its basis a philosophical question. One recent approach is that offered by the philosopher Carolyn Korsmeyer in her monograph *Things: In Touch with the Past* (2019). She writes of the sense of touch being crucial to the experience of originals (a sense which is undervalued in the literature in favour of the primacy of sight). Of course, many, or even most originals in museums cannot be touched, so she has developed the idea that whatever proximity to an original a display allows is equivalent to being able to touch the original, particularly if that proximity is close enough for the museum goer to potentially reach out and touch the artifact if it were allowed. She argues that there is a special quality to originals, an aura conveyed by their presence which is lacking in the presence of copies, and that this is something real and inherent in originals. There *is* something about originals, and aura will do as well as any term to describe whatever it is.[2] Her idea of being in proximity to an original as equivalent to touching it stretches credulity, and would be unnecessary if the originals' presence is what counts. And why wouldn't sight still be the primary sense for feeling awe in the presence of an original? And aura may be wholly or largely a product of belief in the authenticity of the artifact, that is, it's a creation of the viewers' psychology rather than something inherent in the object. And what of the many artifacts which are both original, and copy? It is possible to feel awe in the presence of a copy, many transcend being merely simulacra of something else, pallid, bloodless imitations of real things.[3]

Copies in our Museum

Most of the artifacts in the RASC's Dorner Telescope Museum are "originals," but there are some copies of significant artifacts from other institutions to support the DTM's mission of "telling the story of the telescope in Canada." Amongst these are skillful reproductions and recreations by several RASC members.

Copies by Réal Manseau of 17th-century historical apparatus include:

DTM 13.20190820 (Figure 2), a reproduction (2009) of two of Galileo's (1564–1642) telescopes, the 1677 plaque for the broken objective lens, and the Tribuna di Galileo display stand ca. 1841, now at the Museo Galileo, Florence (inv. 2427-2429); and

DTM 12.20190820 (Figure 3), a reproduction (1987) of the reflector by Isaac Newton & John Wickens 1671-1672 (aka "Isaac Newton's third telescope"), now in the collections of the Royal Society (Collections, MO/1) (Manseau 1999).

To provide some context for these are copies of paper artifacts. Among these are:

DTM 90.20241028 (Figure 4), a reproduction (2024) of one of Galileo's 1609 inkwash lunar sketches, now in the Biblioteca Nazionale Centrale di Firenze, MS Gal. 48, fol. 28r;

DTM 91.20241028 (Figure 5), a reproduction (2024) of Galileo's "shopping list," on the verso of a letter from Dr. Ottavio Brenzoni 1609 November 23, now in the Biblioteca Nazionale Centrale di Firenze, MS Gal. 88, fols. 106r–107v (Strano 2012); and

Figure 2 — Réal Manseau's copy (2009, DTM 13.20190820) of Galileo's (1564-1642) only surviving telescopes, the 1677 plaque by Vittorio Crosten for the cracked objective lens reputed to have been used for the ***Sidereus nuncius*** observations, and the ca. 1840s display stand made for the Tribuna di Galileo, after the originals now at the Museo Galileo, Florence.

Figure 3 — Réal Manseu's copy (1987, DTM 12.20190820) of the reflector by Isaac Newton & John Wickens 1671–1672 (aka "Isaac Newton's third telescope"), after the original now in the collections of the Royal Society, London.

Figure 4 — R.A. Rosenfeld's copy (2024, DTM 90.20241028) of one of Galileo's 1609 inkwash lunar sketches, after the original now in the Biblioteca Nazionale Centrale di Firenze, MS Gal. 48, fol. 28r, crayon on paper.

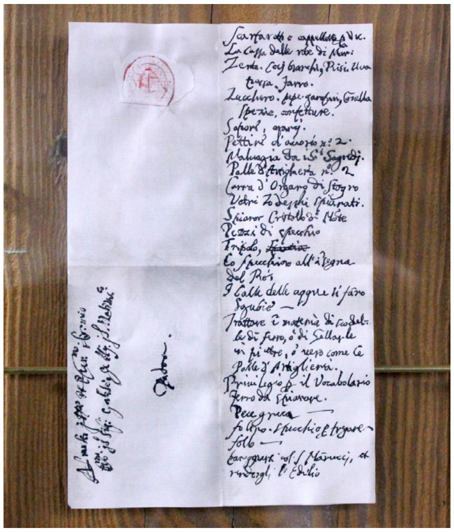


Figure 5 — R.A. Rosenfeld's copy (2024, DTM 91.20241028) of Galileo's "shopping list," on the verso of a letter from Dr. Ottavio Brenzoni 1609 November 23, after the original now in the Biblioteca Nazionale Centrale di Firenze, MS Gal. 88, fols. 106r–107v, pen & ink on paper.

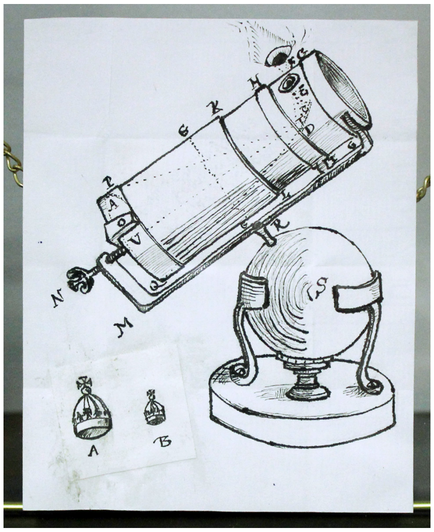
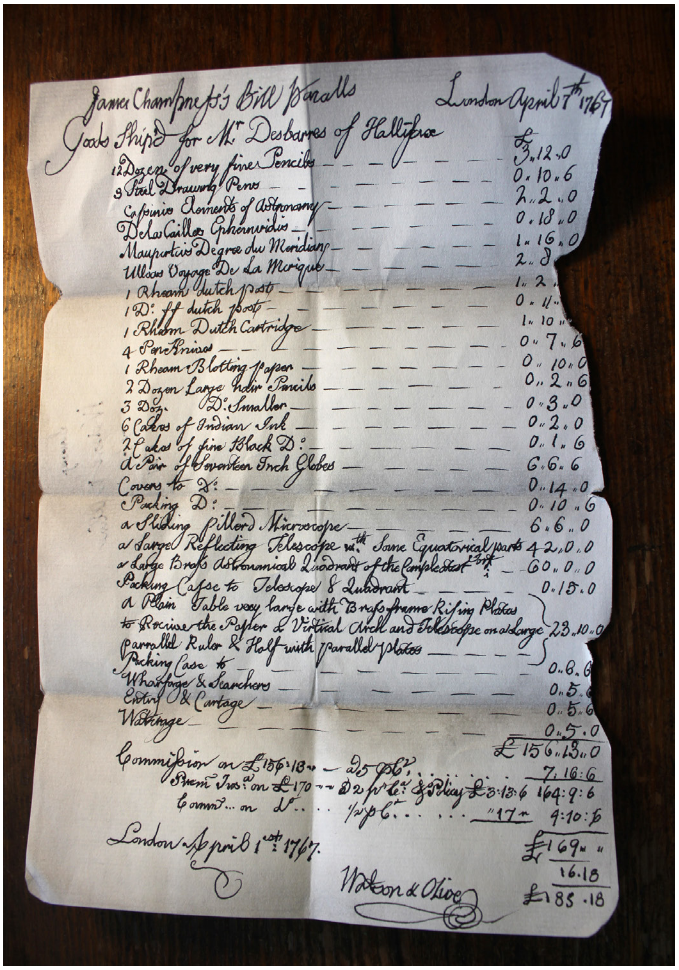


Figure 6 — R.A. Rosenfeld's copy (2024, DTM 94.20241028) of Henry Oldenburg's drawing of 1672 of Isaac Newton's Reflecting Telescope, after the original now in London, Royal Society Archives, Early Letters N1/37/003, pen & ink on paper.

DTM 94.20241028 (Figure 6), a reproduction (2024) of Henry Oldenburg's drawing of 1672 of Isaac Newton's Reflecting Telescope, London, Royal Society Archives, Early Letters N1/37/003 (Fransen et al 2019).

DTM 90.20241028 is in crayon (a departure from the original), and DTM 91.20241028 and DTM 94.20241028 are in pen & ink, like the originals. The lunar drawing shows what a skillful observer could see with such a telescope (stitch together would be more accurate, to borrow a phrase from digital astrophotography), the shopping list includes telescope making tools Galileo was keen to acquire, and the drawing of Newton's telescope is the one which was widely distributed to broadcast (and safeguard) his invention. Also displayed near

Figure 7 — R.A. Rosenfeld's copy (2008, DTM 96.20241028) of a copper-plate engraving of the Marquis de Chabert's temporary Observatory at the Fortress of Louisbourg 1750–1751, after de Chabert 1753, p.1, pencil, pen & ink, printing ink, and watercolour on paper.



James Champness's Bill Parcells London April 7th 1767

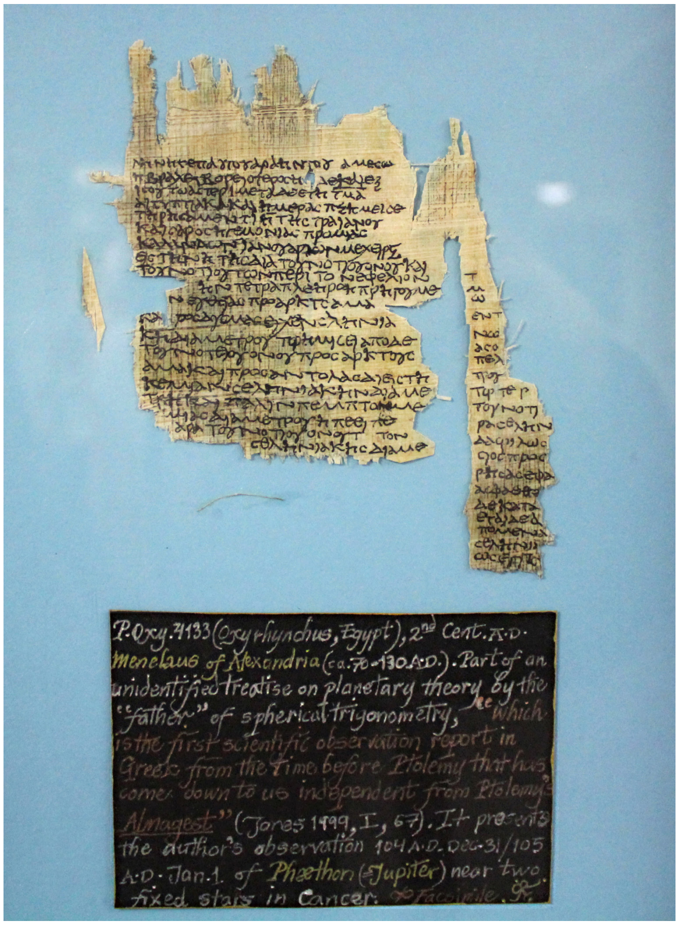
Goods Ship'd for Mr Desbarres of Hallifax

	£
12 Dozen of very fine Pencils	3.12.0
3 Steel Drawing Pens	0.10.6
Cassinis Elements of Astronomy	2.2.0
De La Cailles Ephemerides	0.18.0
Maupertuis Degree du Meridian	1.16.0
Ulloas Voyage De La Merique	2.8
1 Rheam dutch post	1.2.
1 D°: ff dutch post	0.11.
1 Rheam Dutch Cartridge	1.10.
4 Pen Knives	0.7.6
1 Rheam Blotting paper	0.10.0
2 Dozen Large hair Pencils	0.2.6
3 Doz. D°: Smaller	0.3.0
6 Cakes of Indian Ink	0.2.0
2 Cakes of fine Black D°:	0.1.6
A Pair of Seventeen Inch Globes	6.6.6
Covers to D°:	0.14.0
Packing D°:	0.10.6
a Sliding pillerd Microscope	6.6.0
a Large Reflecting Telescope with Some Equatorical parts	42.0.0
a Large Brass Astronomical Quadrant of the Compleatest Sort	60.0.0
Packing Case to Telescope & Quadrant	0.15.0
A Plain Table very large with Brass frame Rising Plates to Receive the Paper & Virtical Arch and Telescope on a Large Parralel Ruler & Half with parallel plates	23.10.0
Packing Case to	0.6.6
Wharfage & Searchers	0.5.6
Entry & Cartage	0.5.6
Watrage	0.5.0
	£156.13.0
Commission on £156:13.. – at 5 pCt.	7.16.6
Prem Insa on £170 -- @ 2 pr Ct & Policy £3:13:6	164:9:6
Comm... on D°... 1/2 pCt... "17"	4:10:6
	£169" "
	16.18
	£185.18

London April 1st 1767.

Watson & Olive

Figure 8 — R.A. Rosenfeld's copy (2024, DTM 97.20241028) of the Bill of lading (London to Halifax) listing astronomical equipment from James Champness for Joseph Frederick Wallet DesBarres's Castle Frederick Observatory, 1767, after the original now in Ottawa, Library and Archives Canada, DesBarres Papers, Series 5 (M.G. 23, F1–5, Vol. 6) Accounts, 1767–1794, 1252–1253, pen & ink on paper.



P.Oxy.4133 (Oxyrhynchus, Egypt), 2nd Cent. A.D.
Menelaus of Alexandria (ca. 70–130 A.D.). Part of an unidentified treatise on planetary theory by the "father" of spherical trigonometry, "which is the first scientific observation report in Greek from the time before Ptolemy that has come down to us independent from Ptolemy's Almagest" (Jones 1999, I, 67). It presents the author's observation 104 A.D. Dec. 31/105 A.D. Jan. 1 of Phaethon (=Jupiter) near two fixed stars in Cancer. Facsimile. R.

Figure 9 — R.A. Rosenfeld's copy (2024, for the DTM) of a papyrus fragment of a treatise on planetary theory attributed to Menelaus of Alexandria (ca. 70–ca. 130 CE), after the original now in Oxford, Ashmolean Museum, P. Oxy.4133 (Oxyrhynchus, Egypt), 2nd century CE, pen & ink on papyrus.

these are reconstructions and one original artifact illustrating the first known use of a telescope for astronomy in Canada (1646; Rosenfeld 2020), an event that partially justifies the inclusion of the Galilean material.

In proximity to DTM 23.20200605, a 5-inch primary mirror Gregorian reflector of ca. 1750 by Francis Watkins, are two copies of two Canadian documents giving context for the presence of such an instrument in the colonial period:

DTM 96.20241028 (Figure 7), a reproduction (2008) of a copper-plate engraving of the Marquis de Chabert's temporary Observatory at the Fortress of Louisbourg 1750–1751, after Marquis de Chabert (=Joseph-Bernard de Cogolin), *Voyages fait par ordre du Roi en 1750 et 1753, dans l'Amérique septentrionale...* (Paris: De l'Imprimerie Royale, 1753), p.1; and

DTM 97.20241028 (Figure 8), a reproduction (2024) of the Bill of lading (London to Halifax) with astronomical equipment from James Champness for Joseph Frederick Wallet DesBarres' Castle Frederick Observatory, 1767, now in Ottawa, Library and Archives Canada, DesBarres Papers, Series 5 (M.G. 23, F1–5, Vol. 6) Accounts, 1767–1794, 1252–1253 (Rosenfeld 2021).

By way of a final example, in the DTM's section of visual observation before the telescope are several copies of observational documents. One (Figure 9) is a reproduction (2024) of a papyrus fragment of a treatise on planetary theory attributed to Menelaus of Alexandria (ca. 70–ca. 130 AD), now in Oxford, Ashmolean Museum, P. Oxy.4133 (Oxyrhynchus, Egypt), 2nd century AD. This, according to Alexander Jones, is "the first scientific observation report in Greek from the time before Ptolemy that has come down to us independent of Ptolemy's Almagest" (Jones 1999, I, 67). Like all the "paper" copies cited in this section, they were made by the DTM Director.

All of the reproductions and reconstructions mentioned here, besides their dual nature as both copies and originals, share a Canadian connection. They are by Canadian amateurs who meant them as tributes to their forebearers in Canada and in Europe, in Antiquity and during the Scientific Revolution. As artifacts in their own right in a museum devoted to the tools of astronomical exploration, they are part of Canada's engagement with astronomy.

Do these copies have an aura, a presence, can they convincingly evoke aspects of the astronomical past? Are they effective for the intellectual and emotional exploration of history? That is for you to decide. ✶

Acknowledgements

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

References

Clifton, G. (2024). The History of Islamic Science and Technology Museum. Bulletin of the Scientific Instrument Society 162 (2024, September), 37

Daintith, J., & Gould, W. (Eds.) (2006). *Collins Internet-Linked Dictionary of Astronomy*. Glasgow: HaperCollins Publishers

de Chabert (=Joseph-Bernard de Cogolin) (1753). *Voyages fait par ordre du Roi en 1750 et 1753, dans l'Amérique septentrionale...* Paris: De l'Imprimerie Royale

Foster, S., & Jones, S. (2020). My Life as a Replica: St John's Cross, Iona. Oxford-Havertown PA: Windgather Press

Fransen, S., Reinhart, K.M., & Kusukawa, S. (2019). Copying images in the archives of the early Royal Society. *Word & Image A Journal of Verbal/Visual Enquiry 35, 3*, 256–276

Furján, H. (2011). *Glorious Visions: John Soane's Spectacular Theater*. London-New York: Routledge, Taylor & Francis Group

Galileo (1656). *Opere di Galileo Galilei...* 2 vols. Bologna: H.H. del Dozza

Gillespie, R. (2011). *The Great Melbourne Telescope*. Melbourne: Museum Victoria Publishing

Gross, G. (2021). *Questar History*. *N.p.*: the author

Jones, A. (1999). *Astronomical Papyri from Oxyrhynchus (P. Oxy. 4133–4300a)*, vols. I–II, Memoirs of the American Philosophical Society 233. Philadelphia: American Philosophical Society

Korsmeyer, C. (2019). *Things: In Touch with the Past*. New York: Oxford University Press

Lending, M. (2017). *Plaster Monuments: Architecture and the Power of Reproduction*. Princeton-London: Princeton University Press

Lowenthal, D. (2015). The Past is a Foreign Country—Revisited. Cambridge: Cambridge University Press

Manseau, R. (1999). Histoire et construction du premier télescope Newton. *JRASC 93, 3* (June), 113–116

Mayer, R. (1991). (Ed.) S. Sheehan, *The HarperCollins Dictionary of Art Terms & Techniques*, 2nd ed. New York: HarperPerennial
OED: Oxford English Dictionary, (Ed.) M. Proffitt et al., copy, n. & adj. Retrieved 2024 December 1.
OED: Oxford English Dictionary, (Ed.) M. Proffitt et al., original, adj. & n. Retrieved 2024 December 1.

Ridpath, I. (2018). *Oxford Dictionary of Astronomy*, 3rd ed. Oxford: Oxford University Press

Rosenfeld, R.A. (2020). Visually Reimagining the First Known Astronomical Use of a Telescope in "Canada": Fr. Bressani's 1646 Eclipse Observation at Sainte-Marie among the Hurons. *JRASC 114, 2* (February), 83–88

Rosenfeld, R.A. (2021). J.F.W. DesBarres's Astronomical Instruments and the Castle Frederick Observatory: Fundamental Documents. *JRASC 115, 6* (December), 252–262

Sezgin, F., & Neugebauer, E. (2010). (Tr.) R. & S. Sarma, Science and Technology in Islam. II. Catalogue of the Collection of Instruments of the Institute for the History of Arabic and Islamic Sciences. 1. Astronomy. Frankfurt am Main: Institut für Geschichte der Arabisch–Islamischen Wissenschaften

Strano, G. (2012). Galileo's Shopping List: An Overlooked Document about Early Telescope Making. In (eds.) A.D. Morrison-Low, S. Dupré, S. Johnston, & G. Strano, *From Earth-Bound to Satellite: Telescopes, Skills and Networks*, Scientific Instruments and Collections, vol. 2 (pp. 1–19). Leiden-Boston: Brill

Tubridy, M. (1998). (Ed.) B. Roden, *Reconstruction of the Rosse Six Foot Telescope, Birr, Co. Offaly 1996–1997*. Birr: Birr Castle

Turner, D. (2005). The Stars of St. John's Church Lunenburg. eCASS. Retrieved 2024 December 1, from www.casca.ca/ecass/issues/2005-me/features/turner/Stars%20of%20St_John%27s.html

Endnotes

1 This instrument was made by Jim and Rhoda Morris. Recent research has shown that their hypothesis that the OTAs were constructed out of wooden staves held together by glue and black cloth has proven erroneous based on further examination of the originals; private communication 2023 October 12 from Dr. Giorgio Strano, curator of the collections at the Museo Galileo of Florence.

2 Bart Fried, the founding President of the Antique Telescope Society, related an instance of this. When ATS members visited the Royal Society, they saw a good copy of Newton's telescope. The artifact had some charisma, but it was as nothing compared to the electrifying effect when the original was brought out.

3 The case for copies as artifacts in their own right is effectively made by Foster & Jones 2020. And Lowenthal 2015, 448–463 offers a better-balanced and more nuanced account of historical difference, historical change, presentism, and the relationship of copies to originals than does Korsmeyer.copies to originals than does Korsmeyer.copies to originals than does Korsmeyer.

CFHT Chronicles

Sometimes Bigger is Better

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

When I write my columns, I often go back to previous columns to make sure that I am not subjecting the readers to a recent repeat in topic. I came to the realization that I have written several times about large programs, my topic for today. Much like this column, each of the previous either announced the naming of a new round of large programs and/or summarized the discoveries of one of the existing programs. As we start CFHT's 46th year, we have another round of large programs, stalwart science strategy dating back over two decades.

CFHT has hosted large programs at CFHT since 2003. The first large program was the CFHT Legacy Survey, or CFHTLS, which started in mid-2003 and finished in 2009. More than 2,300 Megacam hours over 5 years (about 450 nights per year) were devoted to CFHTLS.

CFHTLS had three components: 1) the supernova survey and deep survey, 2) the wide synoptic survey and 3) the very wide survey. With the creativity typical to astronomers, these surveys were known as the SNLS (supernova legacy survey), the deep, the wide, and the very wide surveys. The CFHTLS is a seminal survey for CFHT.

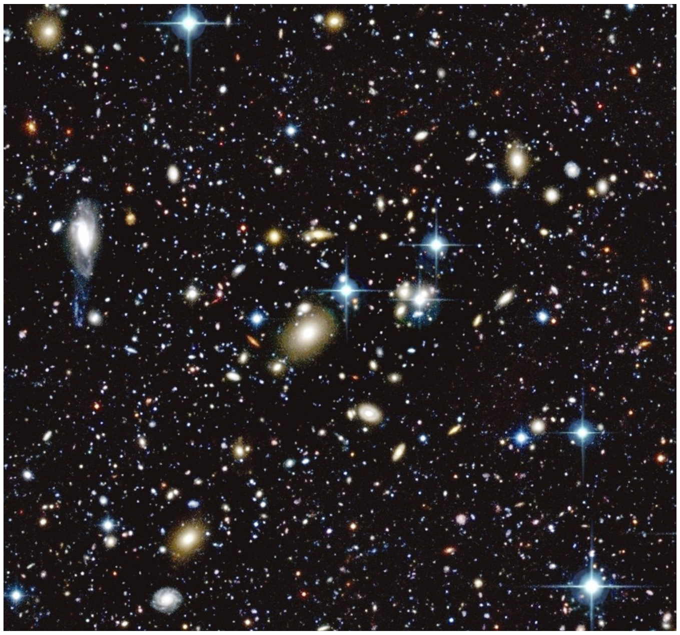


Figure 1 — The CFHTLS Deep Field 1 image with Megacam. (image is at: www.cfht.hawaii.edu/images/CFHTLS-D1-Zoom/)

The CFHT Legacy Survey gave more than just data: it provided a legacy of large programs. The programs range from our solar system to z-7 quasars, from exoplanets to Andromeda, single stars to superclusters. The scientific merit of these programs are also enormous.

In 2008, CFHT moved to smaller and more numerous large programs. The observing time can use several instruments and can be spread evenly over all semesters or concentrated on fewer, specified semesters. Multi-agency proposals are greatly encouraged, with the PIs spread across the CFHT partners. From 2008-2024 A, I counted 20 large programs executed across all 5 of CFHT's instruments. Over the course of the next two years, CFHT aims to execute three more:

UNIONS +: Securing the Imaging Legacy of CFHT
- PI: Dr. Jean-Charles Cuillandre
- MegaCam

PLANETS: PLanets, Atmospheres, and Nativity of ExtraTerrestrial worldS
- PI: Dr. Jean-François Donati
- SPIRou

The Pristine LP: mapping the metallicity of the Milky Way System
- PI: Dr. Nicolas Martin
- MegaCam

Regular readers of this column may recognize the names of the PIs (Principal Investigators), each has featured in a previous column for work stemming out of their previous observations or large programs at CFHT. In the rest of the column, I will provide a summary of each of the large programs and share a science highlight that stemmed from one of our current large programs.

Starting in reverse order, the oldest of these programs is the newest large program, Pristine. The Pristine Survey started in 2015, not as a large program, but a PI program spread across multiple agencies. The goals of the survey are to "gather a large sample of the most metal-poor stars in the galaxy, further characterize the faintest Milky Way satellites and to map the metal-poor substructure in the galactic halo ranging from b ~ 30° to ~78°" according to the paper Pristine Survey I published in 2017.

The survey utilizes the CaHK filter on Megacam in tandem with existing broadband photometry from SDSS. Pristine focuses on the high galactic latitude regions (b> 30°). The filter has a width of about 100 angstroms and covers the wavelength of the Ca, H, & K doublet lines (3968.5 and 3933.7 Å). "When combined with the SDSS broad-band g and i photometry, the team can use the CaHK photometry to infer metallicities down to the extremely metal-poor range." I took the previous sentence directly from the first Pristine paper in 2017 authored by Else Starkenburg and the Pristine team because it nicely foreshadows their current large program.

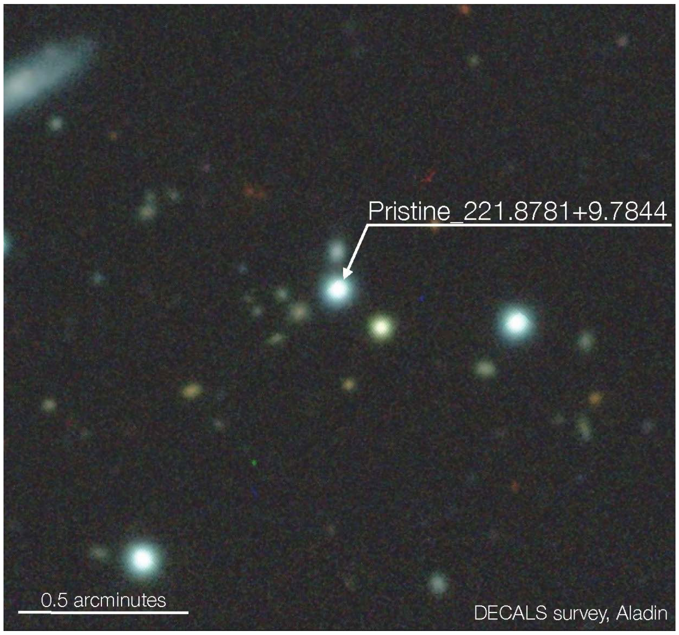


Figure 2 — Sample Pristine image taken from "A PRISTINE Star" news release 2018 October 8, at CFHT. Pristine_221.8781+9.7844 and its surroundings. Credits: N. Martin and the Pristine collaboration, DECam Legacy Survey, Aladin Sky Atlas."

Taken from the Pristine large program abstract, "our program is built around three complementary tiers":

- Tier 1: Provide a full, Gaia-depth coverage of the footprint of the WEAVE Galactic Archaeology halo survey to maximize the construction of the largest sample of the most metal-poor stars ([Fe/H]<–3.0) and their secured follow-up with detailed spectroscopy
- Tier 2: Probe in detail the halo/disk interface in the anticentre direction with a contiguous survey to explore the puzzling presence of a significant fraction of disk-like stars among even the lowest metallicity samples.
- Tier 3: Provide a deep survey of the bright (metal-poor) MW dwarf galaxies and their surroundings to fully determine their metallicity content and their full extent. These observations are essential to place dwarf galaxies in the context of ΛCDM galaxy formation as they are heralded as powerful probes of the cosmological model.

To enhance the legacy value of the Large Program, the team commits to releasing dedicated, regular reduced data and metallicity catalogues. CFHT is uniquely suited to this program with its access to the northern sky as well as the efficient MegaCam/CaHK filter.

While the name PLANETS is new, the team behind the large program is deeply intertwined with SPIRou. Jean-François Donati was the PI of SPIRou and PLANETS is the third large program he spearheaded using the instrument since its commissioning at CFHT in 2018. From the PLANETS' team abstract (text in parenthesis was added by the author for clarity):

Building up on the extensive results of the SLS (SPIRou Legacy Survey) and SPICE (Consolidating & Enhancing the SPIRou Legacy Survey) LPs with SPIRou, PLANETS will now focus on very-low-mass nearby M dwarfs to unveil and characterize their planetary systems, on low-mass pre-main-sequence stars whose accretion processes, inner accretion disks, and inner planetary systems will be investigated to improve our understanding of star / planet formation, and on a handful of exoplanet atmospheres to be repeatedly scrutinized in order to accurately quantify their physical properties. Mostly carried out with SPIRou, PLANETS will utilize key synergies with complementary instruments such as ESPaDOnS, TESS, NIRPS, VLTI/GRAVITY, and JWST to boost science output and go beyond current conceptual limitations in our understanding of the physical processes under investigation.

Lastly, let us talk about UNIONS +, which is the continuation of the UNIONS survey that can trace its lineage to CFIS (Canada France Imaging Survey) and one could argue a thread traces back to the CFHT Legacy Survey started in 2003. The thread is the PI, Jean-Charles Cuillandre, former CFHT resident astronomer who arguably understands the capabilities of MegaCam more than anyone.

From the UNIONS + abstract: The goal of the current proposal is to extend the current CFHT coverage from Dec=30 down to Dec=15. When the original CFIS Large Program began, it was envisioned that the LSST would survey up to Dec=30 in support of Euclid. However in 2022 LSST decided to limit its surveys to Dec=15 over the north galactic cap. This motivates the current extension: this proposal is to image the missing stripe between Dec=15 and Dec=30 (1335 square degrees) in u and r. The north galactic cap covered by UNIONS contains the highest quality sky for Euclid (low on background from the zodiacal light, stellar density, extinction and emission from galactic cirrus), a primary driver for the space survey design. With this extended area, UNIONS will contribute a total of 43 percent of the Euclid ground-based coverage, the remaining 57% coming from LSST. Without the ground-based colours, the Euclid data have greatly diminished value. UNIONS is a collaboration of three major facilities—Subaru, Pan-STARRS, and CFHT.

It is easy to see the large programs through the lens of their science goals only, but the reach of all the CFHT large programs extends farther. Read on….

Galaxies are generally thought of as majestic collections of billions of stars, often arranged on a swirling disk teeming with spiral patterns. Galaxies can also span a wide range of masses; the most massive ones contain hundreds of billions of Suns, while at the other end, galaxies as faint as a few thousand Suns are known. A recent discovery using the Canada-France-Hawaii Telescope and W. M. Keck Observatory on Maunakea, and the Pan-STARRS Telescope on Haleakalā, is now challenging astronomers' understanding of galaxy size.

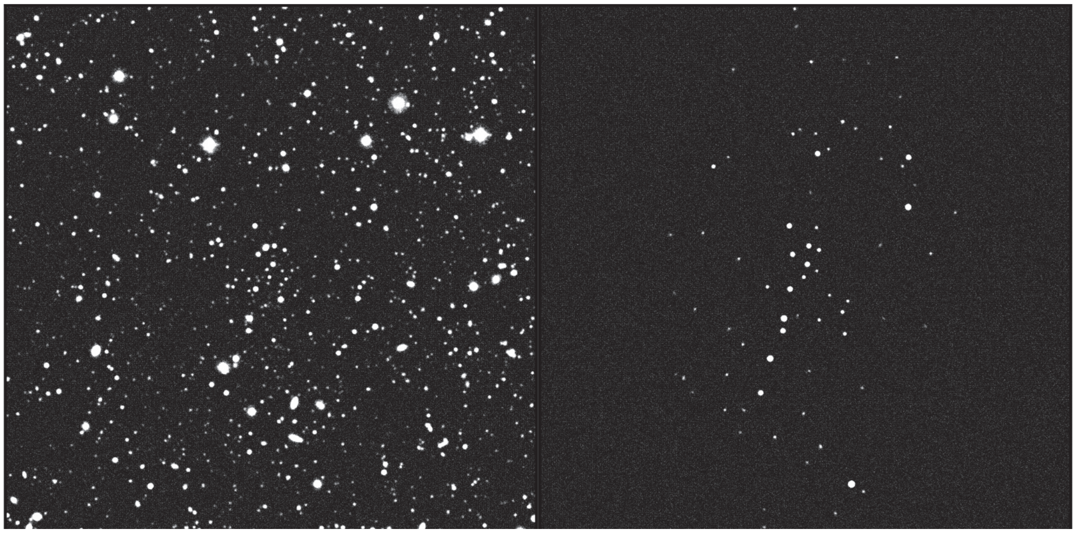


Figure 3 — Hidden in this deep-sky image (left) is a truly miniscule group of stars (right), bound together by their own gravity (and maybe even dark matter!), in orbit around the Milky Way Credit: CFHT/S. Gwyn (right) / S. Smith (left).

An international team of scientists reports in *The Astrophysical Journal* the discovery of an ancient group of stars orbiting the Milky Way. This newly discovered satellite, known as Ursa Major 3/UNIONS 1 (UMa3/U1) consists of only 60 bright stars spread over a volume just 10 light-years across. This is minute compared to the Milky Way, which contains over ten billion stars and measures a hundred thousand light-years across. In comparison, UMa3/U1 is a feeble over-density of ancient stars and the faintest satellite of the Milky Way known to date.

The team obtained the data as part of the Ultraviolet Near-Infrared Optical Northern Survey (UNIONS) at the Canada-France-Hawaii telescope (CFHT). The discovery of UMa3/U1 used UNIONS images from CFHT and Pan-STARRS along with spectra, or rainbows of light, from the W. M. Keck Observatory.

"Being able to detect such a tiny system, with only about sixty stars, speaks for the quality of the UNIONS dataset," explains Simon Smith, a graduate student at the University of Victoria and lead author of the discovery paper. UMa3/U1 consists of stars that are more than 10 billion years old, twice the age of the Sun and roughly two-thirds the age of the Universe. "It is either the faintest ancient star cluster known to date or the faintest and closest known dwarf galaxy ever discovered," says Smith.

The latter scenario is the most exciting. The key difference between the two scenarios hinges on astronomers' ability to determine the presence of dark matter in or around UMa3/U1. Unlike normal matter, dark matter appears not to emit or interact with light or electromagnetic fields. Rather, astronomers infer the presence of dark matter due to its gravitational effects on observable matter.

Confirming the presence of dark matter in UMa3/U1 is therefore critical for determining its origin. Direct confirmation requires stellar spectra of exquisite quality taken over time, which are not yet available. But the presence of dark matter is highly likely, according to a companion study by a group of scientists from Carnegie Mellon University (CMU), the University of Victoria (UVic), and the National Research Council of Canada's Herzberg Astronomy and Astrophysics Research Centre.

This is because UMa3/U1's orbit takes it through the inner regions of the Milky Way, where gravitational "tidal" forces are strongest. Without the gravity of large amounts of dark matter to bind the object together, UMa3/U1 would not be able to survive in its current orbit for even a small fraction of its estimated lifetime.

"Estimating the dark matter content of a dwarf galaxy requires accurate and repeated measurements of its stellar velocities. Remarkably, the spectroscopic measurements obtained with the Keck II telescope are tentatively consistent with those predicted by LCDM. Without dark matter it is not obvious how UMa3/U1 could have been able to survive unscathed for billions of years," says Raphael Errani, a postdoctoral researcher at CMU, and lead author of the theoretical study.

Further observations of UMa3/U1 will shed light on the object's true identity.

"The discovery of UMa3/U1 exemplifies the power of the UNIONS survey," says Todd Burdullis, QSO specialist at CFHT. "UNIONS observations began at CFHT in 2017. The CFHT observations combined with the total integrated data set from Pan-STARRS and observations from the Subaru Telescope create an incredibly deep data set which facilitates the discovery of the faintest of objects." ✶

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

Skyward

Cosmic Thoughts

by David Levy, Kingston & Montréal Centres

Torah study, a meeting among friends and members, takes place on most Saturday mornings. It is the only time that I try to wake up before noon. It is a program of Beth Shalom Temple Center, our synagogue. During each two-hour session we continue our discussion of the Torah, which is composed of the first five books of the Bible. I am a bit uncertain as to my role there. I do begin each session with a poem from my collection of night-sky-related poetry. But once when it was my turn to read from Genesis, a passage described how a group of people stayed on someone's land one night: "Then Jacob offered sacrifice upon the mount, and called his brethren to eat bread: and they did eat bread, and tarried all night in the mount."(*Genesis 31.54)* Without really thinking about it, I added, "And while they were there, they set up their telescopes and enjoyed a lovely evening of stargazing." Most laughed, some were stunned, and possibly one just left.

I love the relationship that the Torah points out that developed between God and Moses. I had the feeling that they had become friends. It appeared that God's anger was kindled frequently, with good reason and that, as our Rabbi pointed out, Moses tried to calm him down. Even though I consider myself agnostic—we cannot know if God even exists—I do take my faith quite seriously. I find it appropriate to think that God has a temper, and even a sense of humour.

As our discussion went on week after week, I suggested the idea that other people might have a similar, personal relationship with God. I suspect that my late wife Wendee did. But before I get to the story I want to tell, it is time to relate just how special Wendee was. Except for eclipses of the Sun and the Moon, Wendee did not come into our marriage with a passion for the night sky, but she built it as time passed. She never tired of urging me to continue and expand my early morning comet-hunting sessions. On occasion, as I looked eastward in anticipation of closing the observatory roof, I would see her smiling face. She did not like to climb out of bed before dawn, but when I asked her if she would like to rise early the morning after I discovered my most recent comet in 2006, Wendee replied that she wouldn't miss that opportunity for the world.

Wendee's passion was not at all limited to looking outward, to the sky. She also encouraged me to look inward. Joining the Torah study was her idea. It began my weekly Saturday early rising. Right from the start I did considerable reading of the Genesis and Exodus chapters, and I began a tradition of reading a poem at the start of each session, which I still do. The Torah study is an activity that remains close to my soul, and I look forward to it always.

Wendee's role in Torah study did not affect just me. "She always had profound words to say," relates Dr. Martin Cohen, the leader of our Torah study group. "I will always remember her insights into scripture and what she felt when she looked up into the heavens, and the potentials she saw in all of humanity."

Now for my purpose in writing this article. I like to think that she used that friendship to her advantage on 2024 April 8, during the total eclipse of the Sun. On April 8, we did catch portions of the incoming partial eclipse. But as the dark umbral shadow of the Moon rushed toward us, the clouds thickened and we could not see the Sun. The sky was darkening quickly, and the temperature was plunging so fast that I could feel it plummet. It seemed obvious to me that we were not going to see the total phase of this eclipse. Then I imagined that in Heaven, Wendee turned to God:

"God," she said, "Why won't you let Doveed see the eclipse?"

"Well," God smiled as he replied, "Doveed hasn't been that good a boy lately. For example, he still doesn't have a handle on my third commandment. He may be trying, but he hasn't got it yet."

"So what?" snapped Wendee. "Let him see the damned eclipse!"

"OK. You're the boss."

In the next minute I saw by far the most dramatic total eclipse I have ever witnessed. The clouds parted magically. There was a spectacular corona, and a lovely prominence at the lower limb of the Sun.

After the total phase of the eclipse was over, I witnessed a spectacular display of sunlight glimpsing its way through valleys on the edge of the Moon, an effect called Baily's Beads. Wendee approached God again and said, "Actually, God, you're the boss."

The smile vanished as God replied, "Yes, I am the boss. But I have tasked you with taking care of Doveed."

I cannot forget that incident. And in a sense, it doesn't matter if it really happened that way or not. It will always live in my memory. I miss Wendee terribly, and wonderfully. She gave me a significantly richer sky, and a much happier life. ✶

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

A Suitcase and Six Car Batteries

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

This column was prompted by a message from my long-time colleague Professor Slavek Rucinski, pointing out that a conference in Vienna in the summer of 2024 marked the end of a significant era in Canadian astronomy and space science. And Slavek was the force behind it— the "father" of BRIght Target Explorer (BRITE)—and its predecessor Microvariability and Oscillations of Stars (MOST). These were two groundbreaking Canadian space-science satellites. I wrote about BRITE almost a decade ago (Percy 2015); now we can look back on its achievements—and those of MOST—with pride. Slavek's paper on the history and prehistory of MOST and BRITE was delivered remotely at the Vienna conference and is freely available here[1]. I urge you to read it. A link to the conference program is here[2].

The first satellite was the 53-kg, suitcase-sized MOST, alias *The Humble Space Telescope*. Its "child" was a "constellation" of six car-battery-sized BRITE nanosatellites. Their claims to fame are several: (1) they can measure changing star brightnesses very precisely—up to a precision of 1 part in 100,000 for MOST, and up to 1 part in 1,000 for BRITE; (2) they showed that, contrary to previous belief, it was possible to build, stabilize, and operate small satellites for astronomical research; (3) they are low-cost— less than $10 million Canadian for MOST, and about $1 million Canadian for each BRITE; (4) they could observe stars much too bright for HST or JWST, but which had been previously studied from the ground for years or decades.

The story goes back to when Slavek was a high-school student and an avid amateur astronomer in his native Poland, and was intrigued by the concept of operating a telescope in space. Fast-forward to 1996 when, now a professional astronomer, he was a faculty member at the Institute for Space and Terrestrial Sciences (ISTS), a Provincial Centre of Excellence located at York University in Toronto. One of his responsibilities was to engage with Ontario's extensive space-engineering industry. At a workshop organized by the Canadian Space Agency (CSA), he met Kieran Carroll, a space engineer from Dynacon Inc. (now Microsatellite Systems Canada Inc.: MSCI).

Figure 1 — MOST, the size of a large suitcase.

In 1996, CSA announced a competition for funding small satellites and payloads. Slavek and Kieran met weekly, to develop a proposal. Funding was obtained in 1998. Sadly, ISTS closed down shortly after, another victim of the Ontario government's "common sense revolution," along with the McLaughlin Planetarium. Slavek then moved to a position at the University of Toronto's David Dunlap Observatory (DDO). A new MOST team was created, with UBC's Jaymie Matthews as leader, but with Slavek and Kieran still involved. Other members were added from across Canada. The team also added two astronomers from Austria, which turned out to be crucial for the subsequent development of BRITE.

MOST was constructed between 1998 and 2003 at the Space Flight Laboratory (SFL) of the University of Toronto's Institute for Aerospace Studies (UTIAS), which also served as the main ground station for the mission. MOST was launched on 2003 June 30, on a Russian rocket, into a 101-minute polar orbit. It functioned well for over a decade but, in 2014, CSA pulled the plug on funding, a victim of federal budget cuts by the Harper government. Later that year, it was acquired by MSCI and operated on an ad-hoc basis until its final demise in 2019.

BRITE was conceived in 2002 through discussions between Slavek and Professor Rob Zee, Director of the UTIAS SFL, but funding from CSA was not immediately forthcoming. By then, however, BRITE had become an international project, thanks to Austria's participation in MOST and its interest in BRITE. Two satellites were funded by Austria—UniBRITE and BRITE-Austria, including one constructed and managed by the Technical University of Graz. Meanwhile, Slavek and his Polish astronomy colleagues convinced the Polish authorities in 2009 to fund two satellites, named BRITE-Lem and BRITE-Heweliusz after the Polish science-fiction writer and the Polish astronomer, respctively. Finally, CSA came through in 2011 to fund another two satellites, prosaically named BRITE-Toronto and BRITE-Montreal. Astronomers in several other countries have also participated in various aspects of BRITE-driven research and continue to do so. The

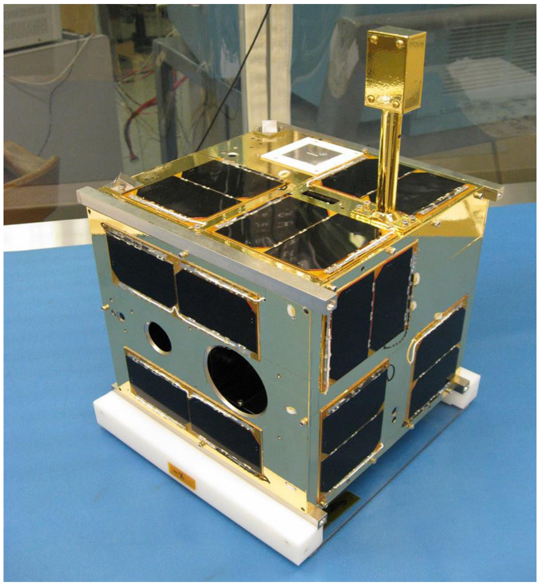


Figure 2 — One of the BRITE Constellation, the size of a shoebox or car battery. Source: Canadian Space Agency.

six BRITEs were launched in 2013–2014 in four separate launches in three different countries by three different space agencies. Sadly, BRITE-Montreal failed to deploy from its Russian rocket, leaving a constellation of five operating satellites. BRITE satellites operated from 2013 to 2024, when the conference was held in Vienna to celebrate BRITE's 10th birthday, and to review and celebrate the end of the mission.

For his work in bringing the BRITE project to Poland, Slavek was awarded the Officer's Cross of the Order of Polonia Restituta in 2015 and was elected an Honorary Member of the Polish Astronomical Society in 2019.

Slavek's contributions to astronomy go beyond MOST and BRITE. Throughout his time on those projects, he continued his own research on stars and stellar evolution, as he served in his "day job" as resident manager of the David Dunlap Observatory until its closing in 2008. It still houses the largest telescope in Canada, and is an important part of Canada's astronomical school audiences.

Slavek personally used the observatory's 1.9-m telescope to generate research leading to a multitude of research papers, as he has recently reported in this *Journal* (Rucinski 2023). He is an expert on close binary stars and has served as President of the International Astronomical Union's commission (interest group) on that topic. His research output and impact are remarkable. Using the widely used Total Objective Research Impact statistic[3], his "relative impact quotient" of 229 is equivalent to that of five average astronomers! He has published 463 research papers, including 136 since "retirement." As mentioned, he has been honoured in Poland, and commemorative stamps for BRITE have been issued in Austria and Poland—but not in Canada. By the way: it is not always appreciated that many academics—like Slavek (and me)—continue some of their academic work after retirement, at little or no cost to the university or the taxpayer. We are, in a sense, amateurs; we do the work for the sheer love of it.

MOST and BRITE have contributed to many areas of astronomy, notably the observation and analysis of stellar pulsation to study the structure and evolution of stars—asteroseismology—and also exoplanet transits—anything requiring long sets of high-precision photometry. They have observed well over 100 of the brightest stars, ranging from solar to the most luminous hot and cool stars in the Milky Way. These stars play a special role in driving nucleosynthesis and star formation and evolution in galaxies like ours. Virtually all these luminous stars show small-scale variability, which can tell us much about the processes in their atmospheres and interiors.

During their lifetimes, MOST and BRITE have *each* contributed to over 200 research papers, with thousands of citations. And there are observations still to be analyzed. The diversity of the scientific projects can be gleaned by looking at the program of the Vienna conference (2).

But the contributions of MOST and BRITE go beyond the science of astronomy, to include advancements in space technology, applications, engineering, and project management. In 2008, the MOST team won the Canadian Aeronautics and Space Institute's *Alouette Award* for just those reasons. Jaymie Matthews has recently been appointed to the Order of Canada. BRITE and Slavek deserve similar awards! ✶

Acknowledgements

I thank Slavek Rucinski for reminding me of the BRITE celebration, for sending me a copy of his conference paper, and for reading and commenting on a draft of this column.

Endnotes

1 Rucinski (2024): zenodo.org/records/13858040
2 britestars.univie.ac.at/home
3 Pepe, A. & Kurtz, M.J. (2012) journals.plos.org/plosone/article?id=10.1371/journal.pone.0046428#abstract0

References

Percy, J.R. (2015), "BRITE-Constellation: Canada's "shoebox satellites for variable-star research," *JRASC, 109*, 132.
Rucinski, S. (2023), "The last years of the David Dunlap Observatory: Personal Reminiscences," *JRASC, 117*, 95.

John Percy FRASC is Professor Emeritus, Astronomy & Astrophysics, and Science Education, University of Toronto, and a former President (1978–80) and Honorary President (2013–17) of the RASC.

Dish on the Cosmos

Sinking PHANGS into Dr. Rosolowsky's Research

by Pamela Freeman
(pamela.freeman@ucalgary.ca)

The keen eye may notice that I am not Dr. Erik Rosolowsky, the long-standing author of this column. Erik was my guide into the world of radio astronomy as he may have been for some of you. He took a chance on me for my first astronomy research project in my undergraduate degree. Fast-forwarding, I am finishing my Ph.D. at the University of Calgary where I use millimetre and submillimetre telescopes to study how the clouds of gas and dust spread through our galaxy form stellar and planetary systems. Erik has now asked me, as a fellow radio-astronomy enthusiast, to support this column moving forward. I hope to share with you the wonders of the low-frequency Universe, just as he has. In this column, we'll have a look at what Erik studies: how star formation influences nearby galaxies.

We generally understand that stars form in giant clouds of gas and dust in a galaxy. Within the clouds, filamentary structures lead into dense regions where stars may be born. If enough matter collapses and collects to ignite hydrogen fusion, a star is born. The structure of gas and dust within a galaxy may influence how and where stars form. This can be shaped by rotation, or by gravitational, magnetic, or turbulent mechanisms. The stars themselves create heavy elements and give back matter and energy into their home galaxy. Stars, then, use up a galaxy's reservoir of gas, and impact how future generations of stars may form. The evolution from clouds of gas and dust to stars, to remnant structures, is essentially how matter cycles through a galaxy.

Not all galaxies, however, form stars equally. The most active star-forming galaxies are spiral galaxies. The spiral structures for which they are named are visible through the collections of gas and stars that make them up. Many galaxies in the local Universe are spiral, including our own Milky Way. It's not possible to study how matter cycles with star formation just by studying the Milky Way, however. Firstly, it is difficult to study a galaxy from inside of it as we must look through the disk. Two, the timescales of galactic evolution are much longer than any human lifetime.

We can solve this pesky problem by observing relatively massive and nearby spiral galaxies that we can see face-on, that are inclined such that we can see the bulk of the disk and the arms. It's also useful to study multiple galaxies to see them at different stages, and that is what Erik and his colleagues are doing with the large program Physics at High Angular resolution in Nearby GalaxieS (PHANGS). PHANGS is an ambitious collaboration to study how stars and star formation cycle matter through a galaxy. They are connecting the small-scale gas properties—the physics, seen at high angular resolution—to galactic evolution, and how these two aspects influence each other.

Not only is the team observing galaxies at different stages, the evolution of stars within a particular galaxy can be seen from before birth to after death. Conveniently, the stages of the baryon cycle emit at observable wavelengths of light, from radio waves to ultraviolet. PHANGS has created a multi-observatory, multi-wavelength data set to capture all these stages, using the Atacama Large Millimetre/submillimetre Array (ALMA), the Very Large Telescope (VLT), the *Hubble Space Telescope* (HST), and the *James Webb Space Telescope* (JWST).

ALMA captures carbon monoxide, CO, which is a particularly good tracer of the distribution and size of the cold molecular gas clouds. Molecular spectral lines are strong in the millimetre and submillimetre bands and are often used to probe the reservoir of material that may form stars.

The VLT observes spectral lines in the optical wavelength range. These are more energetic than those traced by ALMA and arise from the feedback of stars, both at the beginning and end of a star's life. When stars are born, their intense radiation creates expanding regions of ionized gas around them called HII (pronounced H-two, for ionized hydrogen) regions. When stars die, they leave remnants. Stars like our Sun produce planetary nebulae when ejecting their outer layers. In contrast, the cores of stars much more massive than our Sun collapse in spectacular fashion, exploding in a supernova. The heavy elements formed in stars are dispersed into and enrich the interstellar medium.

The HST is used for stars and young star clusters. These hot, fiery balls of gas emit strongly in visible and ultraviolet wavelengths. While telescopes like ALMA can show how matter is being taken up in star formation, linking it to fully formed stars shows us how efficient star formation is.

The Royal Astronomical Society of Canada is dedicated to the advancement of astronomy and its related sciences; the Journal *espouses the scientific method, and supports dissemination of information, discoveries, and theories based on that well-tested method.*

Figure 1 — The JWST, top left, and HST, bottom right, images of the galaxy NGC 628. Credit NASA, ESA, CSA, STScI, Janice Lee (STScI), Thomas Williams (Oxford), and the PHANGS team.

The JWST has a dual capability with near-infrared and mid-infrared observations. The near-infrared, which is shorter wavelength and closer to the optical part of the spectrum, reveals the distribution of stars across spiral arms and in clusters. The mid-infrared, at slightly longer wavelengths, reveals the dust around and between these stars. Dust absorbs visible and ultraviolet light, absorbing it and re-emitting it in the infrared. Importantly, these dusty regions can indicate the early stages of star formation where a star-to-be is still enshrouded in the gas and dust it is forming in. They can also show the shells of bubbles carved out in the interstellar medium that potentially result from stellar explosions.

In Figure 1, a stark difference is seen between the JWST and HST images. This is a visible representation of the unique insight each telescope provides. The bright, swirling arms in the JWST observations show the dust that obscured the visible light in the HST observations. The JWST spots stars dotted through the galaxy, but a vast population of stars and clusters is seen with the HST.

Within the dozens of galaxies PHANGS has observed, upwards of 100,000 stellar nurseries and star clusters have already been catalogued. The initial results are promising. Just scratching the surface, the collaboration has seen that the location of a star-forming cloud within a galaxy affects the cloud's properties and that there are patterns of how gas clumps, whether on the scale of clouds within a spiral arm or in dense star-forming regions along a filament. With the vast amount of data taken (they're "overwhelmed—in a positive way—by the amount of detail" according to collaborator Thomas Williams), the PHANGS program is providing a dataset for the entire astronomical community to sift through for years, getting ever closer to understanding exactly how star formation influences nearby galaxies. ✶

Read more:

sites.google.com/view/phangs/

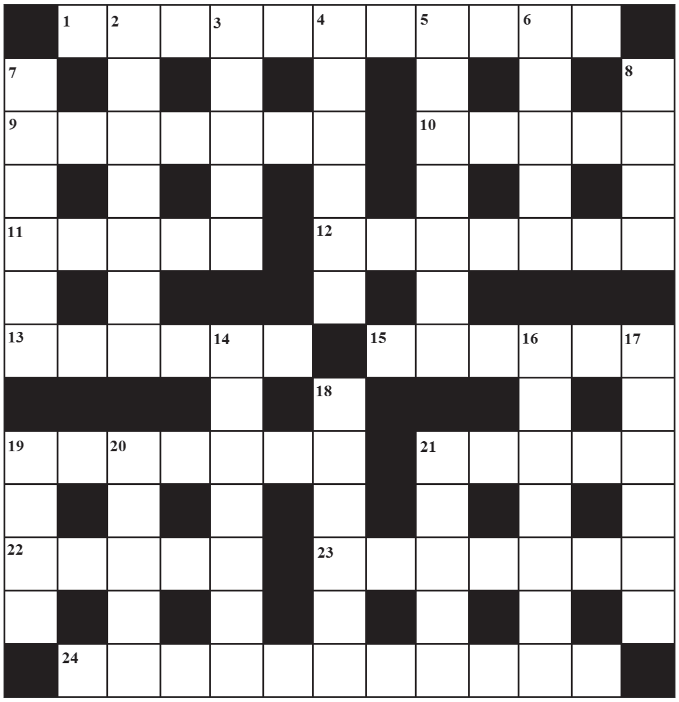
Rosolowsky, E., Hughes, A., Leroy, A.K., *et al.* Giant molecular cloud catalogues for PHANGS-ALMA: methods and initial results, *MNRAS, Volume 502, Issue 1*, March 2021, Pages 1218–1245, https://doi.org/10.1093/mnras/stab085

Henshaw, J.D., Kruijssen, J.M.D., Longmore, S.N. *et al.* Ubiquitous velocity fluctuations throughout the molecular interstellar medium. *Nature Astronomy* ***4***, 1064–1071 (2020). doi.org/10.1038/s41550-020-1126-z

Pamela Freeman recently finished her Ph.D. in astrophysics at the University of Calgary. Specifically, she studies the chemical make-up of star-forming clouds with radio telescopes. Generally, she loves to observe anything and everything about nature.

Astrocryptic

by Curt Nason



ACROSS

1. Like Bard's lovers and Crux (4-7)
9. Gloria turns, begins wakening, turns on chemiluminescent light (7)
10. Stop communicating with one of Jupiter in Hydra (5)
11. High horse sounds tight with purse (5)
12. Rey developed internal irritant making big mirrors in California (7)
13. Can such velocity make one tired? (6)
15. No longer allowed to enter a spiral galaxy (6)
19. He and I are each one (7)
21. An Astronomer Royal now cleans many floors (5)
22. Kids head off before one (5)
23. Said to be keepers of telescope pointers (7)
24. A bluer onion develops in a cloud (5,6)

DOWN

2. Deserter returned a last letter in the eagle's head (7)
3. Cepheus was one with a measureable straight edge (5)
4. At the eyepiece, sketcher backs up to receive the prize (6)
5. Arrow shot at hairy cousin wearing a gas mask backwards (7)
6. Hope returns round start of century for star atlas reference date (5)
7. Ramble around a series of hydrogen lines (6)
8. Canine command to support the pole (4)
14. Broken dish has stifled extraterrestrial communications (7)
16. He further categorized stars in Centaurus, selling his diagram (7)
17. Like Hertzsprung, Bohr had this for breakfast (6)
18. He discovered the relation of stars' temperature and energy in rotating fans (6)
19. Early comsat program based on electron capture with hydroxide backing (4)
20. Electromagnetic energy at the emergency room supplied by Arab chieftain (5)
21. Three points in a decibel at the tail of a swan (5)

Answers to previous puzzle

Across: **1** HECUBA (2 def, he+Cuba); **4** OCTANS (an(n)ag); **9** RADIANS (2 def); **10** ALGOL (anag); **11** TOXIC (anag-e); **12** CAMERAS (anag); **13** CASSINI PROBES (anag); **17** ARIES (hid); **19** SHATTER (S+Hatter); **21** ALGIEBA (2 def (lion)); **22** TRACE (2 def); **23** SIRRAH (rev); **24** URANUS (Ur+an+US)

Down: **1** HERETIC (anag+ic); **2** CODEX (rev+ex); **3** BIANCHI (hid); **5** CHARM (2 def); **6** ALGORAB (Al Gore-e+AB); **7** SOLIS (Sol+is); **8** TSUCHINSHAN (anag); **14** STINGER (2 def); **15** REACTOR (anag); **16** SERPENS (2 def); **17** ADAMS (2 def); **18** SIENA (anag); **20** TRAIN (2 def)

The Royal Astronomical Society of Canada

Vision

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

Mission

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

Values

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

Great Images

By Katelyn Beecroft

It's February, the month of love, so here's a big heart. Katelyn Beecroft imaged the Heart Nebula from London, Ontario, during October 2024 over several nights while the Moon was mostly full, she says. "This SHO image features the intricate Melotte 15, and the Fish Head nebula (IC1795). I also managed to catch WeBo 1, a tiny planetary nebula that surrounds a Barium star (left side of image in the middle)," she says. "In the past, I've had trouble imaging this nebula, so I decided to pour a lot time into it this time around, which really paid off!" She used an Askar FRA400, 72mm aperture telescope at f/5.6, with a ZWO ASI2600MM pro camera, gain 100, 26 MP. 62 x 300s Antlia 4.5 nm Hα filter; 62 x 300s Antlia 3 nm OIII filter; and a 145 x 300s Antlia 4.5 nm SII filter.

Journal

"High in our northern sky in the constellation Cepheus lies this fascinating nebula known as NGC 7822. This is a violent and chaotic star-forming region," says Andrea Girones. She captured the image using a Redcat51 on an AM3 with an ASI 2600MC camera and an L-extreme filter. 9 hours of 300-second exposures taken from her backyard in Ottawa.