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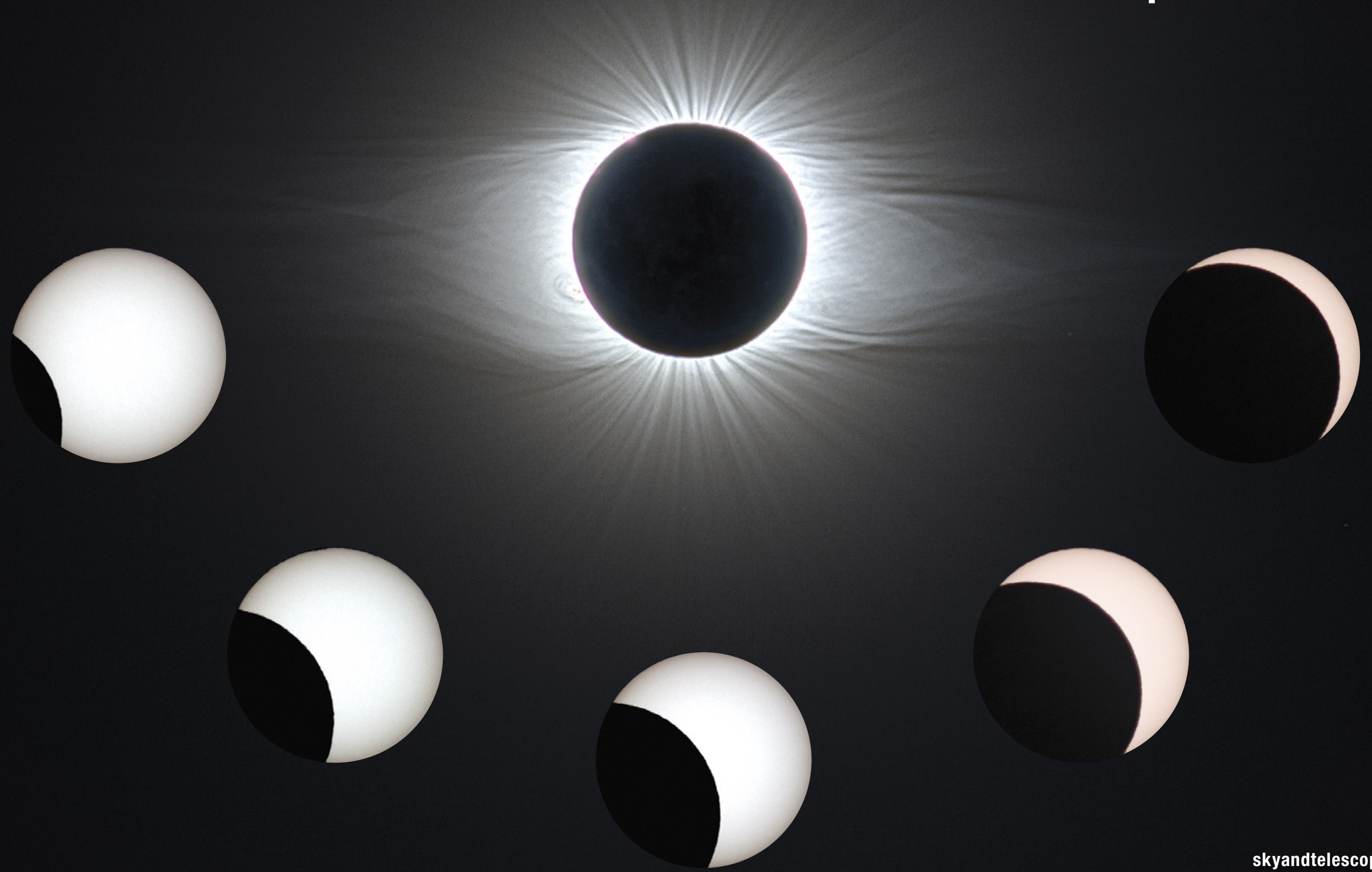
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

APRIL 2024

SHOWTIME

North America's Grand Eclipse



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SKY&TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

April 2024 VOL. 147, NO. 4

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ESA / HUBBLE / NASA / W. KEEL

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ON THE COVER

Composite of the eclipse on July 2, 2019, seen from Chile
PHOTO: SEAN WALKER

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A Rare Gem

OVER THE PAST YEAR, we've devoted three covers to this month's total solar eclipse — April 2023, January 2024, and the current one — as well as multiple articles, starting with Fred Espenak and Jay Anderson's 10-page preview in April 2023. This month's issue offers no fewer than seven eclipse-related pieces.

Why so much coverage? Well, as most *S&T* readers know, a total solar eclipse is one of the most thrilling natural spectacles one can ever behold. After experiencing totality in 1851, Edwin Dunkin spoke for most of us who've seen a total eclipse when he declared, "Few can imagine how much I longed for another minute, for what I had witnessed seemed very much like a dream." Leif Robinson, a former editor in chief of this magazine, stated simply: "No one should pass through life without seeing a total solar eclipse."

One aspect of this month's event worth remembering is just how rare a phenomenon it is. Take the U.S. as an example. Sure, we had a superlative eclipse here just seven years ago, and totals take place every year or two somewhere on the planet. But before 2017's, the last time a total solar eclipse graced any portion of the contiguous U.S. was in 1979, and the last total eclipse that traveled coast to coast occurred in 1918.

▲ Obsidian orb: The final moments of totality on August 21, 2017

SEAN WALKER / *S&T*

The future is just as spare. The next time the Moon's umbra even touches the Lower 48 will be 20 years from now, in August 2044, and it will darken only three of those states — Montana and parts of the Dakotas. The next U.S.-crossing eclipse won't happen until August 12, 2045, when one will sweep from California to Florida.

This rarity is a key reason for our robust coverage. To whet your appetite for April 8th's wonder, read Bob King's preview, with its helpful list of highlights to watch for on eclipse day (page 48). To hear of a unique way to experience totality, see Joe Rao's feature on observing it via AM radio (page 62). Trudy Bell describes how eclipse expeditions in the 19th century pioneered solar studies (page 28), while Alan MacRobert explains how and why solar eclipses happen (page 74). In his column, Jerry Oltion gives tips on how to make an "Eclipsinator" to safely share the event with others (page 72). We wrap up with a dramatic story of a teenager's first eclipse chase by Alan Whitman (page 84).

Lastly, on the opposite page, note our special issue *The Great 2024 Eclipse*. This richly detailed, lavishly illustrated guide covers everything you need to know to ready yourself for the big day. It's available now on newsstands, by phone at 800-253-0245, and through **shopatsky.com**.

Here's to clear skies for all who plan to stand in the Moon's shadow on April 8th!

Peter

Editor in Chief

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▲ NASA's Curiosity rover discovered mud cracks on Mars in 2021. The polygonal shapes depicted here formed after many wet-dry climate cycles.

NASA / JPL-CALTECH / MSSS / IRAP

Dusty Martian Dilemma

I'm looking at the image of the dust-covered Insight Mars Lander on page 6 of the December issue, and I'm wondering: What if that lander had had a little helicopter to partner with? Couldn't the helicopter utilize its downwash to dust off the larger craft? Then there could be another role for Mars-based helicopters other than wayfinding. The technology doesn't need to be invented. It is already there and can be tested anytime the technicians have a spare moment. This would elevate Mars-based helicopters from nice to essential.

Arnold Miller
Lynnwood, Washington

Camille M. Carlisle replies: *I don't know whether a small helicopter could create a forceful enough downwash in the thin Martian air to clean off solar panels — and to be honest, I doubt mission planners would be willing to test the idea. The Ingenuity and Perseverance teams have been careful to keep the two explorers apart, to avoid any possibility of collision and damage. There's also the question of whether the downwash's effect would be positive or negative — it might kick* more *dust onto solar panels.*

*A study from 2022 found that Ingenuity kicks up dust when a few meters above the ground (***https://is.gd/IngenuityDust***). So for any chance of cleaning off a lander or rover, navigators would have to bring the flyer within perhaps 10 feet of a solar panel — a sure way to raise the blood pressure of rover drivers, who are watching from another planet and with several minutes of signal delay. Those dust clouds might also keep circulating and rain dust back down on the panels.*

Even if the panels are spick-and-span, there's still the matter of dust in the atmosphere. Ingenuity itself has had trouble charging its battery when dust levels are high: **https://is.gd/IngenuityComs***.*

"What Mud Cracks Mean for Life on Mars" by Colin Stuart (*S&T:* Dec. 2023, p. 8) was a very interesting article. I know that the implication for extraterrestrial life probabilities was the main point, but I wonder what processes allowed the soft soil features to last for billions of years intact?

Shouldn't they have been eroded by the frequent sandstorms on Mars after the wet-dry cycles had ceased? Though I'm not an expert, preserved ancient soil features on Earth are quickly buried and hardened into sandstone, except maybe in caves or under other special circumstances. When the overlying layers are themselves eroded, they become visible, or they are found during excavation.

Steven Bernstein
Jackson, New Jersey

Monica Young replies: *You pose a good question! The study authors address this in more detail in their paper, noting that the surface on which they see these mud cracks is resistant to erosion: "The present appearance of the sulfate-bearing ridges is probably not the original configuration of these features. More plausibly, they started out as evapoconcentration deposits focused on initially formed cracks that then evolved over a longer history of drying cycles and burial diagenesis (***https://is.gd/MarsCyclesFig3***).*

"They are now exposed as erosion-resistant *polygonal ridges owing to their higher degree of cementation relative to the host bedrock, and an early bias of surface salt precipitation in original mud-crack polygons."*

Page 6 of the December 2023 issue has a photo of the dust-occluded Insight Mars Lander. On page 8 of the same issue is a photo of multi-billion-year-old mud cracks that appear to be free of dust. Is there anything to be gleaned from this beyond whether dust accretes more rapidly in some areas than in others?

George Nehls
La Crosse, Wisconsin

Monica Young replies: *Thanks for writing in. We asked your question of William Rapin (Research Institute in Astrophysics and Planetary Science, France), who published the results on the mud cracks on Mars (*S&T*: Dec. 2023, p. 8), and he agrees with your statement: "There are indeed variations in how dust is deposited on Mars. At a global scale, we have traced dust cover using reflectance spectroscopy.*

"The Mars Global Surveyor's Thermal Emission Spectrometer provides a 'dust cover index' for example, and it shows that there are clear regions with elevated dust deposition rate, like where Insight is, that act as dust pits, and others with enough wind to clear rock exposures."

Curiosity's mud cracks are visible due in part to luck, he adds: "They are preserved within a sedimentary rock layer that is exposed nicely, and luckily, in an area that is accessible to the rover and indeed not particularly dust covered."

Stupefying Spin

As a retired engineer, I am blown away by the scientific progress being made in astronomy. But on a more mundane level, I am baffled by the response to Dan Crow's "Speeding Spiral" letter (*S&T:* Jan. 2024, p. 6) about galaxy rotational speed. What baffles me is that the rotational speed is being measured in km/s instead of rpm. What did I miss?

Jerry O'Shaughnessy
Vienna, Virginia

Monica Young replies: *For a solid object such as, say, a frisbee, rotational speed is indeed typically given in revolutions per minute (rpm). The actual speed of a particle stuck to the frisbee will be lower if the particle is near the center and higher if it's sitting farther out. However, the Milky Way is not a solid object. The bulge near the center does experience rotation like a solid body would, but beyond a certain radius, the rotation curve flattens out, so that particles farther out rotate around the center at the same speed. Because the rotation curve is flat over much of the star-forming disk, 240 km/s applies to most of the disk.*

Welcome Back, Stephen!

It is only fitting that I am "over the Moon" at the return to *S&T* of Stephen J. O'Meara, a great contributor to the astronomy world. O'Meara's observations have inspired many and have been sadly missed in *S&T*. His *Deep-Sky Companions* series is a must in any astronomer's library. Welcome back, Stephen!

Robert Rukrigl
Severna Park, Maryland

Section Correction

On page 25 of the September 2023 issue, in "Vesto Slipher's Fast Stars and Hotrod Galaxies," Douglas MacDougal writes that Slipher "chaired the Nebular Section of the International Astronomical Union." The IAU indeed oscillated between Committees and Commissions (eventually settling for the latter, with Comm. doing service for both), but it never had Sections. From the get-go, Comm. 28 was Nebulae, later Nebulae and Star Clusters, and finally Galaxies, but all were led by Presidents, as are current IAU Commissions and Divisions, never by chairs or chairmen.

Virginia Trimble
Past President
IAU Comm. 28, Galaxies, 1994-97
Irvine, California

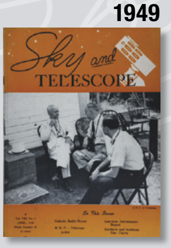
FOR THE RECORD

- The plot on page 19 of the October 2023 issue incorrectly colored the two high-redshift galaxies below and below-right of GN-z11 gray: These galaxies were not Hubble candidates but JWST ones and should have been orange and black.

SUBMISSIONS: Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

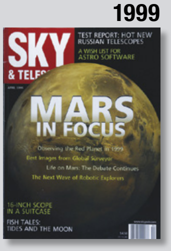
75, 50 & 25 YEARS AGO by Roger W. Sinnott

1949



1974

1999



April 1949

Telescope Artist "The story is told that one day when Mrs. Porter came home she found that in her absence Russell had cut a hole in the living room wall so that he could thrust the barrel of his telescope through and sit inside to study the stars out of reach of mosquitoes. Russell himself refuted this statement, denying that he ever cut a hole through the living room wall — *it was through his den!*

"In 1921, Porter wrote an article for *Popular Astronomy* describing a simple telescope. Among those who read it and became enthusiastic was Albert G. Ingalls, of the *Scientific American* magazine. [Porter] later said, 'It was a fortunate thing for our fraternity that brought us together, and it was not long before the first thin edition of *Amateur Telescope Making* was published.'"

Russell W. Porter's obituary, penned by close friends Leo and Margaret Scanlon, goes on to describe his role as both architect and illustrator for the Hale 200-inch telescope project.

April 1974

Truly Dark? "Most people who believe that nighttime is synonymous with darkness are surprised at how bright a clear, moonless night can be, simply due to natural sources of light from the night sky [free of any light pollution or aurorae]. These principal sources are nighttime airglow (nightglow), the interplanetary [or zodiacal] light, and integrated starlight. . . . For a middle-latitude observatory, each of these three sources provides on the average about one-third of the total light of the night sky.

"The contribution from extragalactic nebulae (cosmic light) is probably less than one percent of the total."

Robert G. Roosen added that the richest parts of the Milky Way are more than 10 times brighter than the sky at the galactic poles.

April 1999

Unseen Supernova "Nearly seven centuries ago a celestial event took place that ought to have astounded observers at the time. An inconspicuous star in the southern constellation Vela should have brightened millions of times, rivaling Venus as the most brilliant point of light in the evening sky. . . . So it comes as a surprise to astronomers that no historical records of this recently discovered supernova have been found. . . .

"Bernd Aschenbach (Max Planck Institute for Extraterrestrial Physics) uncovered evidence for this stellar explosion while studying X-ray images of a much older supernova: the one that created the . . . Vela supernova remnant. . . .

"Independent observations by Anatoli F. Iyudin [and colleagues], this time using NASA's Compton Gamma Ray Observatory, [imply] an age of 680 years and a distance of 650 light-years. [So] why did the apparition of RX J0852.0–4622 around A.D. 1320 go unnoticed?"

EXOPLANETS

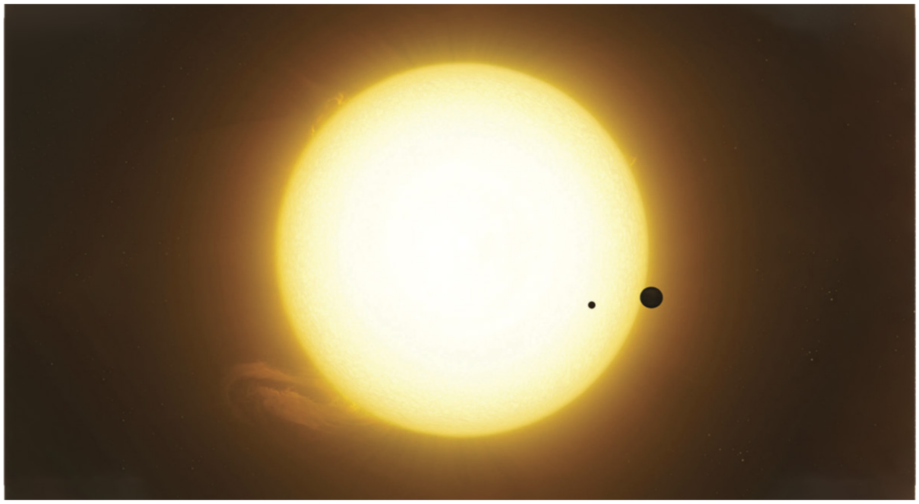
New Doubt Cast on Exomoon Candidates

OUR SOLAR SYSTEM is awash in moons, so it seems reasonable to infer that moons are common in other stellar systems, too. However, astronomers have only found evidence hinting at a few exomoons so far (*S&T:* Sept. 2020, p. 34) — and a recent study casts doubt on two of those detections.

Exoplanets transiting in front of their host stars block some of their light. By measuring dips in stellar light, astronomers can build a picture of the objects causing the partial eclipses. Moons could be found this way, too, but because their dips might occur before, during, or after their planet's, they require additional statistical vetting.

In 2018, Alex Teachey and David Kipping (both at Columbia University) announced the discovery of a exomoon candidate orbiting the super-Jupiter Kepler-1625b. Based on data from the Kepler telescope, this discovery later received support from a Hubble observation. Then, two years ago, a team including Teachey and Kipping identified another candidate orbiting a different giant world, Kepler-1708b.

Now, a study published December 7th in *Nature Astronomy* casts doubt on those exomoon claims. René Heller (Max Planck Institute for Solar System Research, Germany) and Michael Hippke (Sonneberg Observatory, Germany) reanalyzed previous observations with the help of a new and improved computer code called Pandora, developed to validate exomoon transits.



▲ This artist's illustration shows exoplanet Kepler-1625b transiting its star with an alleged moon in tow. A new study suggests the moon signal may not be real.

Heller and Hippke suggest the original team might have overestimated putative exomoon signals in part due to *stellar limb darkening*, which can alter the shape of transiting objects. The effect makes it harder to separate a planet's signal from other variations.

Heller and Hippke also find that the *detrending* method previously used to remove extraneous signals, such as telescope vibrations and stellar activity, might have inadvertently injected moons into the data.

"These moons are extremely challenging to detect, since their signature is very subtle," says Johanna Vos (Trinity College Dublin), adding that independent studies such as this one are important for the field. She praises the new study for developing "advanced tools for detecting and validating possible signatures of exomoons."

In addition, for each candidate, the researchers tested 128 models including only a planetary transit as well as 128 models including both a planet and its moon. Comparing these models to each other, they conclude that Kepler data can only detect massive moons on wide orbits — specifically orbits beyond 30% of the planet's *Hill radius*, within which the planet's gravity dominates over its star's. The solar system's giant planets have no massive moons so far away.

■ KIT GILCHRIST

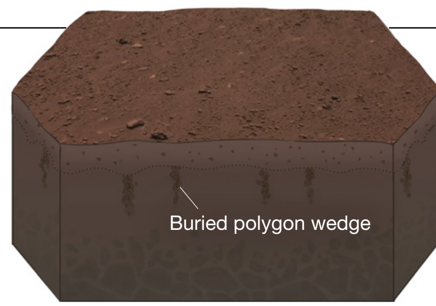
SOLAR SYSTEM

Buried Polygons on Mars Hint at Stark Early Transition

POLYGONS BURIED beneath the surface of Mars indicate an abrupt environmental transition in the planet's early history.

Ground-penetrating radar on China's Zhurong rover has revealed large, wedge-like structures well below ground level on the Red Planet. While previous missions have observed polygonal mud cracks on the Martian surface, created by repeated wet-dry cycles on early Mars (*S&T:* Dec. 2023, p. 8), these larger polygons indicate a different kind of cycle. Lei Zhang, Chao Li, and Jinhai Zhang (all at Chinese Academy of Sciences) and colleagues report the results November 23rd in *Nature Astronomy*.

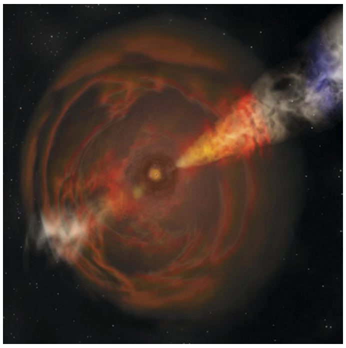
Analysis of Zhurong's radar data has revealed these structures are more than 35 meters (115 feet) below the surface. The cracks between polygons are themselves quite wide (27 meters), almost half again the polygons' average width of 67 meters. The difference in the crack-to-polygon ratio rules out their formation by wet-dry cycles, Zhang says, and instead indicates the presence



▲ This diagram shows wedges from polygonal structures buried 35 meters beneath the Martian surface. (The surface image comes from the Tianwen 1 lander's navigation camera.)

STARS

A Brilliant Explosion That Keeps on Exploding



◀ An artist's impression shows a massive star in the act of exploding.

BILL SAXTON (NRAO / AUI / NSF)

A BLAZING BLUE DOT appeared in images taken by the Zwicky Transient Facility in 2022; the dot shone some 1,000 times brighter than a typical supernova before fading away. That event, designated AT2022tsd and soon nicknamed the Tasmanian Devil, joined a short list of other *luminous fast blue optical transients* (LFBOTs; *S&T:* May 2019, p. 10). Astronomers think these transient lights mark a special kind of supernova, or they could instead come from a feeding neutron star or black hole.

But 100 days later, as Anna Ho (Cornell University) and colleagues were reviewing routine images to monitor the fading flare, they found a surprise: another burst almost as bright as the original and in the same exact position on the sky.

Scouring for data in the archive and with new observations, the astronomers found another outburst — and then another, and another. These flashes were red rather than blue, lasted minutes at most, and shone with the power of a supernova. Overall, at least 14 flares followed the first one, Ho and colleagues report in the November 30th *Nature*; it's likely more were missed.

Ashley Chrimes (ESA), who wasn't involved with the study, calls the discovery "completely new (and unexpected)."

Follow-up observations showed that while the initial, blue light probably originated in the heat of the explosion, subsequent flares probably come not from heat but from speedy plasma spiraling along strong magnetic fields. What's more, the follow-on flares brighten and fade so quickly that the source they hail from must be correspondingly small — no more than a few times the Sun's width.

The nature of the emissions together with the small size and extreme energies suggests that the flares originate in a jet that's escaping at near-light speeds, Ho's team concludes. The result supports ideas that LFBOTs involve neutron stars or black holes, but it still leaves open a lot of possibilities. With the Tasmanian Devil still flashing away, astronomers may soon be able to narrow down what causes this unique type of explosion.

■ MONICA YOUNG

---

of ancient freeze-thaw cycles.

"The [wedges] most likely formed by thermal-contraction cracking," Zhang says. Water, soil, or mixtures of the two filled in the cracks to form the wedges that the team observed. The meters of layers on top of the polygons were deposited over the past 1.6 billion years by long-term weathering, impacts, and transient floods.

"It's very interesting they can see something like that with radar," says Benton Clark (Space Science Institute). "There may be a lot more [ice-related features] around, but we haven't come on places where [the ice] was exposed."

Zhurong landed on May 14, 2021, in Utopia Planitia, a northern plains site that might once have hosted an ancient ocean. In its year of operation, the rover traveled nearly 1.2 kilometers (0.7 mile). Zhang's team found 16 polygon wedges buried along Zhurong's trek.

Zhang's team concludes that the absence of buried polygonal terrain above the 35-meter level marks a "stark environmental transition" between 2 and 3.5 billion years ago, during the end of Mars's wet period.

■ JEFF HECHT

IN BRIEF

Amateurs Discover Asteroid's Moon

When the asteroid 5457 Queen's eclipsed a 12.5-magnitude star on Sept. 4th, Jan Mánek and five other amateur astronomers stationed from Poland to Switzerland timed the exact moment the star winked out. From their data, astronomers derived the rough size and shape of the asteroid — and found something else, too. Mánek captured not only the 1.67-second asteroid occultation but also another eclipse of the same star 0.87 seconds later, as if another object were following close behind Queen's. No one else saw the second occultation that night, but on Sept. 20th, Serge Dramonis from Greece observed Queen's occultation of another star. He, too, saw a "double" eclipse — Mánek and Dramonis had discovered that Queen's has a moon. Analysis by Christian Weber (International Occultation Timing Association, European Section) revealed that the as-yet unnamed satellite measures 2.8 km (1.7 mi) in diameter. Queen's itself, which was discovered in 1980 by Carolyn Shoemaker, is only about 17.5 km wide, according to the same analysis. Hundreds of asteroids are known to have satellites; however, this one is only the second main-belt asteroid moon found and confirmed with the occultation method.

■ JAN HATTENBACH

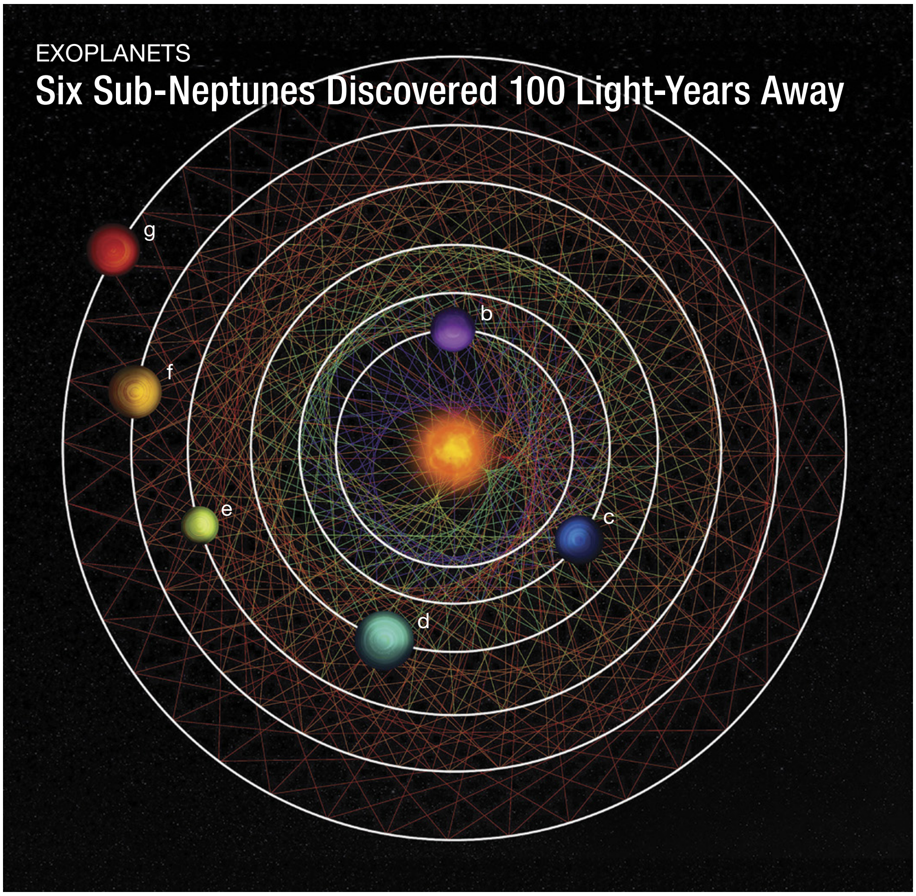
Computers Trained to Find Cosmic Treasure

Graduate student Erik Zaborowski (Ohio State University) and colleagues developed a machine-learning algorithm to help search through millions of images taken by the Dark Energy Camera at the Cerro Tololo Inter-American Observatory in Chile. With the model's help, researchers found 562 new candidate galaxies gravitationally lensed by massive foreground galaxies. They published the results in the September 1st *Astrophysical Journal*. The effort is part of a survey that uses the Dark Energy Camera, or DECam, to explore the Milky Way's neighborhood. The DECam Local Volume Exploration (DELVE) survey has captured a whopping 520 million cosmic sources. Zaborowski's team built a five-layered convolutional neural network that sifted out the 50,000 sources most likely to be gravitationally lensed galaxies. To make the final selections, though, the scientists still had to check each one by eye.

■ HANNAH RICHTER

EXOPLANETS

Six Sub-Neptunes Discovered 100 Light-Years Away



◀ The resonances among the six planets of the HD 110067 system engender a mesmerizing geometric pattern, created by tracing a link between two neighboring planets at regular time intervals as they travel along their orbits.

ASTRONOMERS HAVE UNCOVERED six sub-Neptune exoplanets dancing in lockstep around the same distant star, publishing the finding in the Nov. 30th *Nature*. The ancient system's fixed architecture probably hasn't changed since its birth. It therefore opens a promising window for astronomers studying how planetary systems form.

In 2020, NASA's Transiting Exoplanet Survey Satellite (TESS) helped astronomers observe dips in the brightness of the star HD 110067. Such dips are the calling card of transiting planets, and initial analysis suggested two of them, one with an orbit 5.6 days long and another with an undetermined orbit.

Yet by the time TESS observed HD 110067 again two years later, this interpretation no longer fit the data. A team led by Rafael Luque (University of Chicago) turned to the European Space Agency's Characterising Exoplanet Satellite (CHEOPS). Those new observations quickly made clear that there was a third planet in the system. The trio of planets (called HD 110067 b, c, and d) orbit in 3:2 *orbital resonances*: The innermost planet takes 9.1 days to orbit, the next takes 1.5 times longer (13.7 days), and the third takes 1.5 times longer again (20.5 days). The linked orbits mean that the planets align every few orbits; ensuing "duo transits" caused the initial confusion.

However, even a three-planet system still wasn't a perfect fit. The team dug deeper and uncovered three more planets (HD 110067 e, f, and g). There is a 4:3 resonance between e and f as well as between f and g. All these planets are in the sub-Neptune category.

This is the second six-planet system that CHEOPS has uncovered; the first is known as TOI 178.

"We think only about 1% of all systems stay in resonance," Luque says. "[HD 110067] shows us the pristine configuration of a planetary system that has survived untouched."

The system is ripe for further study; for example, characterization of the planets' atmospheres with the James Webb Space Telescope could shed light on how such planets — the most common in the universe — might form.

■ **COLIN STUART**

SOLAR SYSTEM

Chiron's Rings Are Changing

A SERIES OF *stellar occultations* has provided evidence that the ring system around Chiron, a Centaur in the outer solar system, is evolving.

In 2011, astronomers observed material outside Chiron as the asteroid passed over a background star in a stellar occultation. In 2015, José Ortiz (Institute of Astrophysics of Andalucía, Spain) and colleagues interpreted that occultation as evidence of a double ring system. More recently, Ortiz and another team, led by Amanda Sickafoose (Planetary Science Institute), analyzed additional stellar occultations to take a closer look at the rings. Both found that Chiron's ring system has been changing since its discovery.

During a 2018 occultation, Sickafoose and colleagues found that, for ring-related dips, the background star didn't dim as much during the occultation as expected from the 2011 observations. They conclude in the November *Planetary Science Journal* that the ring material must have decreased in the meantime, either being lost to space or having collapsed onto Chiron's surface.

Chiron also occulted a 12.7-magnitude star in December 2022. Ortiz's team captured six ring-related drops in stellar brightness from the Kottamia Astronomical Observatory in Egypt, consistent with up to three different rings. Ortiz's group published these

GALAXIES

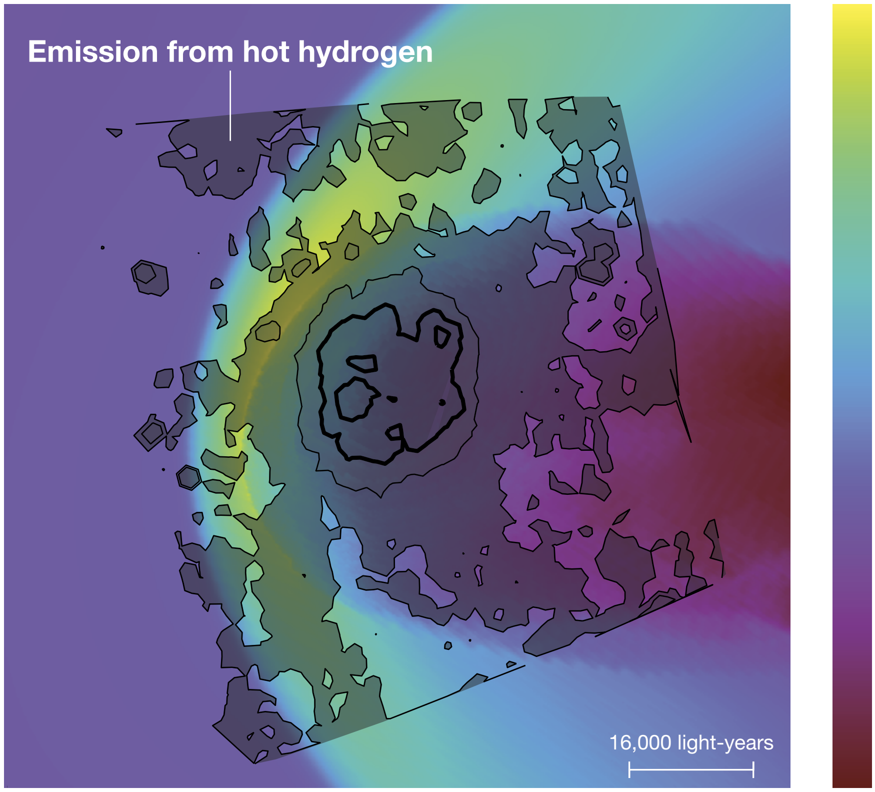
100,000-Light-Year Bow Shock in the Milky Way Halo

ASTRONOMERS ARE WORKING to reveal a humongous bow shock in the Milky Way's outskirts.

Our largest satellite, the Large Magellanic Cloud (LMC), is falling into the hot, sparse gas surrounding our galaxy faster than the local speed of sound (that is, the speed at which pressure waves propagates). Out in this gaseous halo, the speed of sound is 165 kilometers per second (370,000 mph). The LMC is crashing through this sparse medium at almost twice that speed.

Astronomers have long suspected that the LMC's infall should create a bow shock. Now, David Setton (Princeton University) and colleagues have simulated a "wind tunnel" to predict how large it should be. In this computer simulation, the LMC is a bundle of gas and stars that sits at rest in a box. The gas around the Milky Way rushes like a headwind toward and around this bundle. While the stars pass straight through the headwind, the gas pushes into the wind to generate a bow shock that spans three times the size of the dwarf galaxy.

With an idea of what to look for and where, Setton and colleagues then searched recent measurements taken by the Wisconsin H-alpha Mapper (WHAM). The hydrogen-alpha emission that WHAM is mapping marks the presence of hot gas. Projecting WHAM data onto their shock simulation, the researchers found good — though not perfect — alignment. They've posted these results on the arXiv astronomy preprint server.



▲ The contours and gray shading show the distribution of hot hydrogen gas in the direction of the Large Magellanic Cloud, laid over the expected gas density (color background) due to the LMC's motion through the hot, sparse gas around the Milky Way. As in the simulation, the observed gas density shows an asymmetric bow shock.

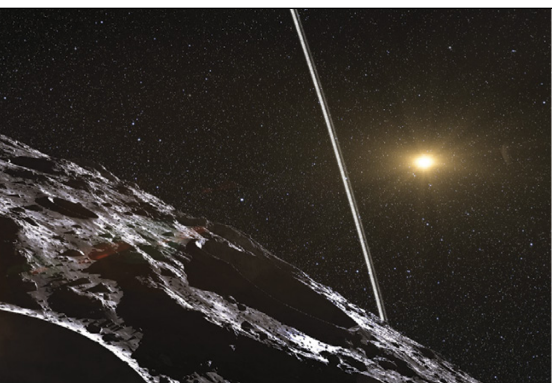
Marcel Pawlowski (Leibniz-Institute for Astrophysics, Germany), who was not involved in the work, thinks it's likely a bow shock is there, but he also notes that more work is needed. "The morphological match isn't that clear," he says.

"However, I expect that more sensitive data and a quantitative comparison would allow [us] to evaluate this better, so the paper can be a good motivation for such follow-up observations."

The team acknowledges that the simplified "wind tunnel" model is a first step, and more detailed work investigating the bow shock and its effect on the galaxy's outskirts is already underway.

■ **MONICA YOUNG**

CHIRON'S RINGS: ESO / L. CALÇADA / NICK RISINGER (SKYSURVEY.ORG); CHART: SETTON ET AL. / ARXIV: 2308.10963



▲ An artist imagines what rings might look like from the surface of Chiron.

results in the August *Astronomy & Astrophysics*. The 2022 dips were deeper than in 2018, indicating that the occulting material seemed to have been somewhat replenished.

Ortiz and his team suspect the evolving rings might be related to the unexpected brightening of Chiron in the first half of 2021. A surface event might have ejected material that remains close to the parent body.

Alternatively, Chiron might have crossed a swarm of debris from a disintegrated Centaur or comet, in the process releasing dust or ice particles. Archival evidence supports this scenario: A similar event preceded the 2021 brightening almost 50 years ago, which is close to Chiron's orbital period.

"At this point, small-body rings are an emerging field of study," concludes Sickafoose. "We need more observations to understand their formation and evolution mechanisms."

■ **JAN HATTENBACH**

See the data at https://bit.ly/chironring.

Mapping Our Galactic

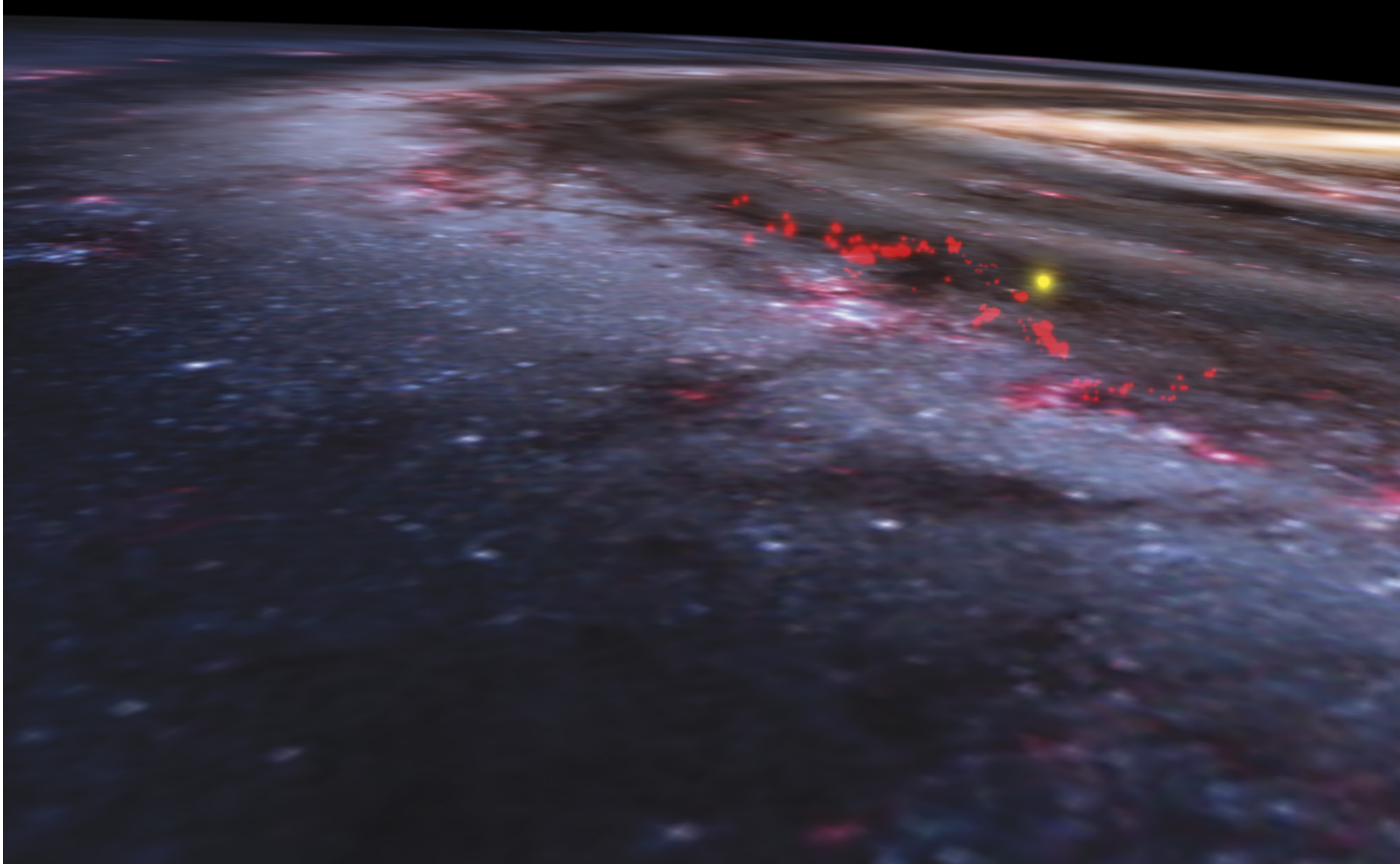
An innovative technique is revealing our suburb of the Milky Way in new and surprising detail.

Many of us have looked up on a clear, dark night and seen the hazy band of light stretching across the sky. This band of light is an edge-on view of the disk of our home galaxy, the Milky Way. The Milky Way's disk is shaped like a thin pancake with a bulge near its center. Our Sun lies about halfway out from the center of this 100,000-light-year-wide pancake, embedded deep within its disk. As a result, our view of the sky is simply a super-close-up, internal view of our galaxy's structure.

Since we are confined to our vantage point on Earth, bird's-eye views of our galaxy's structure have traditionally been artists' impressions, showing what we think our galaxy *might* look like from the outside. These artists' impressions have been painstakingly reconstructed from astronomical observations.

All astronomers agree that our galaxy has a characteristic pinwheel pattern, with several arms spiraling around the central bulge. However, while these artist's impressions appear crystal clear, the truth is that many of the details are uncertain. Astronomers even argue over how many arms make up this pattern and what their precise structure is (*S&T:* Nov. 2019, p. 16).

This uncertainty has held true even for the section of the Milky Way we should know the best: the *solar neighborhood*, where our Sun currently resides. Simply put, we



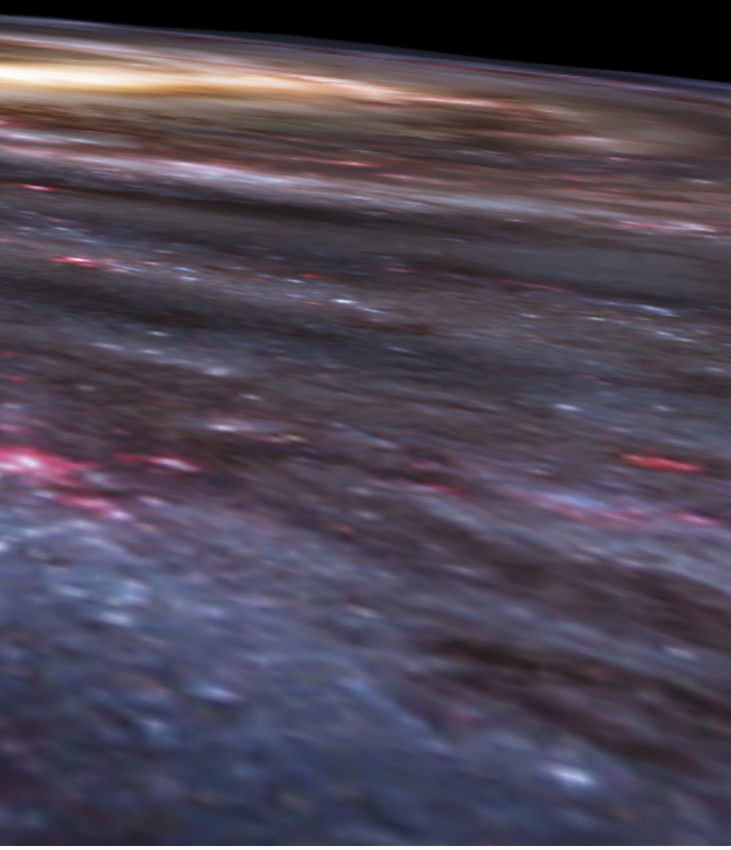
WORLDWIDE TELESCOPE / COURTESY ALYSSA GOODMAN

Backyard

know the structure of other galaxies — tens of millions of light-years away — much better than we know the structure of what lies within a few thousand light-years of the Sun.

As a galactic cartographer, I aim to change that. The goal of my research is to build more accurate maps of the Milky Way's structure. I care about the nitty-gritty details in artists' impressions because to know our galaxy's structure is to know its history, and in particular, the history of its youngest stars. In this article, I'll present work my collaborators and I have done to map stellar nurseries in the solar neighborhood. Our research reveals a hitherto-unseen, colossal gaseous structure; forces a revision to the shape of the closest spiral arm in maps of our galaxy; and sheds new light on how the baby stars in our corner of the Milky Way may have formed.

I care about the nitty-gritty details in artists' impressions, because to know our galaxy's structure is to know its history.



The Distance Dilemma

To turn 2D images of the night sky into a 3D model of the Milky Way, we first need to know how far away things are. Yet distances have been a challenge in astronomy for as long as the field has existed. My favorite example of the need for accurate distances is the Great Debate, which took place in 1920 between the astronomers Harlow Shapley and Heber Curtis. They were debating whether celestial objects known as "spiral nebulae" were small and nearby or big and far away — because confusion about distance leads to confusion about size.

Curtis argued that the Sun sat near the center of a small Milky Way and that spiral nebulae were external galaxies. In contrast, Shapley argued that spiral nebulae were nearby gas clouds, and that the universe contained only one very large galaxy, with the Sun situated far from its center.

Over the next decade, new observations largely resolved the debate — and proved the two astronomers both right and wrong. In the mid-1920s, Edwin Hubble observed and analyzed Cepheid variable stars in Andromeda, the closest spiral nebula. He deduced that the nebula was much farther than even Shapley's proposed extent of the Milky Way. Andromeda had to be an external galaxy separate from our own, as Curtis had argued. But history ultimately proved Shapley the winner regarding both the Milky Way's large size and the location of our Sun closer to its outskirts.

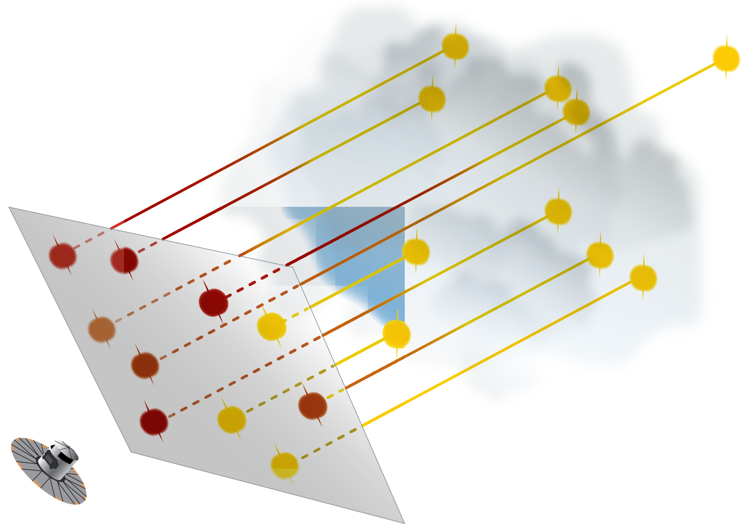
◀ **THE RADCLIFFE WAVE** A new technique is showing the Milky Way in 3D, revealing previously unseen structures like the Radcliffe Wave, a sinusoidal alignment of stellar nurseries.

The Nearest Stellar Nurseries

A century later, many themes surrounding the Great Debate persist, with entire subfields devoted to finding distances to a variety of celestial objects. Some objects, such as Hubble's Cepheid variables, are much easier to measure distances to than others.

In 2018, as a third-year PhD student at Harvard University, I set out to find distances to a class of celestial objects that presented a particular challenge: interstellar gas clouds. These are enormous clouds of gas occupying the space between the stars within our Milky Way.

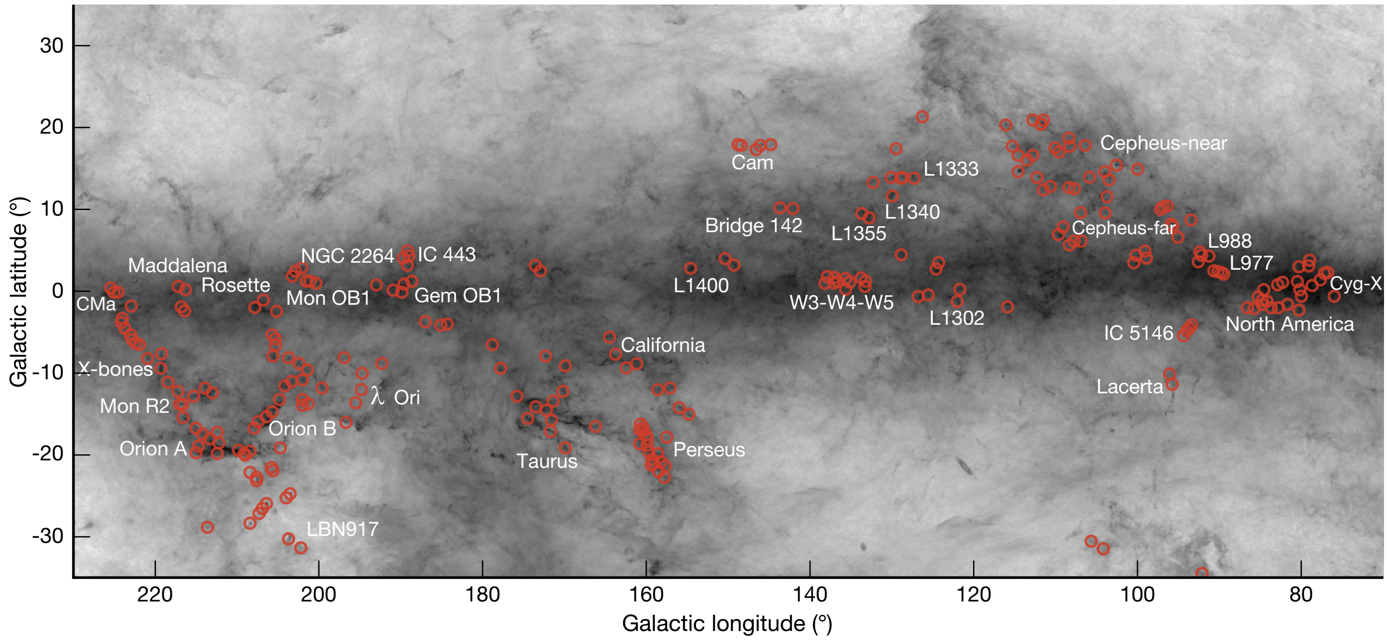
Our targets were specifically interstellar gas clouds in the solar neighborhood. These nearby clouds are of interest because they are the closest sites of star formation: They contain pockets dense enough to collapse under their own gravity and give birth to new stars. Given their proximity, these interstellar clouds have informed much of our knowledge about the intricacies of the star- and planet-formation process. Stellar nurseries are also one of the best tracers of the Milky Way's pinwheel structure, because those spiral arms constitute traffic jams of material where denser gas builds up (*S&T:* Mar. 2023, p. 14).



▲ **IN BETWEEN** Dust reddens stars' colors, much as our atmosphere reddens the sunset. Since astronomers infer what stars' colors should be (all shown here as yellow) as well as their distance, we can deduce how much dust lies between us and them, and how far away that dust is.

▲ **DUST MAP** Determining the distances to dusty, star-forming clouds enables astronomers to map out their distribution across our local neighborhood, as shown in this data visualization. (See additional visualizations at **https://bit.ly/dustmaps**.)

DUST-MAPPING DIAGRAM: BEATRIZ INGLESSIS / *S&T*; SOURCE: ALYSSA GOODMAN; ARTIST'S CONCEPT OF ACTUAL DUST MAP: GREGORY GREEN / CC BY-SA 4.0 DEED



▲ **HIDDEN IN PLANE SIGHT** Viewed in the plane of the sky, facing away from our galaxy's center, the Radcliffe Wave is invisible. It's only when astronomers create a 3D map of the nearby stellar nurseries (red circles) that the wave reveals its shape. (Not all of the nurseries shown are in the Wave.)

J. ALVES ET AL. / *NATURE* 2020

Without precise distances, it is difficult to pinpoint even the most basic properties of these interstellar gas clouds, such as their size or mass — let alone their distribution in the galaxy. With the goal of helping astronomers better understand how stars form, I set out to chart the distances to the closest clouds with more accuracy than ever before.

But these clouds are simply dense blobs in a continuous distribution of mostly hydrogen and helium gas known as the *interstellar medium*. How does one find distances to structures with no finite boundaries or sharp edges? To do so, I needed help from a space mission called Gaia.

A 3D Dust-Mapping Revolution

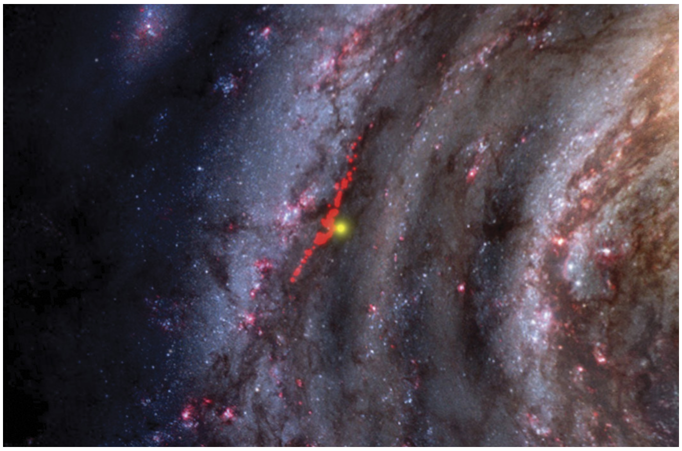
One of the leading goals of the Gaia mission, launched in 2013, is to reveal the 3D structure of our Milky Way by providing accurate distances to more than 1 billion stars, about 1% of the total number of stars in our galaxy. While an early-1990s mission, Hipparcos, provided distances to more than 100,000 stars out to a few hundred light-years from the Sun, Gaia now measures distances to stars 200 times more accurately and over a much larger volume of our galaxy (*S&T:* Feb. 2023, p. 34).

Gaia provides distances to *stars*, though, and I wanted to find distances to the stuff *between* the stars. Key to solving that puzzle is the composition of the interstellar medium. About 99% of the mass of the interstellar medium is hydrogen and helium gas, but about 1% is dust: tiny, sooty particles composed of heavier elements like silicon and carbon. Dust has an outsize influence on how we view our night sky due to an effect called *reddening*, in which dust absorbs and scatters blue light more than red light. The effect makes stars appear redder than they would if no dust lay between us and them. (A similar effect causes sunsets to appear red.) How reddened a star becomes depends on how much dust its light passes through before reaching our telescopes.

Historically, astronomers considered dust a nuisance, an obnoxious smoke-like substance that obscures our view of the cosmos. For me, though, dust was not a nuisance but a boon, because encoded in the color of every reddened star is information on how much dust the light has passed through on its way to Earth. And now thanks to Gaia, we know many stars' distances. Each of these stars thus helps reveal the distance of the dusty clouds, since the dust must lie closer than the star does for us to observe this reddening effect. The idea that the colors and distances of stars can tell us the distances of interstellar clouds underpins a technique known as *3D dust-mapping*.

Imagine we want to use 3D dust-mapping to find the distance to the Orion Nebula — one of the most famous nearby regions of massive star formation. Stars are scattered throughout the dusty cloud in 3D, but as seen in a 2D image of the nebula, everything is projected onto the flat plane of the sky. Yet stars behind the cloud (at greater distances) will on average have more reddened colors than stars in front of the cloud (at lesser distances). If we combine the colors of stars with their distances from Gaia in this patch of the sky, we will find a distance where a jump in reddening occurs. That jump must be the distance of the cloud.

In reality, the situation is more complicated, because not every star is the same intrinsic color in the absence of dust. However, thanks to the precision of large photometric surveys (which provide constraints on stellar colors sampled at dif-



▲ **BIRD'S-EYE VIEW** A top-down view of the Radcliffe Wave in the Milky Way shows its linear shape from that angle. The Sun is the yellow star (not to scale) next to the Wave.

ferent wavelengths), data-science techniques, and a lot of computing hours, it is possible to account for these effects.

While 3D dust-mapping existed prior to Gaia, astronomers used solely stellar colors. Those maps had low resolution because there's only so much information about distance and dust that you can squeeze out of stellar colors. Gaia's distance measurements aren't based on stars' colors, and adding its results provided a huge resolution boost, improving our accuracy by a factor of five essentially overnight. With the deluge of stellar distances available in Gaia's second data release in April 2018, we had all the necessary data to finely chart the distances to nearby stellar nurseries for the first time.

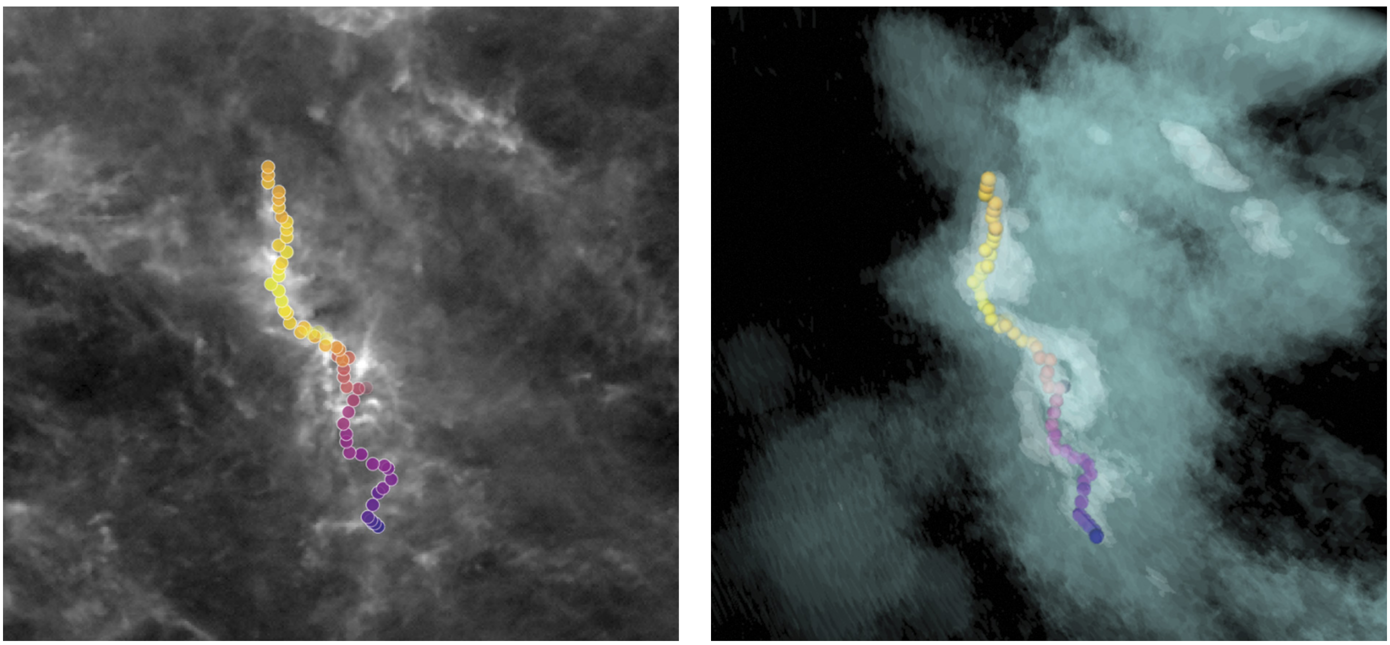
Rise of the Radcliffe Wave

In collaboration with fellow PhD student Josh Speagle and under the auspices of Doug Finkbeiner's 3D dust-mapping group, I spent that summer developing our new Gaia-informed 3D dust-mapping pipeline and applying it to nearby stellar nurseries. However, it was not until later that fall, when we started collaborating with João Alves (University of Vienna), that we started to see a pattern.

João, who was spending his sabbatical year working on Gaia data as a fellow at Harvard's Radcliffe Institute, came to me with a kernel of an idea. He had been staring at previous 3D dust maps (the ones built on stellar colors alone) and thought he saw the barest hint of a physical connection between the Orion Nebula and a second stellar nursery, called Canis Major OB1.

By transforming the new distances into an updated 3D map of the gas in this region, we found the two nurseries are indeed connected, forming a 3,000-light-year-long filamentary arc that starts from the midpoint of our galaxy's pancake-like disk (near CMa OB1) and dips all the way down to Orion, 500 light-years below the disk.

But we did not stop there. Over the following months, in collaboration with Alyssa Goodman (also at Harvard), we mapped more and more of the filament until ultimately its full shape was revealed: a 9,000-light-year-long wave, undulating in and out of the disk, along which tens of thousands of new stars are forming. Named the Radcliffe Wave in honor of João's time as a Radcliffe Fellow, the structure contains a majority of the stellar nurseries in the solar neighborhood (*S&T:* Jan. 2023, p. 26), connecting gas clouds over such a



▲ **BONES** Star-forming clouds, once thought to be roughly spherical in shape, are anything but. These dusty, gaseous regions are arranged in elongated filaments. Using 3D dust mapping, the author and colleagues mapped the Perseus molecular cloud, visualizing the region in 2D *(left)* and in 3D *(right)*. The cloud is densest along its "spine," whose points are colored by distance from near (blue-purple) to far (yellow-orange). View an interactive version of this figure at **https://bit.ly/perseusskeleton**.

RADCLIFFE WAVE, TOP-DOWN: WORLDWIDE TELESCOPE / ALYSSA GOODMAN; FILAMENTARY "BONES": C. ZUCKER ET AL. / *ASTROPHYSICAL JOURNAL* 2021 large range in distances that astronomers never predicted they could be related. Containing around 3 million times our Sun's mass, the wave also represents the largest coherent gaseous structure known in our galaxy.

The Sun lies roughly 400 light-years away from the closest point of this colossus — the wave has been right in front of our galactic noses. While many regions in the wave are visible in the sky with a backyard telescope (*S&T:* Jan. 2023, p. 26), we only discovered it now thanks to the huge boost in 3D dust-mapping's distance resolution that Gaia enabled. With accurate distances, we could finally turn the 2D view of our sky into a 3D view of star formation throughout the solar neighborhood.

So, given that stellar nurseries are excellent tracers of the Milky Way's pinwheel pattern, what's the relationship between this wave-like structure and the nearby spiral arms seen in artists' impressions of our Milky Way? It turns out that — at least as far out as our 3D dust maps can see — the Radcliffe Wave is the gaseous reservoir of the nearest spiral arm to our Sun, dubbed the Local Arm.

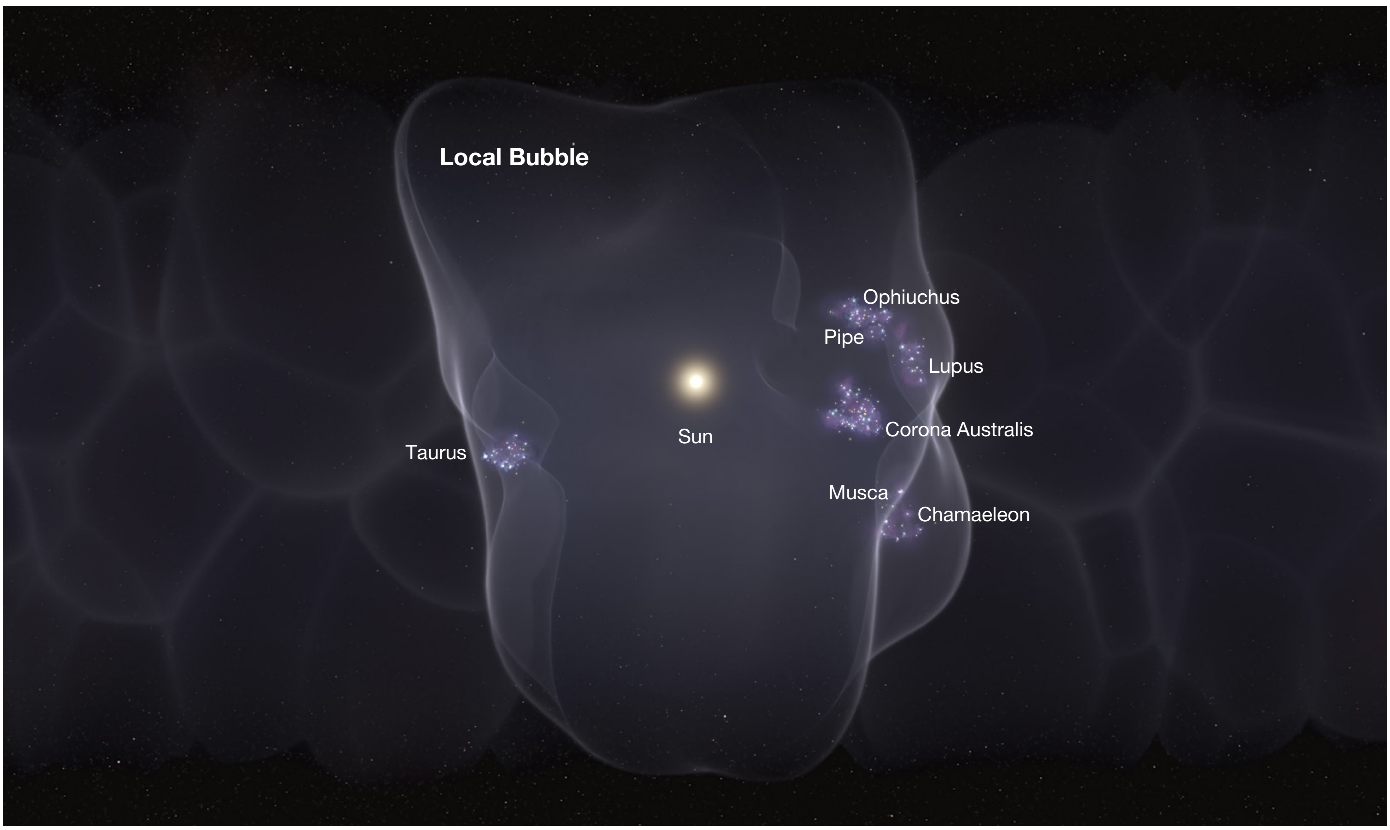
Previous pictures, which relied on the stellar nurseries sparsely scattered throughout the galaxy, had suggested that the Local Arm lies nestled within the Milky Way's pancake-disk when seen edge-on. Artist's impressions show it as having an arc shape when seen from above the disk, kind of like a chocolate swirl in the batter.

But our new view, using the galaxy's ubiquitous dust to trace where gas lies, suggests a different, much more dynamic picture. Rather than being flat when seen edge-on, the Radcliffe Wave dips above and below the midpoint of the disk's central plane, with an amplitude of about 500 light-years. This amplitude is about three times larger than the thickness that astronomers have traditionally assumed for the Milky Way's dense gaseous disk, out of which stars form, based on approaches that average over the entire galaxy. And rather than curving when seen bird's-eye, the wave is straight, stretching about 25 times as long as it is wide.

In fact, on large scales, all spiral arms may be made up of a series of such linear sections. It's only when stuck together that they make a curved shape, like a long train of boxcars rounding a bend in the tracks (*S&T:* Mar. 2023, p. 14). Needless to say, we now need a new artist's impression of our galactic backyard.

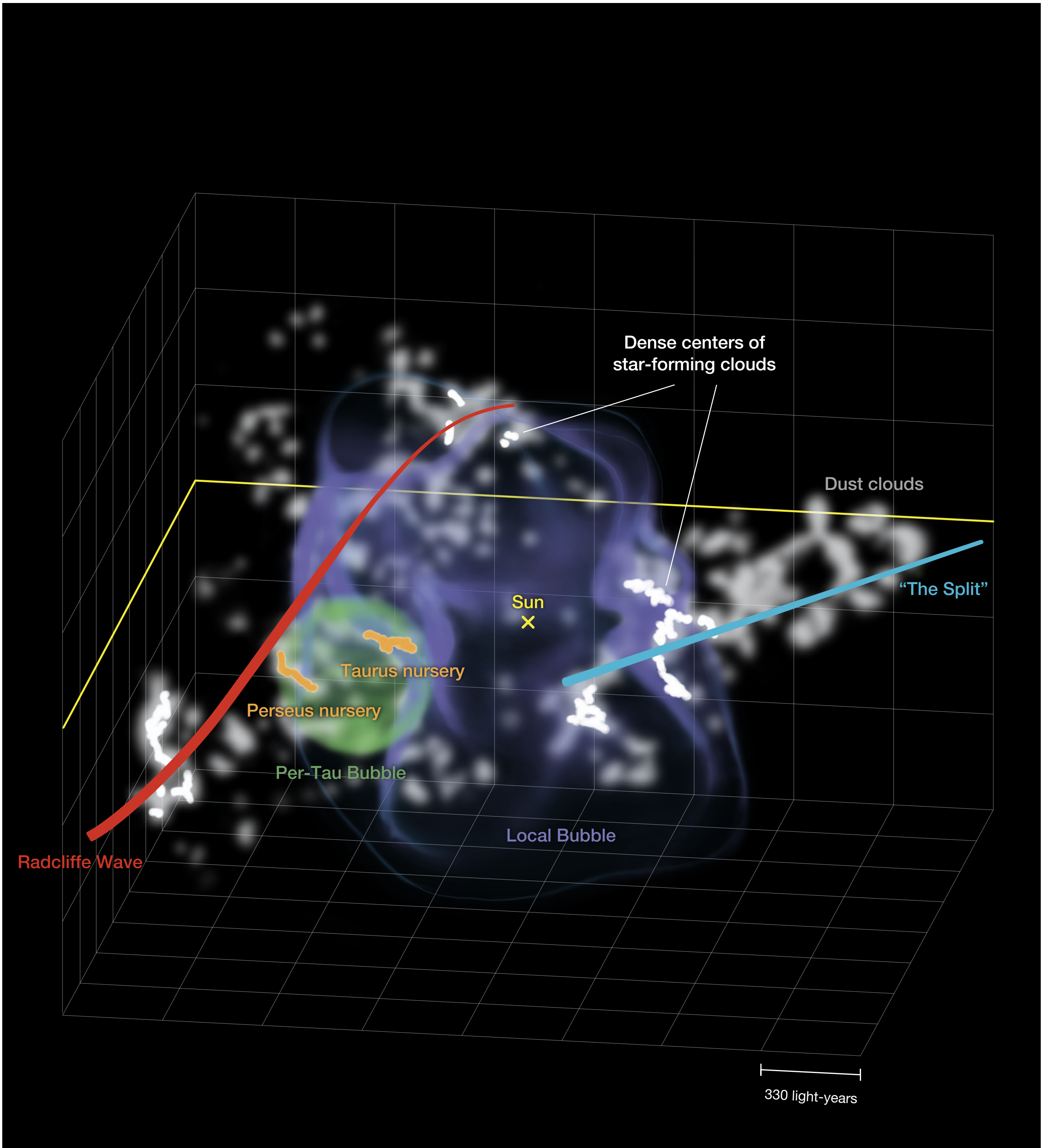
Origin of an Undulation

The wave's peculiar shape also has profound implications for how the youngest stars in our local Milky Way may have formed. To understand the formation of these youngest stars, though, we need to understand the formation of the wave. One culprit could be an external source of disturbance — a clump of dark matter or an infalling cloud of gas hitting the disk of the Milky Way would have shaken the disk up, like a



▲ **NEW LIFE** As the Local Bubble expands outward, it sweeps up gas like a snowplow, compressing it until stars begin to form. 3D dust-mapping has revealed that stellar nurseries line the edges of the Local Bubble.

CENTER FOR ASTROPHYSICS, HARVARD & SMITHSONIAN / LEAH HUSTAK (STSCI)



OUR NEIGHBORHOOD The 3D dust-mapping technique has revealed a map of our Sun's surroundings. Dusty gas clouds appear gray, and denser star-forming regions are white. The Sun, marked with a yellow X at center, is traveling through the Local Bubble (purple), a supernovae-carved cavity. The nearby Radcliffe Wave (red line) extends along the red line from the stellar nursery CMa OB1, through Orion, Perseus, and Taurus nurseries, and on to Cepheus. The Perseus and Taurus nurseries (orange) are about halfway up the wave. These nurseries sit on the edge of the Per-Tau shell (green), another bubble-like cavity. Several stellar nurseries are also found along the roughly 5,000-light-year-long spur nicknamed "The Split," which follows the blue line. (See this visualization in 3D at https://bit.ly/3DLocalMap.)

pebble making waves in a pond's surface. However, origins closer to home are also possible: A series of supernova explosions might have pushed the disk's gas hundreds of light-years beyond the midplane of the disk.

Thanks to Gaia's third data release in 2022, we are closer to discriminating between such ideas. Unlike Gaia's second data release, which mainly provided information on the 3D positions of stars, the third release also includes constraints on the 3D *motions* for millions of stars, including many that are still forming within the wave. These young stars inherit the motion of their natal clouds and act as proxies for the gas's motion, which is much more difficult to measure.

Using the 3D motions of the wave's baby stars, new work by Harvard PhD student Ralf Konietzka shows that the Radcliffe Wave doesn't just *look* like a wave, but it also *moves* like a wave. In other words, it is oscillating.

The oscillation is consistent with being what physicists call a *traveling wave*: Like waves propagating over the open ocean, the crests and troughs of the Radcliffe Wave shift position with time, so the gas disk in this section is never completely level. The baby stars forming in the wave act similar to buoys, bobbing up and down and revealing the rippling motions of the gaseous disk. Comparing the specifics of this oscillation with predictions from computer simulations should ultimately shed light on exactly how the wave formed.

One thing, however, that the wave has already taught us is that star formation is much more dynamic than previously thought. Nearby stars do not form in static blobs of gas that evolve gently in isolation. As our Milky Way's disk is bombarded by external disturbances from outside and by supernova explosions from within, its gas is repeatedly shaken and stirred; as a result, star-forming clouds likely disperse quickly.

Our Sun passed by the Radcliffe Wave roughly 13 million years ago and now lies (by chance) at the Local Bubble's center. The dynamic nature of star formation means that the part of the galaxy we are leaving behind may appear unrecognizable 13 million years in the future. The artists' impressions of today are not the artists' impressions of tomorrow.

From Distances to Shapes

The 3D dust-mapping revolution has accelerated even faster than I could have predicted. Thanks to advances in data-science techniques led by Torsten Enßlin's group at the Max Planck Institute for Astrophysics, the field has shifted from being able to determine distances to clouds to being able to outline their shapes. We can now figure out not just where clouds are, but what they look like.

Analyzing the shapes of dense clouds in and beyond the Radcliffe Wave in 3D for the first time, we recently found that they are not spherical (as traditionally assumed) but rather shaped like filaments. We've found that these stretched-out clouds in turn appear to be intimately related to cavities of tenuous gas carved out by supernovae.

When we matched up the orientation of these filaments with the walls of cavities around supernovae, we found that the closest clouds are draped over these cavities' boundaries. Like a snowplow that sweeps up and compacts snow on the edge of its blade, these supernovae sweep up the ambient gas, evacuating the cavities and leading to a pile-up of denser gas along their surfaces.

Our Sun happens to be traveling through the center of one of these supernova-swept cavities, called the Local Bubble. We've found that this bubble is actually still expanding, sweeping up and compacting the gas in the closest region of the Radcliffe Wave.

In fact, such bubbles are everywhere — in the wave and around it, with a huge range of sizes. Those inside the wave carve out its gas, while those outside push it this way and that. The entire wave looks like holey string cheese (made of Swiss instead of the traditional mozzarella).

This means that nearby star-forming clouds do not just lie *in* the Radcliffe Wave, but they also lie *on* the surfaces of bubbles. Stellar death therefore likely plays a role in shaping stellar birth — regardless of whether supernovae are ultimately responsible for the wave's overall undulation.

The Hidden Milky Way

Despite these exciting discoveries made close to home, the solar neighborhood ultimately represents a small suburb within the sprawling metropolis that is the Milky Way. About 90% of our galaxy is yet to be fully resolved with 3D dust-mapping, including the entire half of the Milky Way located on the other side of our galaxy's center. Such vast distances are largely beyond the reach of current visible-light observatories, even those as powerful as Gaia.

To unlock the hidden Milky Way, we must turn to the next generation of observatories, including the Nancy Grace Roman Space Telescope, set to launch between late 2026 and early 2027. With a field of view about 100 times larger than that of the Hubble Space Telescope and equipped with an infrared camera to peer through the heart of our Milky Way's dusty disk, Roman will open new doors for understanding the structure and dynamics of our galaxy. I and many other galactic astronomers are advocating for a survey of the disk with Roman. Such a survey will constrain the colors of tens of billions of stars, a subset of which would also have accurate distances — the two key ingredients necessary for building reliable 3D dust maps over the remaining 90% of our Milky Way.

The Copernican principle tells us we are not privileged observers of the universe, so we cannot happen to lie right beside the only example of a bubbly, sinusoidal wave of stellar nurseries in our galaxy. There must be more out there, waiting to be discovered. With next-generation space telescopes like Roman, we will be on the hunt to find them.

■ **CATHERINE ZUCKER** is an astronomer based in Cambridge, Massachusetts. She spends her days combining data science, data visualization, and gigantic ground- and space-based surveys to better understand the galaxy we call home.

Exploring the Lion's Den

Are you brave enough to enter and discover what treasures this celestial feline hoards?

Leo, the beloved celestial Lion, is one of the most recognizable constellations in the spring sky. It's also the 12th largest, covering nearly 950 square degrees. Within its borders are five Messier galaxies (not to mention a few obvious misses!) and a dizzying array of others ranging from a distance of less than a million light-years to more than 2 *billion* light-years. And they can all be seen in amateur telescopes. On this expedition, we'll start inside our own Milky Way Galaxy — just 7.9 light-years away, in fact — with a star, before heading deeper and deeper into the extragalactic den.

Selection of Stars

The best-known *high-proper-motion* star in Leo is the 13.5-magnitude red dwarf **Wolf 359**. German astrophotographer Max Wolf first noticed its relatively rapid proper motion of 4.7″ per year in 1918 — it's currently a bit more than 2° west of 4.6-magnitude Chi (χ) Leonis. In my 6-inch reflector at 56×, it's merely a faint field star in a 1.5° field, while in my 16-inch Dobsonian at 300× I could discern an off-white color.

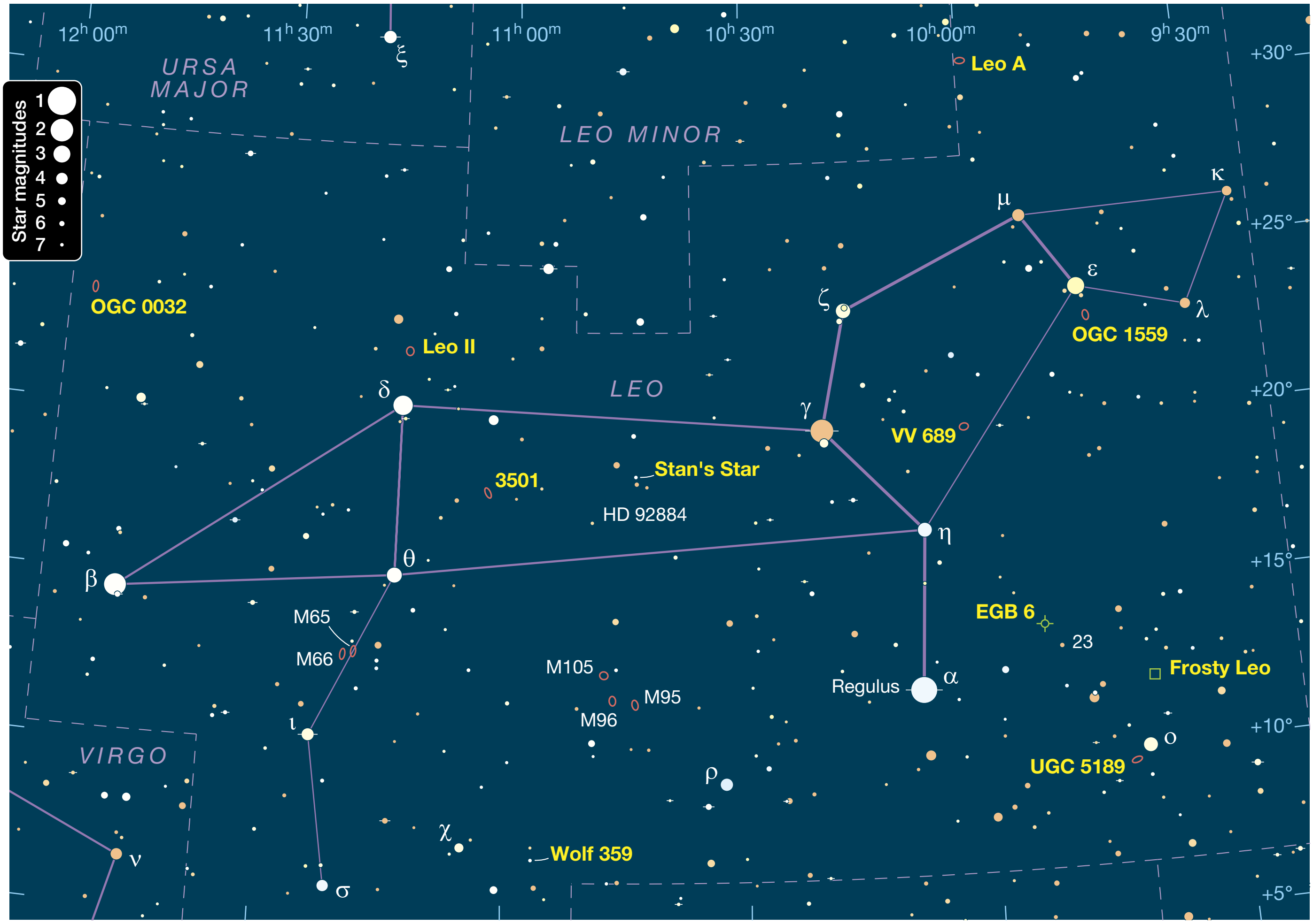
I also know of a high-proper-motion star in Leo that was discovered *visually* a bit less than a century later than Wolf's find. On May 4, 2010, Kansan amateur astronomer Stanley Howerton was star-hopping between two faint galaxies in central Leo using his 17.5-inch Dob when he noticed something odd. He saw two stars of magnitudes 13.5 and 14.7 some 18″ apart, even though the photographic chart he had in hand showed only a single star. Intrigued, he got on his computer and checked the *National Geographic – Palomar Observatory Sky Survey* (*POSS*) images of the area.

Howerton found that while the 14.7-magnitude star wasn't visible in the first survey images taken in 1952, it *was* visible in the second survey images from 1996. Since the star also appeared in the Sloan Digital Sky Survey images from 2005, he knew it couldn't be an asteroid . . . but was it perhaps an uncataloged variable star? The next day, Brian Skiff (Lowell Observatory) looked into this and quickly solved the mystery. **Stan's Star**, as it's now known, was a previously unidentified high-proper-motion dwarf traveling westward at a bit more than 0.32″ per year. As it happens, in 1952 it was superimposed on the brighter star!

To see it for yourself, look 5.8° east-southeast of 2.4-magnitude Gamma (γ) Leonis and 13′ north of 6.5-magnitude, golden-hued HD 92884. In my 6-inch at 164×, I can make out both Stan's Star and the 13.5-magnitude one with averted vision.

◀ **GALACTIC DANCE** The interacting pair of galaxies known as VV 689 lies at a distance of 700 million light-years and was recently imaged as part of the "Gems of the Galaxy Zoo" Hubble Space Telescope program (see *S&T:* Oct. 2023, p. 20).

ESA / HUBBLE / NASA / W. KEEL



▲ **IN THE LION'S DEN** While Leo, the Lion, is one of the most recognizable constellations in the sky, for owners of small- to medium-size telescopes it offers a wealth of unique galaxies and even a few nebulae.

Planetary and Pre-Planetary Nebulae

Astronomers have identified planetary nebulae in nearly every constellation, and Leo is no exception. But have you heard of **EGB 6**? Glenn Ellis, Earl Grayson, and Howard Bond (all then at Louisiana State University) first reported Leo's one and only planetary nebula in 1984 — at 11′ × 13′, its unusually large size and low surface brightness being the secret to it escaping detection for so long. They found it by examining paper prints of *POSS* plates held at arm's length!

To locate this old, 10th-magnitude planetary, look 4.2° northwest of Regulus or about 0.8° northeast of 23 Leonis. My first look at it came around two years ago in my 5.1-inch reflector at 34× with the aid of a DGM Optics Narrow Pass Band (NPB) filter. But my best view came a year ago in my 6-inch reflector since it can achieve a wider true field. At 25× and 39×, the planetary's somewhat amorphous disk was more distinct and slightly easier to see with the NPB filter than with an O III filter.

Pre-planetary nebulae are short-lived and hence rare — they represent the ephemeral phase a low- to intermediate-mass star goes through before evolving into a planetary nebula. Astronomers identified the first examples of pre-planetaries in the 1940s, but it was several decades before they understood them better. The brightest in the sky is . . . you guessed it, in Leo! It's known fondly as the **Frosty Leo Nebula** due to its abundance of silica dust grains coated with ice. The Infrared Astronomical Satellite detected it in 1983 (which is reflected in the nebula's official designation), as pre-planetary nebulae largely emit scattered light in the infrared and optical.

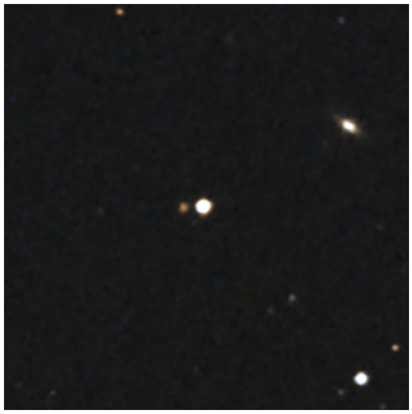
The first time I saw the Frosty Leo Nebula was in 2015, but viewing it two years later in my handheld 8×56 binoculars forever gave it a special place in my heart. In fact, it was one of the first objects I looked at after acquiring my 16-inch in 2022. With that telescope at 105×, it appeared barely nonstellar at around 11th magnitude just 1′ southwest of a 12.6-magnitude star. But increasing to 300× revealed a very small, high-surface-brightness glow tinged with an impressive blue color that appeared elongated roughly north-south. At 600×, the glow split into two cores, with the fainter one at the northern end. I never thought to look for its *ansae* (extensions), but Contributing Editor Bob King has detected the northern one in his 15-inch Dobsonian at 400×.

Challenging Dwarfs

Contributing Editor Steve Gottlieb covered Leo I and Leo II in his article about dwarf spheroidal galaxies in the October 2023 issue (page 57). But I was surprised to read that he observed **Leo II** — the Milky Way's second-most remote satellite — with his 18-inch. Ever since my first view of it in my trusty 10-inch Schmidt-Cass eight years ago, its brightness has continually surprised me!

In fact, just two years ago, with Leo II near the zenith and my Sky Quality Meter (lensed) reading 21.50 in the area, I looked for the galaxy 1.6° north of 3rd-magnitude Delta (δ) Leonis. In my 10-inch at 94×, it was a very soft, round glow with a 13.4-magnitude star that I could tell is slightly displaced north of the 12th-magnitude galaxy's center. On a whim, I got up and walked over to my 5.1-inch and tried the same. Using 59×, I could *just* detect Leo II as a very faint, round glow 5′ across centered on a 13th-magnitude star. I almost couldn't believe it! Steve was certainly right when he mentioned "the visibility of dwarf spheroidal galaxies mainly depends on the darkness and transparency of the sky, along with the observer's experience. A large telescope isn't necessarily a requirement." Can you make it out?

While we'll visit several fascinating galaxies on this tour, this next one is probably one of the more intriguing. Fritz Zwicky discovered **Leo A** photographically, while Walter Baade determined its distance and likely group membership less than five years after Edwin Hubble coined the term "Local Group."



◀ **PEEKABOO STAR** Amateur astronomer Stanley Howerton was surprised to find an object where there shouldn't have been one. It turned out that the object that today is named for him is a high-proper-motion star that had moved some 18″ from its position in the *POSS* plate taken in 1952 (at left) to when he observed the area in 2010. The image at bottom is the *POSS* plate from the second survey in 1996.

Leo A lies at the outskirts of the Local Group and is among the most isolated of the nearby galaxies — and astronomers believe that it will continue to stay that way essentially forever. In a 2007 article, Andrew Cole (then at the University of Minnesota) and his colleagues wrote, "Dwarf galaxies are the most common class of galaxy in the universe, which gives them significance far beyond their mass." Talk about a coincidence — later that year, Warren Brown (Smithsonian Astrophysical Observatory) and collaborators published a study that reported that the dwarf galaxy contains at least four times as much dark matter as luminous matter!

On the same exceptional night that I observed Leo II with my 5.1-inch reflector, I also attempted Leo A. It lies 5° north-northeast of the 4th-magnitude Sickle star Mu (μ)

Treasures in the Lion's Den

Name	Designation	Mag(v)	Size	Distance (l-y)	RA	Dec.
Wolf 359	Gliese 406	13.5	—	7.9	$10^h 56.5^m$	+07° 01′
Stan's Star	2MASS J10435622+1831478	14.7	—	600	$10^h 43.9^m$	+18° 32′
EGB 6	PN G221.5+46.3	10.4	11′ × 13′	2,840	$09^h 53.0^m$	+13° 45′
Frosty Leo Nebula	IRAS 09371+1212	11.0	0.5′ × 0.3′	10,000	$09^h 39.9^m$	+11° 59′
Leo II	UGC 6253	12.0	12′ × 11′	760,000	$11^h 13.5^m$	+22° 09′
Leo A	UGC 5364	12.6	5.0′ × 3.2′	2.7 million	$09^h 59.4^m$	+30° 45′
NGC 3501	—	12.9	3.9′ × 0.5′	75 million	$11^h 02.8^m$	+17° 59′
UGC 5189	CGCG 063-048	13.2	1.8′ × 0.7′	150 million	$09^h 42.9^m$	+09° 28′
VV 689	CGCG 093-025	—	0.5′ × 0.5′	700 million	$10^h 01.7^m$	+19° 48′
OGC 1559	CGCG 122-067	~14.9	0.8′ × 0.6′	1.2 billion	$09^h 44.9^m$	+22° 53′
OGC 0032	MCG +04-28-097	~15.4	0.2′ × 0.1′	1.8 billion	$11^h 55.3^m$	+23° 24′

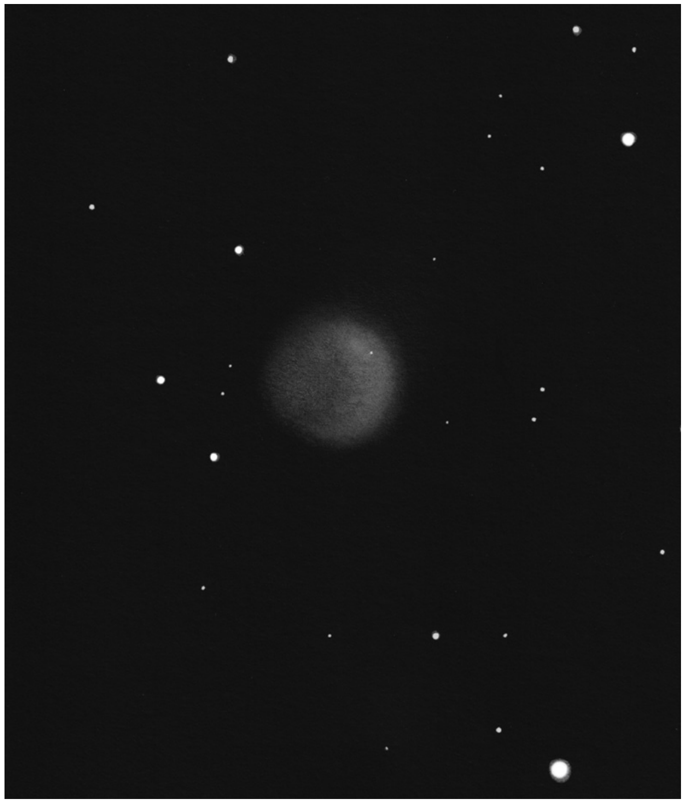
Angular sizes are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY (2)

Leonis and a mere 0.2° from the border with Leo Minor. I was pleased to again find that — as for Leo II — at 59× I could just glimpse Leo A with averted vision as a 12.6-magnitude little smudge 3′ southwest of an 11.4-magnitude star! And using my 10-inch at 94×, with averted vision the galaxy was still a surprisingly distinct glow that spanned roughly 2.5′ × 0.8′.

Galaxies Galore

For those who love observing galaxies night after night, *flat galaxies* offer an exciting and challenging subset. These are spiral galaxies seen edge-on with little-to-no nucleus to upset their sleek figures. After observing several examples in Leo culled from amateur astronomer Alvin Huey's *Observing Flat Galaxies* field guide, **NGC 3501** is the one I found to be the longest and brightest.



▶ **ELUSIVE PREY** The planetary nebula EGB 6 likely escaped detection until 1984 due to its large size and low surface brightness, and even then it was only noticed when a group of researchers carefully examined paper reproductions of images. This sketch was made at the eyepiece of an 8-inch f/4 Newtonian at 31×.

▼ **IN THE FAR REACHES** Leo II, a dwarf spheroidal galaxy, is the second farthest from the Milky Way in the Local Group. You'll find it just north of Delta Leonis, the star that marks the Lion's hindquarters. The image below was acquired with a 10-inch f/3.7 telescope.

EGB 6: UWE GLAHN; LEO II: GREGG RUPPEL

To find it, first search for its brighter neighbor, 10.9-magnitude NGC 3507, which is 3.5° southwest of Delta Leonis. It's a face-on spiral that's similar in size and distance to the edge-on, which likely means that the two galaxies are members of the same group. However, be aware that there's an 11.0-magnitude star superimposed very close to NGC 3507's center.

Look for NGC 3501 some 12½′ southwest of NGC 3507. With my 5.1-inch at 34×, 13th-magnitude NGC 3501 is a little, faint slash of light running north-northeast to south-southwest, while in my 10-inch at 94× it's the epitome of an edge-on galaxy. Increasing to 200×, averted vision reveals a sword of light that's slightly brighter at the very center, with a 15.2-magnitude star 2.3′ southeast of the core. It's such an intriguing sight, what with NGC 3507 seemingly hiding behind a star and NGC 3501 looking like the permanent remains of a meteor trail.

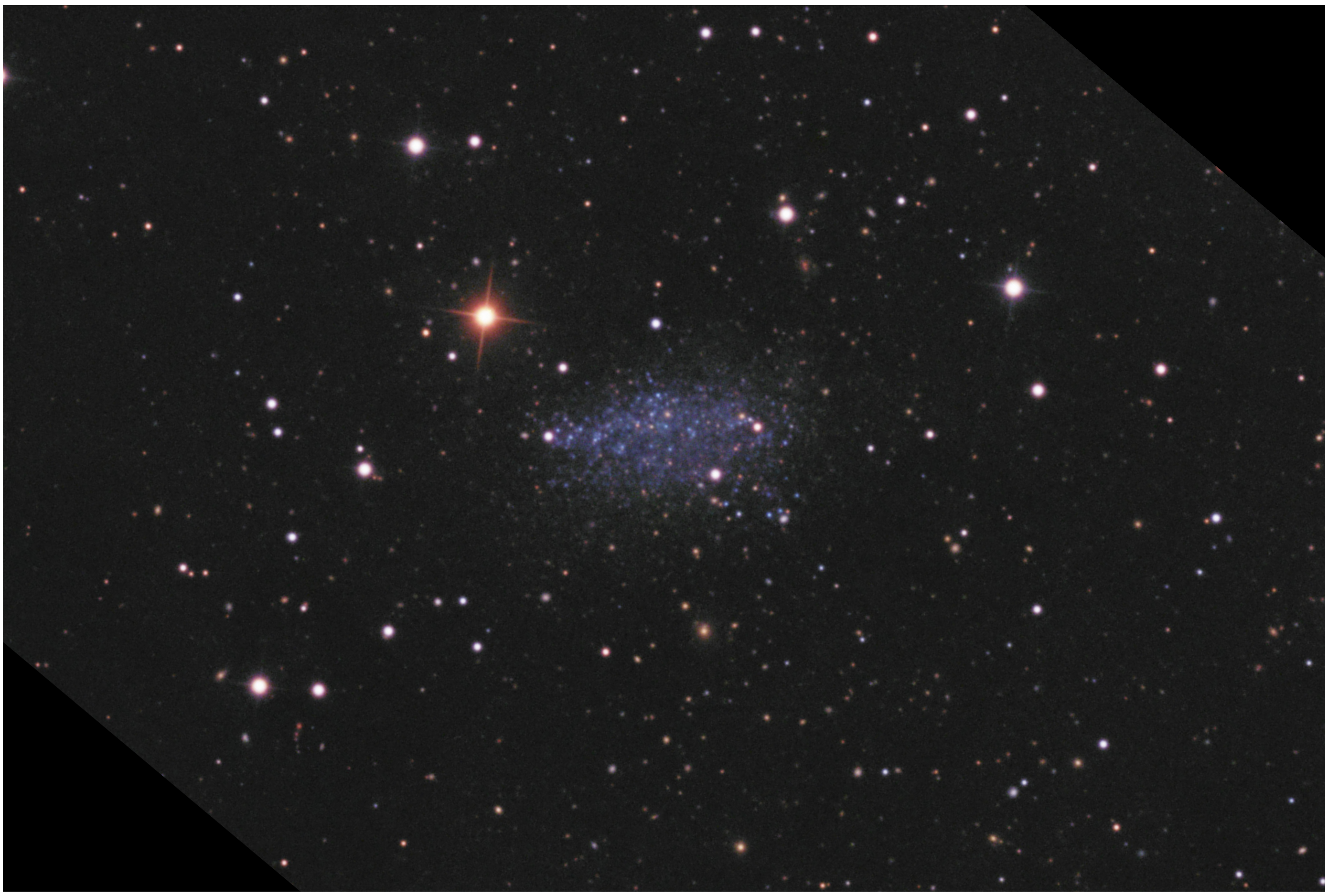
UGC 5189 is an obscure, heavily disturbed galaxy that a French astronomer discovered in February 1906 using the 30-inch refractor at the Nice Observatory. His name was Stéphane Javelle, and even though he's not very well known today, he's credited with having visually found more than a quarter of all the objects in both volumes of the *Index Catalogue* (IC) using that telescope! However, UGC 5189 is just one of 400 additional discoveries Javelle made that for some reason he never published before his death in 1917. Thus, Zwicky and his colleagues were the first to list it in their *Catalogue of Galaxies and of Clusters of Galaxies* in the early 1960s.

Situated in southwestern Leo, 13.2-magnitude UGC 5189 lies just 0.6° southeast of 3.5-magnitude Omicron (ο) Leonis. However, it's hard to spot if you don't know exactly where to look. Trust me. Javelle described and cataloged two distinct objects at the galaxy's location. For the northwestern section (component A), he described it as "Faint, poorly defined, about 40″ . . . looks granulated," while for the southeastern section (component B), he noted it was "Very faint, about round, 20″ × 30″, gradually condensed."

In my 10-inch at 260×, I can discern A as a soft, short, grey smudge running vertically, while at 440× in my 16-inch I can see that smudge and fainter B about 1.5′ to its southeast. With concentration, I can tell that A has a subtle curve to it, and B consists of a compact knot and a faint haze trailing east.

What could have caused such a galactic mess? Well, while astronomers believe UGC 5189 is the result of two dwarf galaxies in the process of merging, a third galaxy may have been involved. The prime suspect sits less than 4′ southwest and lies

▼ **WHAT'S IN A NAME?** Around 1950, astronomers began assigning the "A" designation to objects that were the brightest at radio wavelengths in their constellation. However, Leo A most likely received its designation because it was the first dwarf galaxy found in Leo. The photographer used a 17-inch telescope to obtain this image.

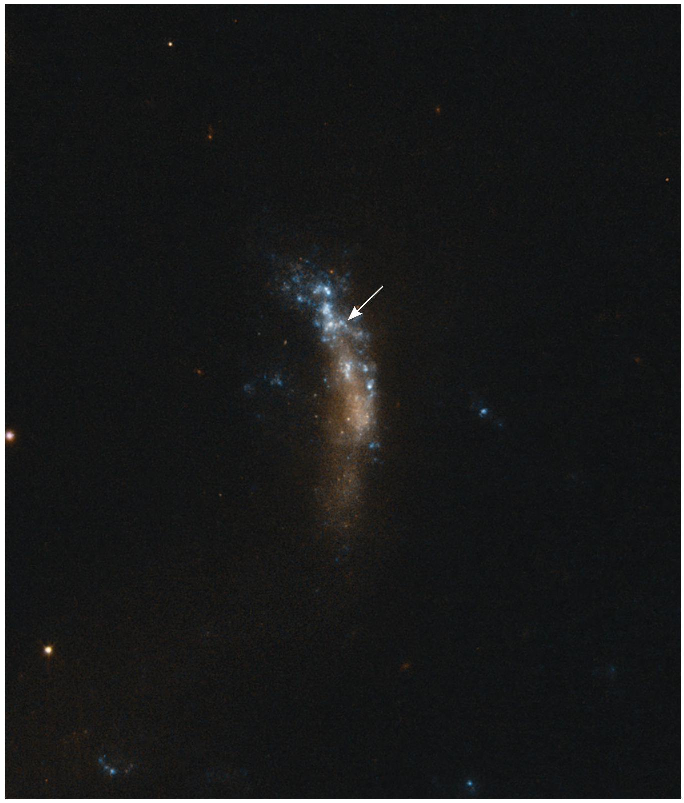


JIM MORSE

at the same distance. Cataloged as LEDA 1365365, I could just detect it as a very small, diffuse glow in my 16-inch at 300×.

Upon seeing the mesmerizing image of the colliding galaxies on page 20 for the first time, I wondered if I could glimpse this object at the eyepiece. Before trying, though, my research revealed that **VV 689** was discovered some 60 years ago on *POSS* plates and mistakenly cataloged by Russian astronomer Boris Vorontsov-Vel'yaminov as an interacting *triple* in his *Atlas of Interacting Galaxies* published in 1977.

I was shocked to find VV 689, which lies 4.3° west of the gorgeous golden double star Gamma Leonis, visible in my 10-inch at 260×! I couldn't hold it steady with averted vision, but it displayed a roundish glow of even surface brightness less than 10″ across. While it was easier to see in my 16-inch at 300×, the details stayed the same. I couldn't resist trying with the motor-driven 36-inch Dobsonian at Whispering Pine Observatories (WPO) in northwestern Arkansas. Only



▶ **SITE OF A SUPERNOVA** The irregular dwarf galaxy UGC 5189 presents two components in the eyepiece, with the northern component (A) having higher surface brightness than the southern one. A supernova, SN 2010jl, exploded in the northern component in 2010 (arrowed).

▼ **EDGE-ON BEAUTY** NGC 3501's dimensions, measuring at least seven times long as it is wide, earns it a place in the *Flat Galaxies Catalogue* that Igor Karachentsev and his colleagues compiled in 1993. An 11-inch telescope acquired this image.

NGC 3501: GARY IMM; UGC 5189: ESA / HUBBLE / NASA in that telescope at 664× did the round glow appear to be unevenly illuminated, and during brief moments I could also detect the main body of each galaxy forming a bright "bar."

Far, Far Out

Another galaxy that was discovered on *POSS* plates some 60 years ago became entry number 1559 in the Ogle Galaxy Catalog. Recently compiled by Patrick Ogle (Space Telescope Science Institute) and colleagues, it lists *superluminous* galaxies out to 3.5 billion light-years. **OGC 1559** is classified as a rare *super spiral* for having eight times the Milky Way's luminosity along with a disk of stars more than twice as wide, too!

Considering OGC 1559's distance of 1.2 *billion* light-years, it's amazing that I could see it with averted vision as a very faint, compact glow in my 10-inch at 260×. Moving up to 440× in my 16-inch, the 15th-magnitude face-on galaxy is clearly a 10″-wide patch. At its edge is a star that became quite evident in the WPO's 36-inch at 664×, while the galaxy itself displayed a bright, diffuse core in a larger, lower-surface-brightness glow.

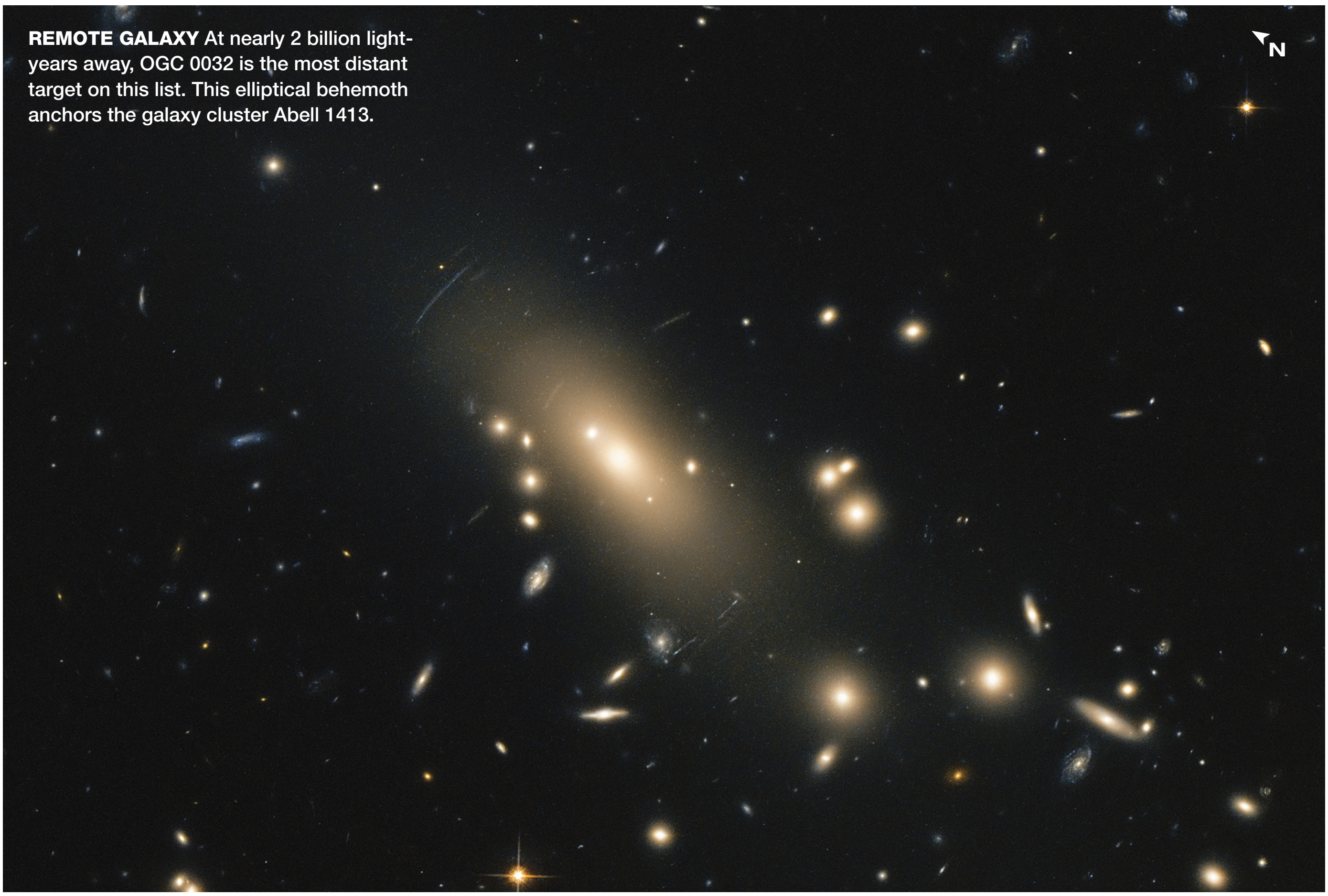
Our final and farthest target lies an incredible 1.8 billion light-years away and yet is still visible in my 10-inch. First cataloged as MCG +04-28-097 and more recently as **OGC 0032**, it's a massive elliptical galaxy at the heart of the galaxy cluster Abell 1413 that, incredibly, is 50% *more luminous* than the much closer M87. Wow!

Astronomers first noticed the object, which is located in far northeastern Leo and just 0.7° west of the border with Coma Berenices, on *POSS* plates in the 1950s, and its measured redshift made it one of the farthest known galaxies at the time. In my 10-inch at 260×, it's hard for my eye to lock onto its position since there's no star visible for 4′ in any direction. When it does, I see a faint, ghostly glow . . . which doesn't sound like much, but it's the farthest *nonstellar* object I've seen in that scope! Using my 16-inch at 300×, it still takes a moment to pin down, and it's hard for me to tell if it's elongated or not.

Surprisingly, OGC 0032 is not the end of the line for how far you can see in Leo with a 10-inch. The stellar, 14.7-magnitude (but variable) quasar PG 1116+215 — not far from Leo II, in fact — will help you break the 2-billion-light-year barrier. But I hope this all-too-brief tour in the celestial Lion has left you as amazed as I am at the variety it holds and reminds you that there's always more to see!

■ Contributing Editor **SCOTT HARRINGTON** hopes you'll forgive him for cutting his own trail through the jungle to visit his friend Leo. He can be reached at **sn4ark@gmail.com**.

FURTHER MATERIAL: You can purchase Alvin Huey's field guide *Observing Flat Galaxies* at **https://is.gd/alvin_huey_guides**. Go to **https://is.gd/ogle_catalog** for data on other galaxies in the *OGC*.



REMOTE GALAXY At nearly 2 billion light-years away, OGC 0032 is the most distant target on this list. This elliptical behemoth anchors the galaxy cluster Abell 1413.

Eclipse Expeditions that "Discovered" the Sun

In the mid-19th century, astronomers were astounded to see unexpected and spectacular phenomena during totality.

Peculiar fact: Initial major discoveries about the physical structure of the Sun in the 19th century were made when its brilliant face was utterly blocked from sight. Moreover, the discoveries were accidental — a classic case of serendipity. Astronomers were seeking something entirely different (and entirely terrestrial) but instead beheld wondrous, unexpected solar phenomena that ultimately launched the discipline of solar physics.

A little context is crucial. As many of us prepare to witness the April 8th total solar eclipse, it's worth contemplating how fortunate we are to be able to do so with such ease. Some readers will take in the spectacle from their own homes, while many others will simply get in their cars and drive to the eclipse path. Still others will board a commercial airplane and fly for a few hours to reach the centerline. From our 21st-century, GPS-enabled vantage point today, it's difficult to fathom just how different the world was just two centuries ago. In 1824, there was no telegraph, telephone, or other means of instantaneous communication beyond the line of sight. There were few truly accurate clocks. There was no electric power. Great Britain's first steam-powered locomotive ran in 1825, and no rails were yet laid in the still-young nation of the United States. Neither photography nor spectroscopy yet existed. To the degree anyone thought about the physical nature of the Sun, the most influential hypothesis was that of renowned British astronomer William Herschel, who reasoned that the Sun was a giant planetary body that might even be inhabited.

So how did we get from there to here? Much of the credit goes to eclipse expeditions that were launched in the late 18th century and throughout the 19th century.

Of Beads and Prominences

In that era, when Newton's laws of gravity and motion were still being tested, astronomy was prized principally for its value to terrestrial cartography. In the Old World and the New, there was an acute need for both accurate maps on

◀ **IN THE STICKS** Among the remotest sites to which American and French solar eclipse expeditions traveled was Caroline Island, a tiny coral atoll (now part of the independent Republic of Kiribati) located some 3,400 km (2,100 miles) south of the Hawaiian Islands. Caroline Island was almost on the centerline of the eclipse of May 6, 1883, and experienced nearly 5½ minutes of totality. Round-trip, the 22-member U.S.–English expedition — whose camp is shown here — took 101 days and covered more than 24,000 km.

land and navigational charts at sea. Recording contact times during total eclipses of the Sun offered a rare and important opportunity to determine accurate longitude differences of widely separated locations using the then-current theory of the Moon's motion in its orbit.

The need for accurate maps was so pressing that astronomical expeditions were even granted safe conduct behind warring parties' enemy lines. For example, in 1780, during the American Revolution, the just-founded American Academy of Arts and Sciences received (grudging) governmental permission for Harvard astronomer Samuel Williams and nine assistants to have safe conduct for a few days near a British garrison in Penobscot Bay, Maine, to time the contacts of the total solar eclipse of October 27th. "Though involved in all the calamities and distresses of a severe war," as Williams put it, the expedition was allowed to proceed.

What they saw during that eclipse was something quite unexpected. Because of inaccuracies in eclipse calculations and/or available maps, the astronomers set up several small telescopes at a location that happened to be just outside the southern edge of the path of totality. So, instead of seeing distinct second and third contacts, Williams was surprised when ". . . the sun's limb became so small as to appear like a circular thread . . . Both the ends lost their acuteness, and seemed to break off in the form of small drops or stars; some of which were round and others of an oblong figure."

Williams offered no hypothesis to explain the strange phenomenon, but the illustration accompanying his report to the Academy unequivocally shows that he observed the limb of the Sun shining through valleys on the mountainous profile of the Moon — what six decades later Astronomer Royal George Biddell Airy called "Mr. Baily's beads."

However, in 1780, the eponymous British stockbroker-astronomer Francis Baily was just a child of six. Although at least as early as 1820 he had read other accounts describing the same phenomenon Williams saw, Baily did not see it himself until he traveled to Scotland to observe the annular eclipse of May 15, 1836:

> *. . . when the cusps of the sun were about 40° asunder, a row of lucid points, like a string of bright beads, irregular in size and distance from each other, suddenly formed round that part of the circumference of the Moon that was about to enter . . . on the sun's disc. Its formation indeed was so rapid that it presented the appearance of having been caused by the ignition of a fine train of gunpowder.*

After a substantial review of previous sightings (he seemed to have been unaware of Williams's observations), Baily urged astronomers to be on the lookout for the phenomenon during the upcoming solar eclipse of July 8, 1842, during which the path of totality would cross Spain, southern France, and northern Italy.

Baily traveled to Pavia in Italy, where he was offered an upper room of a university building to observe the only total solar eclipse he ever saw. Just before second contact, he wrote, "the beads were distinctly visible." He was measuring their duration by counting seconds on his chronometer when,

> *I was astounded by a tremendous burst of applause from the streets below, and at the same moment was electrified by the sight of one of the most brilliant and splendid phenomena that can well be imagined. For, at that instant the dark body of the moon was suddenly surrounded with a corona, or kind of bright glory, similar in shape and relative magnitude to that which painters draw round the heads of saints, and which by the French is designated an* auréole.

The corona appeared to have a breadth of half the diameter of the Moon and "had the appearance of brilliant rays." Baily thought its color to be "quite white" with a "vivid and flickering appearance," somewhat like gaslight.

But even more remarkable were "three large protuberances apparently emanating from the surface of the Moon, but evidently forming a portion of the corona." They resembled mountains "of prodigious elevation," their color "red, tinged with lilac or purple" or "peach blossom." He was so captivated by the unexpected sight of what we now know to be solar prominences that he forgot to note whether any brilliant beads heralded third contact. Other European astronomers stationed elsewhere along the path of totality, some battling clouds, also reported seeing the corona and similar "red flames" or "fiery red tongues."

The arresting phenomena accompanying totality incited astronomers on both sides of the Atlantic to ask: What were the brilliant beads? Was the gossamer corona an atmosphere of the Sun or the Moon? What caused the prominences? The sightings so awakened fascination with the physical nature and constitution of the Sun that many astronomers vowed to chase and observe every total solar eclipse, no matter how brief the totality, how distant the travel, or how arduous the journey.

Eclipse Reading

With all the publicity surrounding the total solar eclipses of 2017 and 2024, several popular books have been published about historical eclipse expeditions. Recent examples include Steve Ruskin, *America's First Great Eclipse: How Scientists, Tourists, and the Rocky Mountain Eclipse of 1878 Changed Astronomy Forever* (Alpine Alchemy Press, 2017); David Baron, *American Eclipse: A Nation's Epic Race to Catch the Shadow of the Moon and Win the Glory of the World* (Liveright, 2018); and Thomas Hockey, *America's First Eclipse Chasers: Stories of Science, Planet Vulcan, Quicksand, and the Railroad Boom* (Springer Praxis, 2023).

Enduring historical classics include Samual Alfred Mitchell's *Eclipses of the Sun* (Columbia University Press, 2nd ed., 1924); Mabel Loomis Todd's two books *Total Eclipses of the Sun* (Roberts Bros., 1894) and *Corona and Coronet* (Houghton, Mifflin & Co., 1899); and several chapters of Agnes M. Clerke's in-depth *A Popular History of Astronomy During the Nineteenth Century* (Adam and Charles Black, 4th edition, 1902).

But for raw astronomical adventure, there is no substitution for reading the original 19th-century reports of eclipse expeditions at full length, many of which — despite their dry-sounding titles and their publication in official scientific periodicals — describe planning, places, mishaps, and hardships in vivid detail.

The Birth of Adventure Astronomy

Astronomers' interest in the nature of the phenomena they observed during totality came at a propitious confluence of several important independent socio-technical developments. First, the 19th century was a heyday of the European and American age of exploration — of charting "terra incognita." That included adventurous astronomical explorers making precision measurements of long-distance arcs of meridians or parallels of latitude, lugging tons of equipment across waterless deserts or through dense jungles. Second, the 19th century was the heyday of the industrial revolution on both sides of the Atlantic. Improved navigational techniques along with new transportation technologies that included transatlantic steamships and extensive railway systems made far-off lands accessible. Third, fundamental advances in spectroscopy allowed astronomers to begin to understand the chemical composition of celestial objects, including the Sun.

The result? Governments, scientific institutions, and even individual philanthropists were willing to fund eclipse expeditions sent halfway around the world. Making astronomical discoveries had become a matter of high-stakes worldwide national prestige. Small or large, Victorian solar eclipse expeditions were a significant enterprise — some being possibly the most advanced field expeditions of any science. These ranged in size from those comprising a few individuals, to undertakings that required upwards of 50 (including such helpers as carpenters, bricklayers, mule drivers, seamen, and kitchen staff). They necessitated careful planning and overcoming challenging logistics, especially later in the 19th century as instrumentation grew larger and more complex.

One to four years in advance, often via handwritten letters sent through uncertain postal systems, an expedition leader needed to ascertain distant local terrain and meteorological conditions of unknown regions, as well as the presence of plague or unfriendly inhabitants, or the absence of adequate water or food supplies. There would of course be instrumentation to sort out — custom optical and photographic equipment had to be borrowed, purchased, or built. Temporary shelters for both equipment and people would have to be designed and constructed, then disassembled for transportation if wood or other local resources were unavailable at the expedition's destination. Ships or trains had to be chartered or free passage arranged through government officials. And somehow expedition leaders would have to find and hire the local guides the endeavor's success would require.

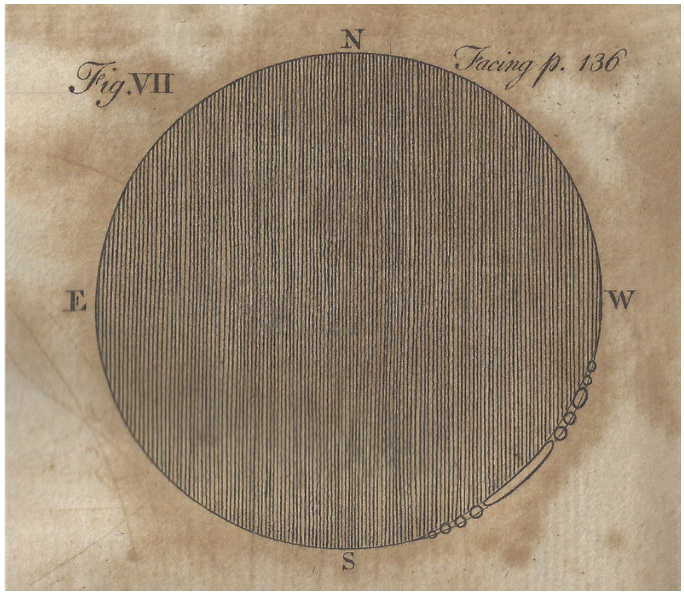
Depending on the location, the travel time could range from weeks to months. And extra time at the destination needed to be added to allow time for meeting local dignitaries, finding and hiring guides, setting up camp, testing equipment, determining precise local coordinates, and rehearsing observing procedures to take full advantage of the precious, fleeting moments of totality.

Risk and Reward

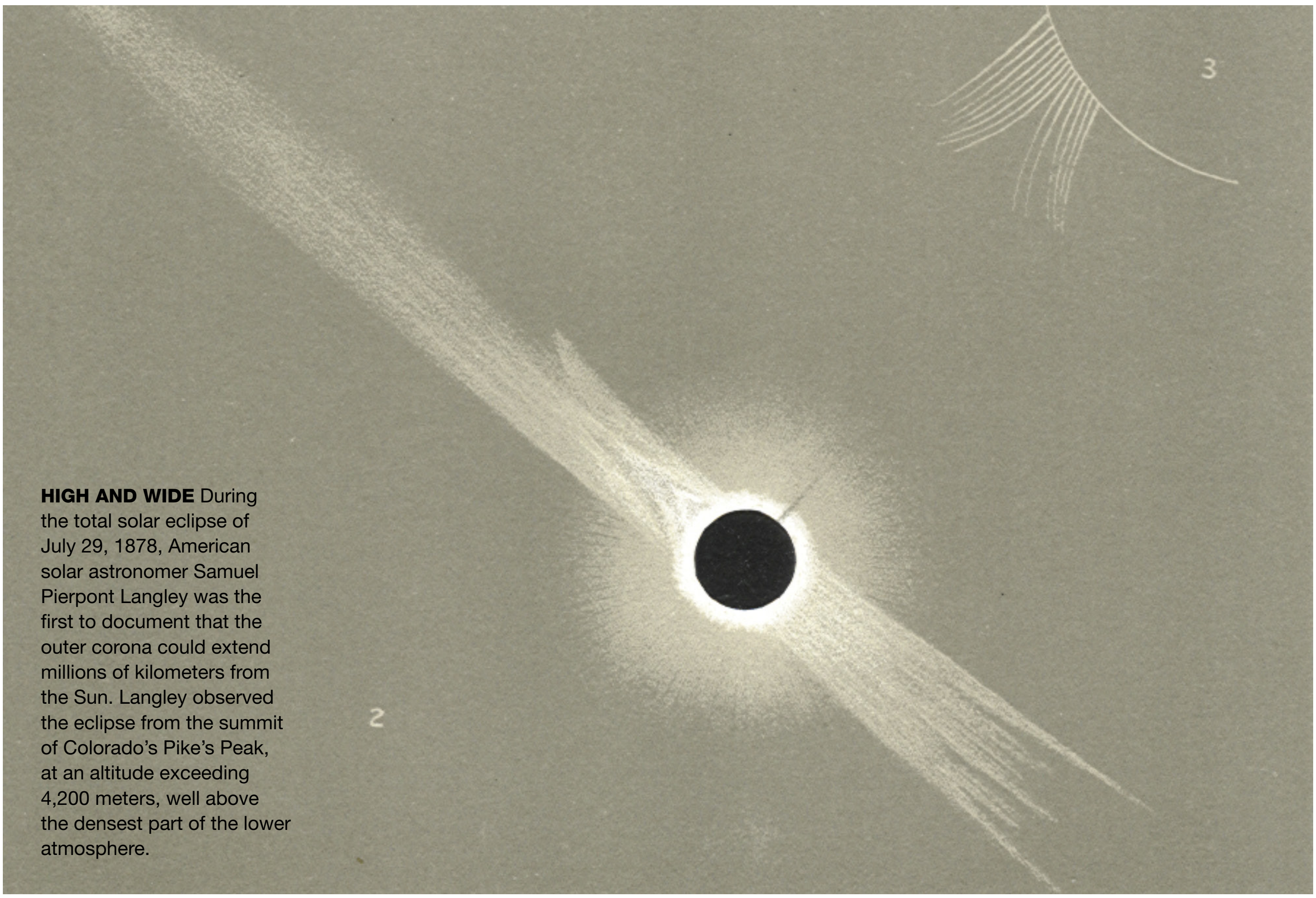
Even with careful planning and preparation, there was no guarantee of success — or even *survival*. James Melville Gilliss led a four-man U.S. Navy expedition to Olmos, Peru, for one minute of totality on September 7, 1858. While crossing the formidable, windswept deep sand of Peru's Sechura Desert, he became so severely dehydrated that in Olmos he collapsed. "Whilst lying upon the ground," he wrote, "I instructed my young friend as to each portion of the telescope until it was satisfactorily mounted."

As we saw with the 1780 Williams endeavor, war sometimes added an extra complication. The eclipse of December 22, 1870, coincided with the German siege of Paris during the Franco-Prussian War. French astronomer Jules Janssen daringly escaped German bullets in a hot-air balloon in time to get to the path of totality in Algeria. Unfortunately, he was unable to escape thick clouds.

Pursuing that same eclipse was British astronomer Norman Lockyer and his party, bound for Sicily, Italy. Eighteen kilometers from their destination, their government ship, the *Psyche*, ran aground on an uncharted submerged rock. The ship was abandoned, and the instruments were quickly unloaded onto the boulder-strewn coastline. Through a momentary gap in thick clouds overhead, Lockyer caught just



▲ **WILLIAMS'S BEADS?** This drawing of the 1780 solar eclipse by Harvard professor Samuel Williams clearly shows what we now call "Baily's beads," 56 years before they were first seen and described by British astronomer Francis Baily. Williams was one of several astronomers who independently observed them before Baily, who never claimed to have seen them first.



HIGH AND WIDE During the total solar eclipse of July 29, 1878, American solar astronomer Samuel Pierpont Langley was the first to document that the outer corona could extend millions of kilometers from the Sun. Langley observed the eclipse from the summit of Colorado's Pike's Peak, at an altitude exceeding 4,200 meters, well above the densest part of the lower atmosphere.

one brief glimpse of the eclipsed Sun and corona.

Another British astronomer, Father Stephen Perry, traveled to Salut Isle off the coast of French Guiana to observe the total solar eclipse of December 22, 1889. He fell so ill with dysentery that on E-day he had to be carried to his instruments so he could observe. Five days later he died.

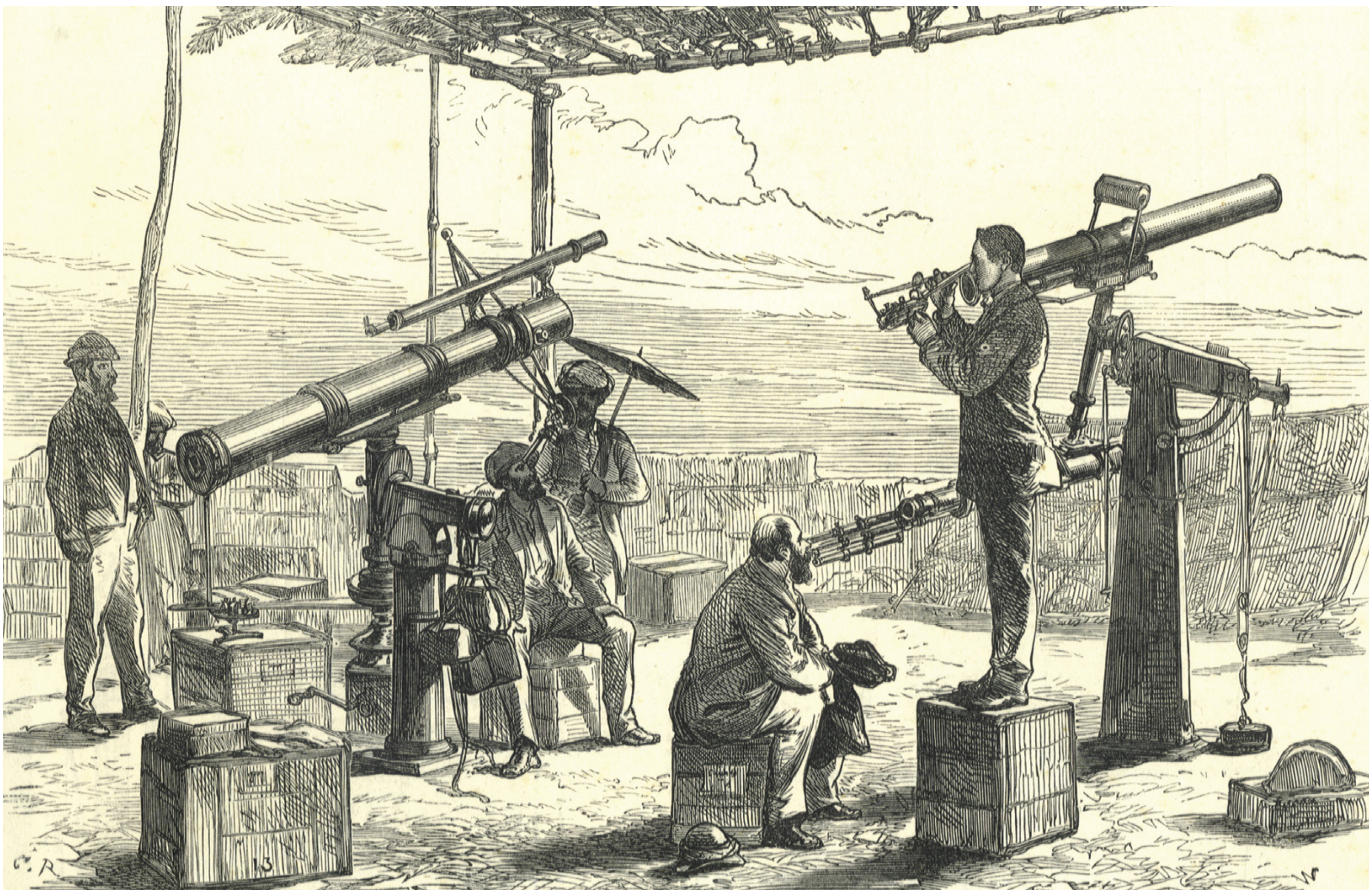
Birth of Solar Physics

Despite the hardships of travel and the frequently unfavorable weather that marked many expeditions, discoveries about the physical structure and chemical makeup of the Sun unfolded surprisingly quickly. During the eclipse of July 28, 1851, British astronomers Robert Grant and William Swan and Austrian Karl Ludwig von Littrow hypothesized that prominences were part of the Sun because the red flames clearly were seen to be progressively covered and uncovered by the Moon at the beginning and end of totality. During that same eclipse, Airy observed that the prominences seemed to rise from a narrow, jagged crimson layer around the Sun's circumference — a layer he described as a "sierra" (for its mountain-chain appearance) but that Lockyer in 1868 renamed the *chromosphere*.

Only one year after Robert Bunsen and Gustav Kirchhoff realized that the bright and dark lines in the spectrum of a heated glowing substance revealed its chemical composition, Jules Janssen aimed his spectroscope sunward during the 3½-minute total solar eclipse of July 18, 1860. Janssen realized that the prominences glowed at the same red, blue, and violet wavelengths emitted by hot hydrogen gas, indicating that the "red protuberances" were largely composed of hydrogen — an observation confirmed during the total eclipse of August 18, 1868.

But Janssen's spectroscope also revealed a brilliant yellow emission line that didn't seem to match the spectrum of any known earthly substance. More than two decades later, it was identified as an element new to the periodic table and named "helium" because it was first seen on the Sun, "Helios" being the ancient Greek god of the Sun. Later solar eclipses revealed unfamiliar emission lines in the corona that were eventually recognized as highly ionized states of familiar elements such as nickel and iron.

Three months after the 1868 eclipse, both Lockyer and Janssen independently discovered that the spectra of prominences could be detected and observed without a total solar eclipse



▲ **SOLAR DIPLOMACY** English astronomer Norman Lockyer led an expedition to observe the total solar eclipse of December 12, 1871, from several locations in Ceylon (now Sri Lanka) and India. Shown is Lockyer's own station set up in Bekul, India; Lockyer himself is left of center, seated under the parasol. Note that Lockyer and a second observer (standing on the packing crate) are viewing the event through spectroscopes. (The third observer, seated at center, was a local host from the Madras Public Works Department.)

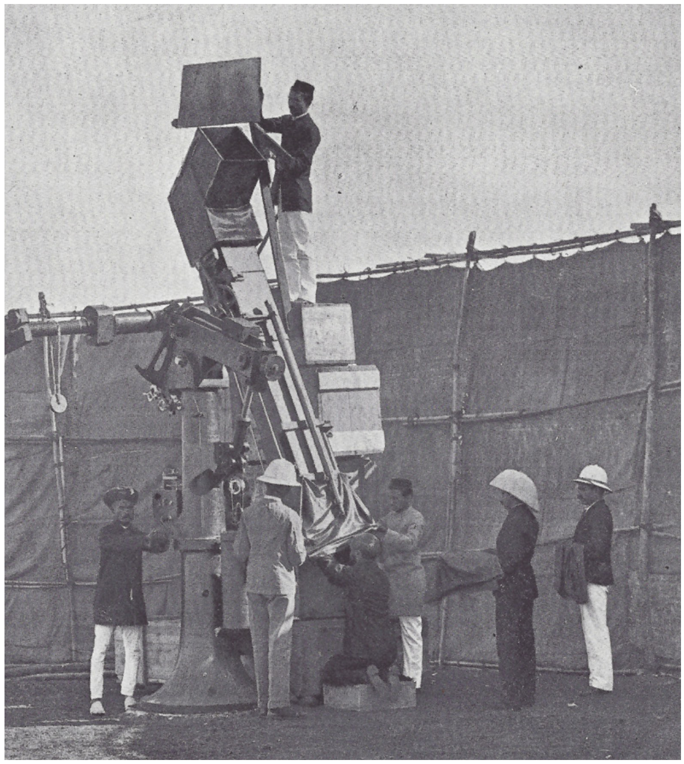
— the first steps toward freeing astronomers from the need to rendezvous with the Moon's shadow to study solar phenomena.

Eclipses for Everyone

The rapid expansion of the railroads in the 19th century meant that anyone who could come up with train fare could travel to the path of totality. Eclipse chasing was no longer the exclusive domain of expeditionary astronomers. That became especially evident during a pair of major total solar eclipses that crossed the United States on August 7, 1869, and on July 29, 1878. Both occurred after the completion of the first transcontinental railroad, both were highly publicized, and both offered more than three minutes of totality.

For the eclipse of 1869, several expedition observatories were roped off and even guarded by police officers to prevent local spectators from disturbing the scientists at work. Even so, Arthur Searle of Harvard College Observatory, who set up his equipment near the train station in Falmouth, Kentucky (to have ready access to the station's telegraph), was nonplussed when "just as the total phase was about to begin, the train from Lexington drew up at the station, remained there during the totality, with the passengers shouting, screaming, laughing and talking all the time, and started again as the Sun re-appeared." The intrusion ruined his timing observations.

Sometimes the sightseers were downright weird. At the 1869 eclipse camp of Vassar College astronomer Maria Mitchell in Iowa, "there passed in and out among our telescopes and observers an unknown, closely veiled woman." In Denver for the 1878 eclipse, Mitchell noticed a complete stranger who "came to the front" when the expedition photographer wanted to take a group picture. "There was something regal in his audacity," she remarked, "but he was none the less a tramp."



▲ **PRECARIOUS PERCH** Just a week and a half before the eclipse of January 22, 1898, the Cooke 6-inch achromatic triplet prismatic camera from the College of Science at Poona, India, arrived in Jeur in Western India by rail. In 10 hours of incessant labor, a team of oxen hauled its packing crates from the Jeur train station to the eclipse camp 6 kilometers (4 miles) away. When set up, the instrument stood 4 meters (13 feet) tall. Because the camera (box at top of telescope) had no shutter, the aperture was covered with a sheet of cardboard, which a student perched atop a ladder removed at the instant of the flash spectrum.

Appreciating Totality

Despite the monumental advances in solar physics and understanding gained through scientific expeditions, after the much-anticipated Moon's umbra had passed, some astronomers felt not triumphant but empty.

"My own feelings were those of excessive disappointment and depression," Lick Observatory astronomer Edward Emerson Barnard candidly confessed after the total eclipse of January 1, 1889. In a report that modern eclipse photographers can probably relate to, he said, "[S]o intent was I in watching the cameras and making the exposures, that I did not look up to the Sun during totality, and therefore saw nothing of the Corona." After that same eclipse, Chabot Observatory astronomer Charles Burckhalter similarly remarked, "To the majority of photographers the beautiful phenomena attending a total solar eclipse are yet to be seen in drawing and photograph, and the opportunity of a lifetime was allowed to pass, for the sake of the scientific results hoped for."

C. H. F. Peters, director of the Litchfield Observatory at Hamilton College, New York, surprised astronomy writer Mabel Loomis Todd when he told her he had never seen a total solar eclipse, despite having observed several. When she asked what single astronomical instrument he would recommend taking on an eclipse expedition, he replied, "A pillow" for watching the majestic celestial event in comfort.

"Persons who observe an eclipse of the Sun always try to do the impossible," Maria Mitchell ruminated after the 1878 eclipse, adding:

> *Great is the self-denial of those who follow science. Those who look through telescopes at the time of a total eclipse are martyrs; they severely deny themselves. The persons who can say that they have seen a total eclipse of the Sun are those who rely upon their eyes.*

But the self-denial and risks taken by 19th-century expeditionary astronomers revealed a wealth of knowledge about the composition and nature of the nearest star, our Sun, and laid much of the foundation for solar and stellar physics. What a gift to contemplate while awaiting totality on April 8th.

■ Contributing Editor **TRUDY E. BELL** is coeditor of *Neptune: From Grand Discovery to a World Revealed* (Springer, 2021). Her journalism and research awards include the David N. Schramm Award from the American Astronomical Society.

 by Zach Cano

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Join us on a fanciful expedition through the life cycle of a neutron star.

Picture, if you will, a spiral galaxy with a bulge, disk, and arms — something akin to the Milky Way. Seen face on from a distance of several hundred thousand light-years, its beauty may fill you with a sense of awe: Brilliant hues of blue, red, yellow, and white are peppered with dark, dusty patches along the galactic disk, and hundreds of globular clusters surround it with a spherical glow.

The galaxy is not alone; a smaller companion lies 150,000 light-years away. Telltale distortions in both galaxies indicate that these neighbors collided some 10 million years ago. The collision generated a shock wave that surged through the larger galaxy at roughly 100 kilometers per second (200,000 mph). As it passed through the galactic disk, the wave encountered a massive gas cloud, one containing more than 1 million solar masses of hydrogen. This compression created the ideal conditions for stars to form.

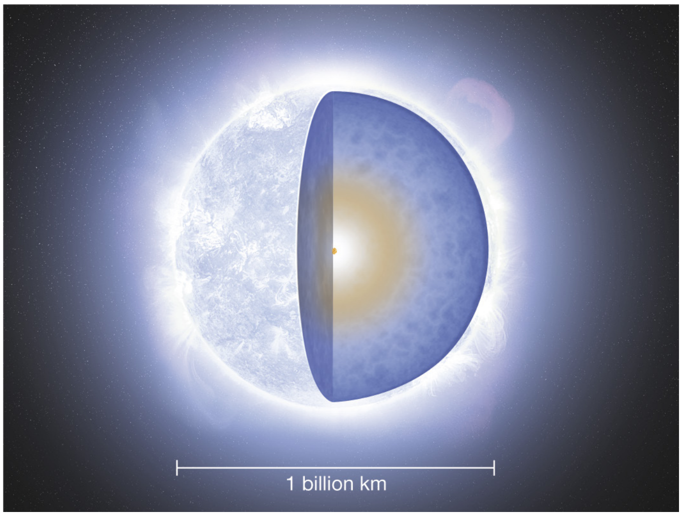
We zoom in on a particularly bright patch in this compressed cloud: a stellar nursery. In this star-forming region, there are dozens of stars 10 to 40 times more massive than our Sun. These massive stars are also extremely bright, as the scorching temperatures and immense pressures in their cores enable them to fuse atomic nuclei at unfathomably rapid rates. Such luminosity comes at a cost, however, as they burn through their fuel in only a few million years; in contrast, a star much like our Sun will burn up its fuel in roughly 10 billion years.

In this star-forming complex, we are drawn to a particularly bright, rapidly rotating star — one that is about to go supernova. Deep in the star's core, nuclear reactions are fusing atoms into increasingly heavier elements: hydrogen to helium through carbon, nitrogen, and oxygen, all the way up to silicon and then iron. The outpour of radiation and energy that nuclear fusion creates counteracts the inward crush of gravity.

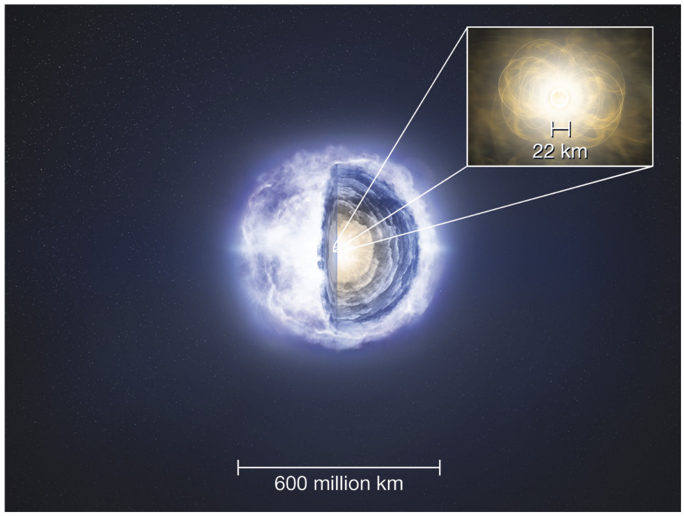
Fusing iron into heavier nuclei would consume more energy than it produces, however, so when the star reaches this point, the fusion reactions falter. In the blink of an eye, gravity overcomes the delicate balance of forces. The Earth-size iron core implodes, shrinking down to the diameter of a city. Quantum-mechanical laws halt further collapse, and the core now resembles a large ball of neutrons with some protons and electrons mixed in: A neutron star has formed.

◀ **BIRTH OF A MAGNETAR** When a massive star dies, its core can become a rapidly spinning, highly magnetized neutron star.

LEAH TISCIONE / S&T



▲ **DEATH OF A MASSIVE STAR** This illustration shows a blue giant star at the moment when it has consumed all the fusible elements in its core, leaving a small iron core (red dot) at its center. The outward pressure of fusion-released energy that has held the star up against its own weight is now gone, and the star will quickly collapse, triggering a supernova.



▲ **A NEUTRON STAR IS BORN** The collapse produces a superdense neutron star with a strong magnetic field at its center (inset). Soon the star's collapsing outer layers will rebound off the neutron star and explode outward.

As a parting gift, the progenitor imprints the newborn neutron star with its own spin. The rapidly rotating progenitor rotated around its axis once every 20 hours or so. This rotation has a profound effect on the newly formed neutron star, in two ways.

First, just as a twirling ice skater spins faster when she folds her arms close to her body due to the conservation of angular momentum, the remnant neutron star's rotation is even greater than that of its parent star. It now completes a thousand rotations every second.

Second, this swift spin causes particle fluids inside the neutron star to flow. These strange fluids, with their unique magnetic and conductive properties, create a magnetic field that is among the most powerful in the universe.

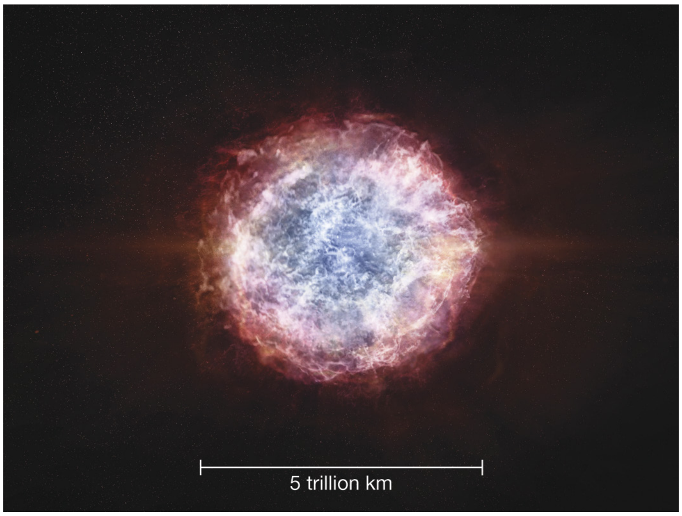
The exceptionally large magnetic field and rapid rotation are unmistakable clues that we have just witnessed the birth of a *millisecond magnetar*. We will call it the MM from now on, the main protagonist of our story.

Meanwhile, immediately after the star's core collapses, its outer layers fall inward, colliding with the newly formed MM. This collision generates a powerful blast wave that propagates outward through the infalling stellar envelope. A colossal number of neutrinos, produced when the iron core collapsed, now pass through the star and mix with the shock wave, energizing it. This energized shock wave then propels the stellar material out into space, creating a supernova.

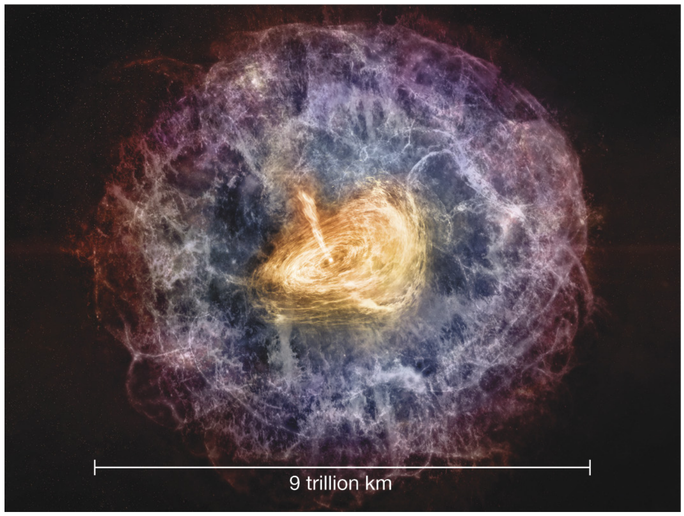
For ordinary supernovae, this is where the explosion ends. However, for our MM, the fun has just begun. In this tale, we will follow the MM through a series of events, from birth to cataclysmic death. Each event happens to real neutron stars in the universe, although not necessarily all to the same neutron star. In this way, we'll gambol along several evolutionary pathways, learning about neutron-star physics as we go.

◀ **NEITHER A BIRD NOR A PLANE** The supernova explosion sends the magnetar rocketing through space.

STAR TO SUPERNOVA REMNANT CREATION: MELISSA WEISS, NRAO / AUI / NSF (4); STAR FLYING THROUGH SPACE ILLUSTRATION: LEAH TISCIONE / *S&T*



▲ **SUPERNOVA** The explosion ejects a shell of debris into interstellar space. At this stage, the debris shell is dense enough to shroud the neutron star inside.



▲ **PULSAR WIND** Over a few decades, the debris shell expands and thins, revealing the pulsar within. Astronomers can now detect radio emission from charged particles accelerated by the rapidly spinning neutron star's powerful magnetic field. This phenomenon is called a *pulsar wind nebula* (yellow, along with the pulsar's jet).

Blowin' in the (Pulsar) Wind

Due to its powerful magnetic field and rapid rotation, the MM launches a jet of energetic particles from each of its magnetic poles. Simultaneously, a strong wind blows from the MM, which, along with the pair of jets, accelerates subatomic particles and drives them into the expanding supernova. In this manner, the MM acts as an engine, pumping energy into the ejecta. This type of "engine-driven" event is called a *superluminous supernova*, due to its exceptional brightness relative to garden-variety supernovae. Another type of engine-driven supernova is associated with a *long gamma-ray burst* (GRB). However, the jets in GRB-supernovae bore all the way through the ejecta to escape into space, while in superluminous supernovae the jets fail to punch through, instead injecting all of their energy into the exploded star's debris.

For the next weeks and months, the MM continues to inject energy into the expanding supernova, but as the ejecta become increasingly distant, the effect of the injected energy fades to essentially nothing. Over a few decades, the ejecta expand so much that they become *optically thin*, allowing well-equipped astronomers to peer all the way to the center of the explosion. At this time the MM is still rotating rapidly, and any distant observers positioned near one of its poles will see the jet repeatedly appear and disappear, manifesting observationally as pulses of radio, X-ray, and gamma-ray photons with astonishing regularity. The MM has now entered the pulsar phase.

As part of this phase, the wind rushing from the MM creates a nebula around the neutron star, its edges defined by where the outflow collides with the dense surrounding material, creating a shock like that around the bow of a ship speeding through the sea. The extent and duration of this *pulsar wind nebula* depend on the rapid rotation of the MM, which will take thousands of years to slow down.

Neutron stars are among the most exotic objects in the known universe. They are also far from inert, and events such as starquakes and misbehaving magnetic fields occasionally cause them to emit bursts of radiation, from radio waves to gamma-rays. Magnetars such as our MM are even more rambunctious. Within the expanding supernova and the wind nebula, the MM also infrequently ejects material at velocities that are only a thousandth of a percent slower than the speed of light. This outflying matter collides with nearby gas, creating magnetized shocks, which in turn accelerate electrons. These tiny particles cool rapidly by emitting a short burst of *coherent* (rather than random) radio waves. Astronomers refer to such an event as a *fast radio burst*, or FRB. This astrophysical tantrum does not last long, however, and eventually the MM calms down to an uneasy quiescence.

Speeding Toward a Fateful End

Although its emission may be calm, the MM's trajectory is not. The asymmetric nature of the original supernova explosion bestows a "kick" of a few hundred kilometers per second to the MM. Due to this kick, the MM no longer resides precisely where it was born. After a few decades, it has traveled a couple thousand astronomical units from the explosion center, roughly the distance between the Sun and the inner edge of the Oort Cloud. Rushing away from its natal stellar nursery, the itinerant MM heads away at an oblique angle to the galactic disk, out into the halo. It covers some 9,000 light-years every 10 million years.

After a few hundred million years, it has left the warm light emitted by hotter, younger stars residing in the disk far behind. Out in the halo, it encounters the faded and inert remnants produced by other supernovae, finding a new home in the stellar cemetery of neutron stars and black holes that enshroud the galaxy.

Over time, the MM's trajectory takes it just close enough to another neutron star that they, almost imperceptibly, gravitationally attract each other. After another several million years, the pair will join to become a binary neutron-star system, revolving around their shared center of mass. Over even more time, measured in units of hundreds of millions of years, the distance between the stars dwindles, as they ominously and inevitably head toward an event that will end both of their nearly billion-year-long existences.

Orbital energy leaks away in the form of weak *gravitational waves*, ripples in spacetime. This radiation decreases the separation between the two neutron stars. Eventually the stars come so close together that they slam into each other, releasing an immense burst of gravitational waves. The collision tears matter from the stars' surfaces, and due to the prodigious amount of angular momentum still present in the system, this material forms a disk around the merged stars. Jets from the poles of the newly made object at the disk's center fire particles off into space.

Anyone observing with a line of sight near these poles will see a GRB, but one that lasts a much shorter time than the longer GRBs produced by the core collapse of a rapidly rotating massive star. Fortunate astronomers will also observe a burst of gravitational waves like the one researchers detected in 2017 for the event GW170817 (*S&T:* Feb. 2018, p. 32).

This event marks the final act in the life of our MM, and so too for its companion. After the merger, all that remains is a stellar-mass black hole.

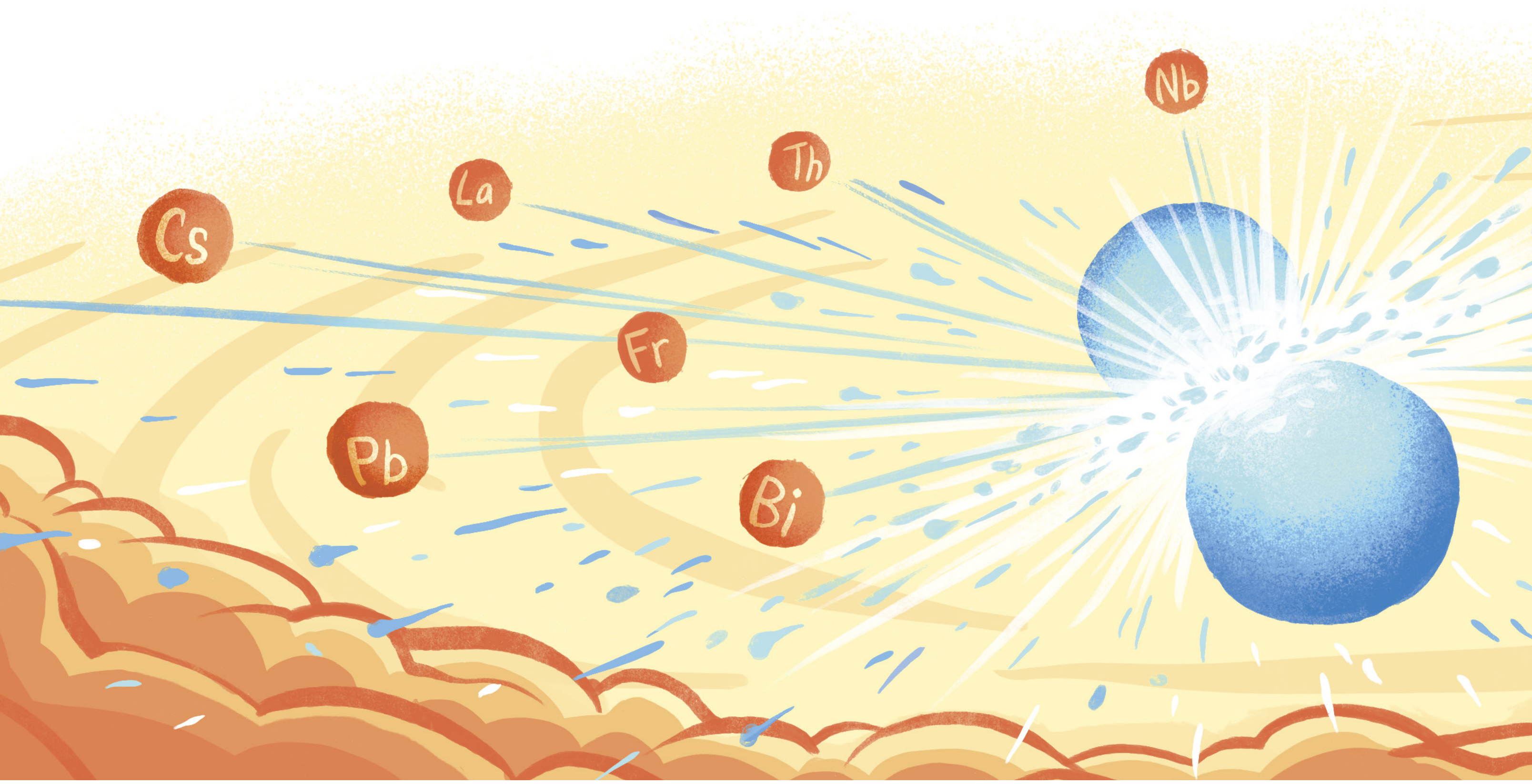
However, the event has not yet played out completely. During the merger, not all of the thrown-off material went into the accretion disk: Some of it was propelled into space like in a supernova, but in a less-energetic, and thus less-luminous, manner. Astronomers call this event a *kilonova*. While a supernova is approximately 10,000 times brighter than a common nova, a kilonova is only 1,000 times brighter than a nova. This kilonova is (relatively) bright at optical and infrared wavelengths for only a week or so.

As with a supernova, the explosion synthesizes elements heavier than iron and scatters them into space, enriching the gas of the *interstellar medium*. But a kilonova creates a different cornucopia of elements than supernovae do. During the kilonova, the extremely neutron-rich ejecta, along with energy from the explosion, create the ideal conditions for synthesizing *r-process elements* (*r* for rapid, as these neutron-capture reactions occur very quickly), including strontium and rare lanthanides such as lanthanum and cerium, which we humans use in certain kinds of lights and other technologies.

In its death throes, our MM has briefly illuminated its host galaxy, spraying photons from the entire electromagnetic spectrum into the cosmos as well as emitting gravitational waves and neutrinos. Its emissions enable astronomers to observe it in myriad ways — a suitably energetic end to an astonishing journey across its galaxy.

▼ **MERGER** When neutron stars collide, they create a plethora of heavy elements and throw the debris into surrounding space.

LEAH TISCIONE / *S&T*



Pulling Back the Curtain

The story of our MM is quite fantastical. It powered a superluminous supernova, went through a pulsar stage lasting millions of years, produced an FRB, and then ended its existence in a final spectacular explosion when it merged with another neutron star, producing bursts of gravitational waves and gamma-rays and nucleosynthesized *r*-process material. Although it is quite unlikely that a single neutron star would experience every one of these events, it is certainly not impossible.

Countless billions of neutron stars across the universe are created when massive stars end their short lives as supernovae. Some of the stellar remnants will collide with each other and create short GRBs and kilonovae. In most cases, it is likely that the neutron star has come from a more ordinary core-collapse supernova, but it is not inconceivable that the neutron stars in at least a few short GRBs were produced during a long GRB or superluminous supernova, as we've surmised here. For the same neutron star to have also produced an FRB, the odds are (quite literally) astronomically low but, as we will see below, not 0%.

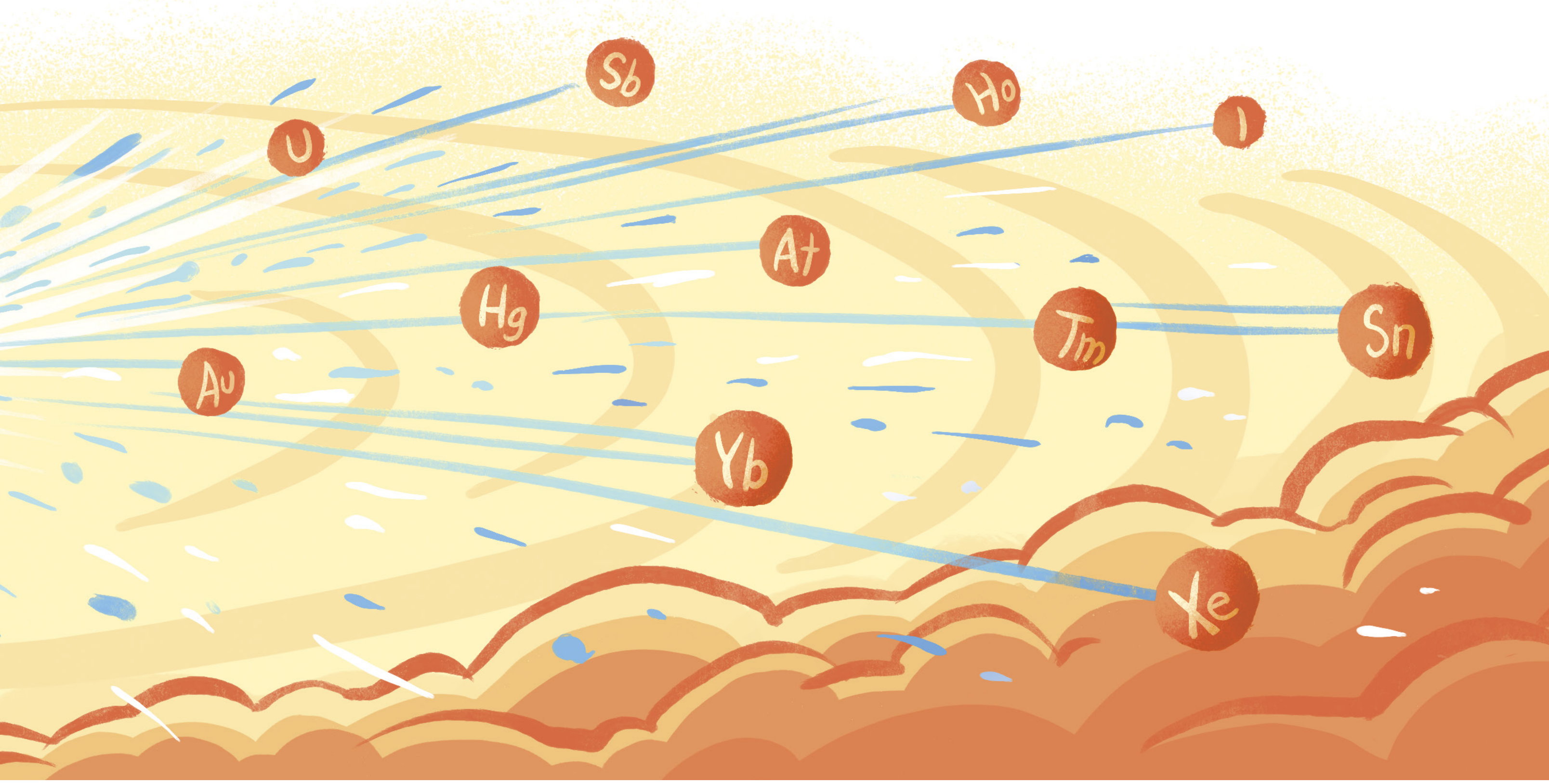
There are many valid alternative evolutionary stages that our MM protagonist could have undergone in our story, although some of them, such as the superluminous supernova and long GRB pathways, are quite similar.

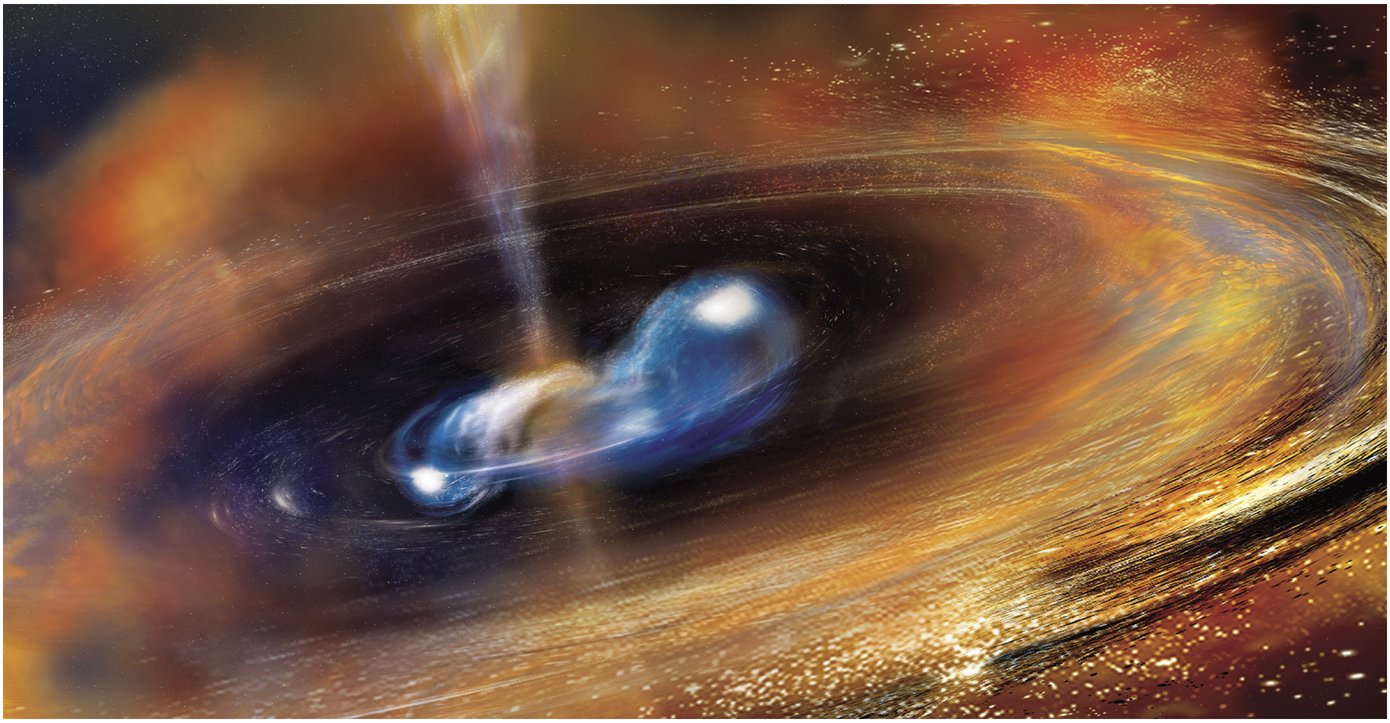
One possibility is that the neutron star could have been born in a different kind of galaxy. Over the past couple of decades, observations of the host galaxies of hundreds of long GRBs and superluminous supernovae have revealed that the majority of these galaxies are small, blue, actively star-forming, and relatively depleted in heavy elements. In many cases, the irregular morphologies of these galaxies imply galactic interactions in the several million years preceding the star's explosion. Such interactions can trigger episodes of star formation, thus providing an organic explanation for the prevalence of long GRBs and superluminous supernovae in these types of galaxies.

Vitally, such triggered star formation lasts, in cosmological terms, very briefly, meaning that the conditions giving rise to these extreme cataclysmic stellar events are quite ephemeral and rare.

However, observers have found that some long GRBs and superluminous supernovae occur in larger galaxies with higher levels of heavy elements, commensurate with what we see in galaxies like the Milky Way. Today, astronomers accept that it is the natal conditions at specific locations in a galaxy, rather than the bulk properties of the galaxy itself, which really matter: These types of explosions tend to happen in chaotic, energetic, and densely populated stellar nurseries with many binary stars and low-to-moderate levels of heavy elements. Nearby events such as GRB980425/SN1998bw and superluminous SN2017egm are two such examples of these rare events happening in Milky Way–like galaxies.

It is also worth pointing out that while some GRBs do form magnetars, many more are thought to produce black holes. In those cases, a disk made of stellar material forms around the black hole, and accretion of this material onto the black hole causes a pair of jets to form, which then race





▲ **COLLISION** Two neutron stars begin to merge in this artist's concept, blasting jets of high-speed particles and producing a disk of debris. Astronomers detect the former as a *short gamma-ray burst*; the latter glows as a *kilonova*.

A. SIMONNET (SONOMA STATE UNIVERSITY) AND NASA'S GODDARD SPACE FLIGHT CENTER

out into space. Blobs of material in the jet, traveling at ultra-relativistic speeds, interact and produce a burst of gamma-rays. The jets then continue propagating away from the explosion, eventually colliding with surrounding interstellar gas. This collision creates shocks that accelerate electrons, which then cool rapidly, producing a type of emission called *synchrotron radiation*.

A perceptive reader may note here the similarity in the different scenarios encountered in this story: Most involve material moving at a whisper under the speed of light, which violently collides with other material, creating shocks and, in turn, light. Such scenarios are thought to produce all types of GRBs and explain how magnetar central engines help blow stars apart, how bow shocks are created around pulsar wind nebulae, and perhaps, too, how FRBs are generated.

The FRB scenario presented here is just one way astronomers think these radio bursts could be produced. Presently, there is no consensus on how they actually form (*S&T:* Sept. 2022, p. 26). Another complication is that some FRBs occur only once per source, while others repeat.

Some theories suggest an FRB is emitted toward the very end of a neutron star's life in a binary system: In the decades to centuries prior to coalescence, complex interactions between the stars' magnetic fields might lead to the emission of coherent radio waves. A similar scenario includes an FRB being emitted when a lone, rapidly spinning neutron star collapses into a black hole.

On the other hand, other models suggest an FRB is emitted soon after a neutron star has been created, powered by a plasma of electrons and positrons escaping from the star's extremely strong magnetic field. Interestingly, astronomers recently caught the galactic magnetar SGR 1935+2154 emitting luminous, millisecond-duration bursts, providing at least one observational connection between an FRB and a magnetar (*S&T:* Sept. 2020, p. 10). The current state of the research field of FRBs is not dissimilar to that of GRBs 30 years ago: There are, theoretically, many ways to produce an FRB, but not enough observations of well-localized events that allow astronomers to determine which of the scenarios is valid. For now, we await more FRB detections for this puzzle to be solved.

In closing, each of the evolutionary stages our fiducial MM experienced has been observationally verified — in many cases, by literally thousands of events (i.e., GRBs, pulsars, and supernovae). Neutron stars abound in the universe, being key components of supernovae, GRBs, and systems like X-ray binaries. They ripple the very fabric of space and time with bursts of gravitational waves, and they influence the chemical makeup of later generations of stars and planets.

With present and upcoming ground-based surveys likely to detect many new and exotic stellar systems in our galaxy and others, the list of astrophysical events that contain at least one neutron star will undoubtedly grow larger. A decade from now, a sequel to our MM's saga might contain even more astonishing escapades than what it encountered here.

■ Astronomer and writer **ZACH CANO** currently meditates on the mysteries of the universe in rural Hungary.

6 **DAWN:** Face east-southeast before sunrise to watch as the waning crescent Moon, Mars, and Saturn rise. Mars leads the trio above the horizon, while the Moon brings up the rear. See page 46 for more on this and other events listed here.

8 **NEW MOON (2:21 PM EDT)** A total solar eclipse will be visible along a path that stretches from the Pacific to the Atlantic. The Moon's shadow will sweep across northern Mexico and into the U.S. and Canada. Turn to page 48 for further details.

10 **DAWN:** Mars and Saturn climb in the east-southeast with a mere ½° separating them. Catch this sight before the rising Sun washes away the view.

10 **DUSK:** Look toward the west after sunset to see the waxing crescent Moon some 4° upper right of Jupiter.

11 **EVENING:** The lunar crescent is in Taurus where it hangs about 6° upper left of the Pleiades. Watch as this scene sinks toward the west-northwestern horizon as midnight approaches.

14 **EVENING:** High in the west the Moon, one day shy of first quarter, forms a triangle with Gemini's bright lights, Castor and Pollux. The Moon gleams around 6° below Pollux.

18 **EVENING:** The waxing gibbous Moon trails Leo's lucida, Regulus, by around 6° as they travel across the southern sky.

22 **EVENING:** The almost-full Moon is in Virgo, about ½° from Spica. Look southeast to take in this sight.

21–22 **ALL NIGHT:** The Lyrid meteor shower is expected to peak, but moonlight will severely hamper the display.

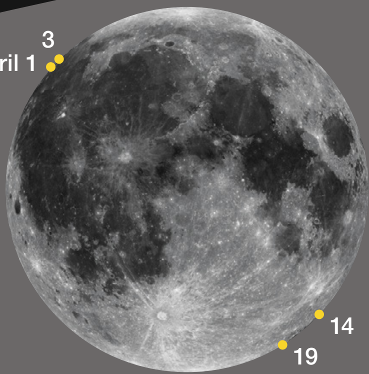
27 **MORNING:** Face south-southeast in the wee hours to see the waning gibbous Moon around 5° lower left of the red supergiant Antares, the Scorpion's heart.
—DIANA HANNIKAINEN

▲ A total solar eclipse will cross the North American continent on April 8th, and millions of people are expected to witness it. This series of images is from the 2012 eclipse in the South Pacific, and the sequence runs from lower right to upper left.
RICK FIENBERG / TRAVELQUEST INTERNATIONAL / WILDERNESS TRAVEL

APRIL 2024 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.

NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

LAST QUARTER

April 2
03:15 UT

NEW MOON

April 8
18:21 UT

FIRST QUARTER

April 15
19:13 UT

FULL MOON

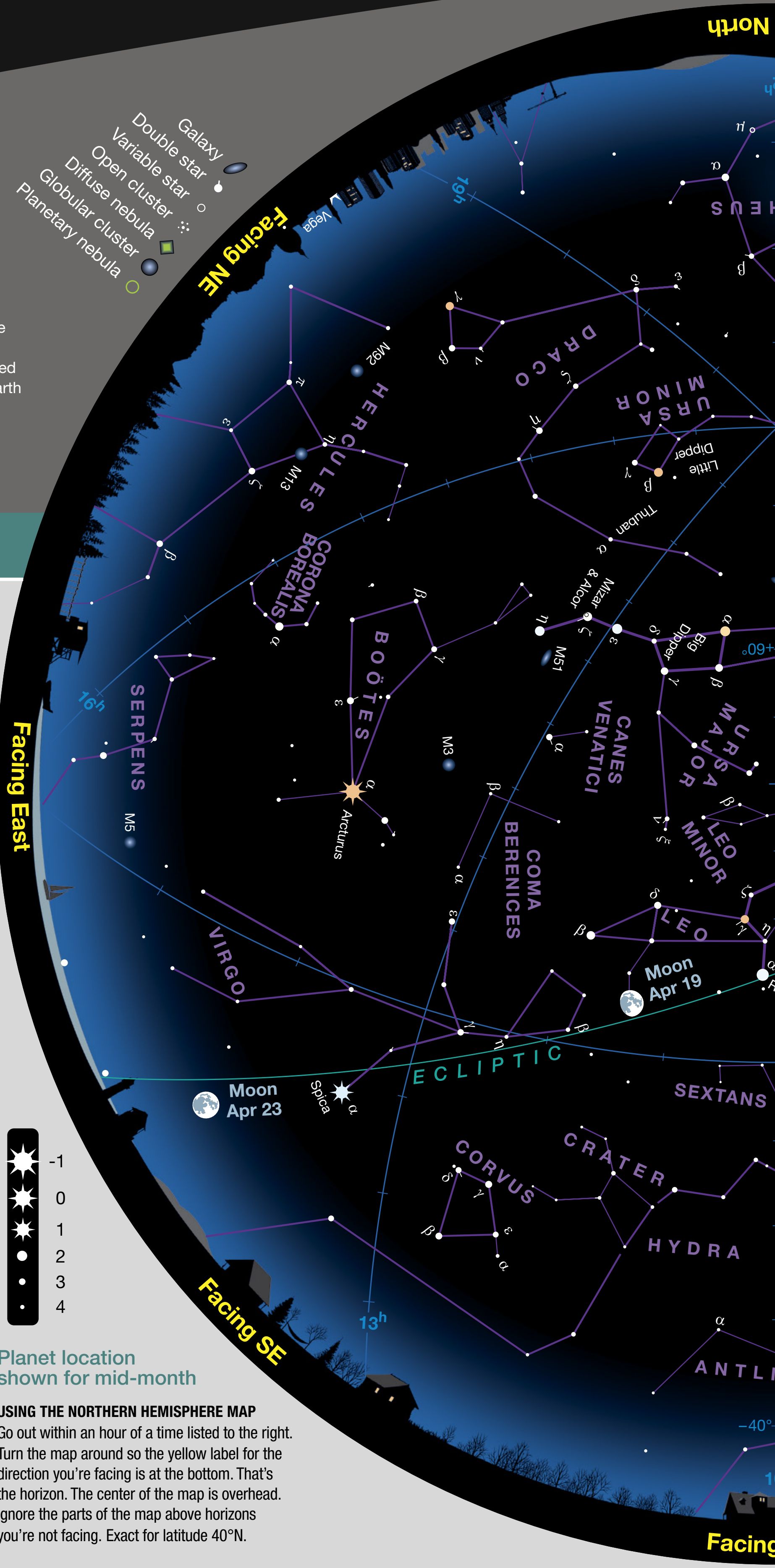
April 23
23:49 UT

DISTANCES

Perigee	April 7, 18^h UT
358,851 km	Diameter 33′ 18″
Apogee	April 20, 02^h UT
405,622 km	Diameter 29′ 28″

FAVORABLE LIBRATIONS

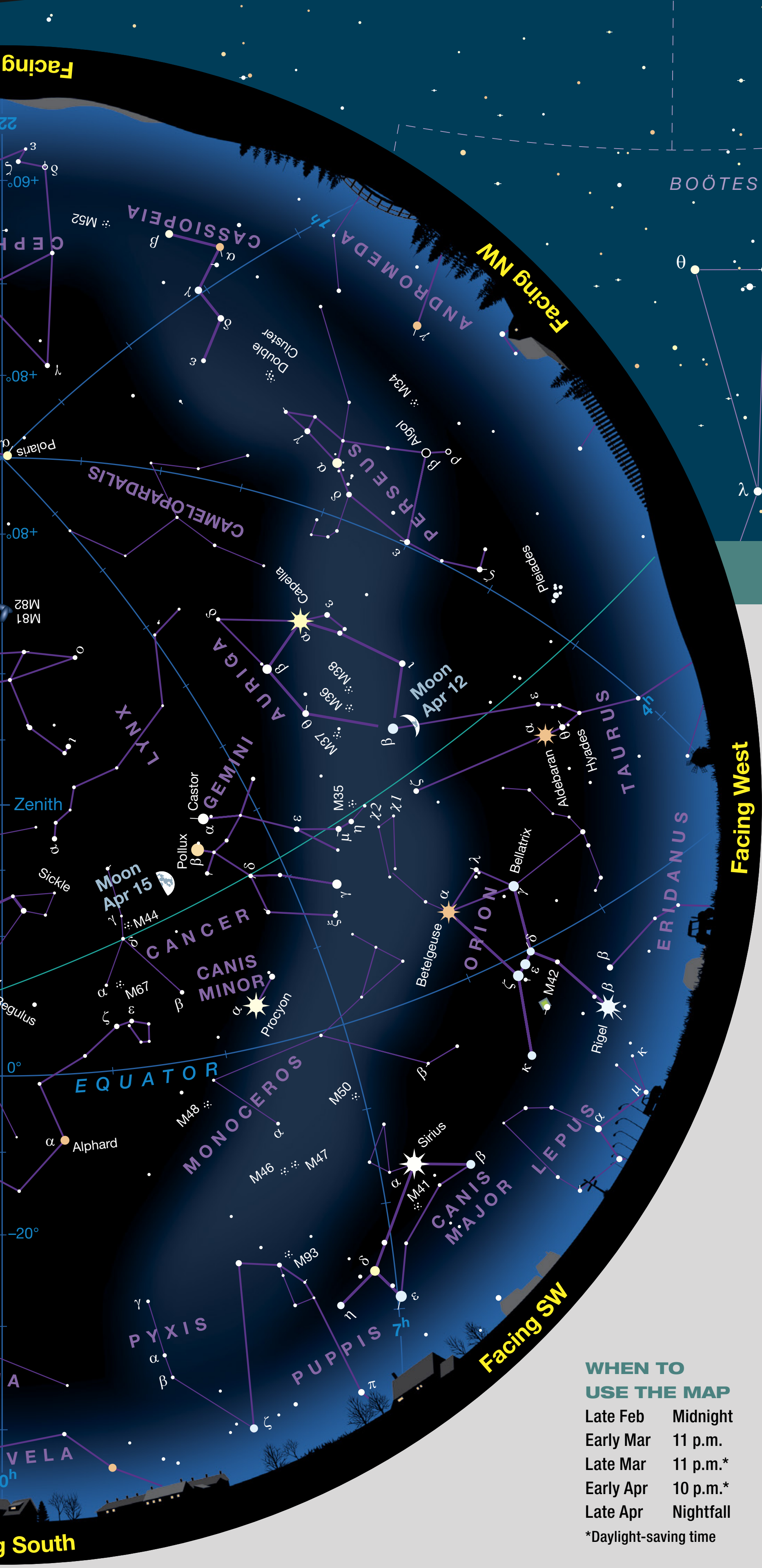
• Lavoisier Crater	April 1
• Harding Crater	April 3
• Hamilton Crater	April 14
• Lyot Crater	April 19

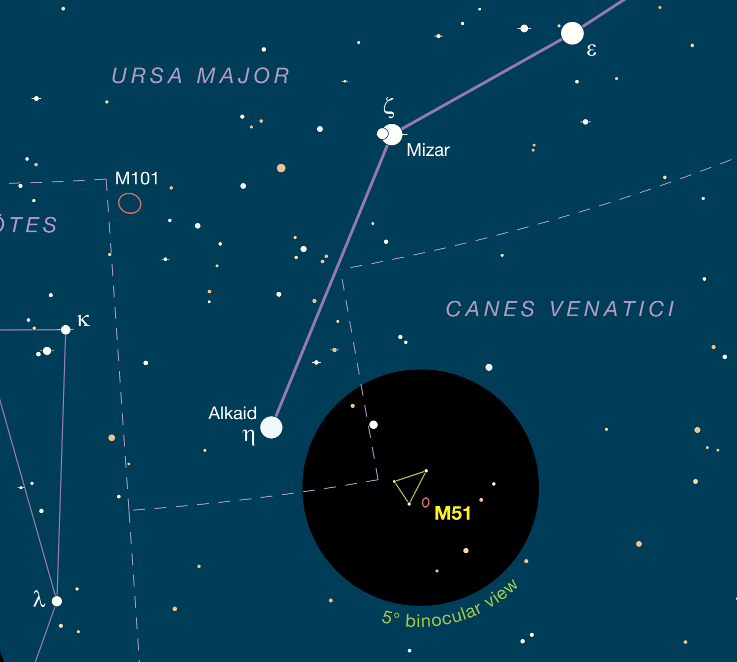


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for latitude 40°N.





Binocular Highlight by Mathew Wedel

Whirlpool Time Machine

Our target this month is **Messier 51**, the Whirlpool Galaxy. M51 lies in the constellation Canes Venatici, the Hunting Dogs, but it's in the far northeastern corner — it's closer to the Big Dipper asterism in Ursa Major, the Great Bear. Trace the last line of the Dipper's handle, from 2.2-magnitude Mizar, or Zeta (ζ) Ursae Majoris, to 1.9-magnitude Alkaid, or Eta (η) Ursae Majoris. Then hang a left and scan 3° southwest to find a neat little triangle of 7th-magnitude stars, like a pyramid pointing back to Alkaid. M51 lies just past the base of the pyramid.

You've seen M51, of course. The Whirlpool is a perennial favorite of amateur and professional astronomers alike. And you'll see it again in binoculars — at magnitude 8.4, it's an easy catch under reasonably dark, clear skies. But in anything smaller than giant, mounted binoculars you won't see any detail, possibly just an oblong, fuzzy glow. The trick to observing galaxies with binoculars is to look not just with your eyes, but with your mind.

M51 lies about 30 million light-years away. The light we see now started its journey when our ancestors, the Old World monkeys, were only recently separated from the New World monkeys. Presumably that separation happened when the latter were swept out to sea on natural rafts of vegetation, to cross an Atlantic Ocean that was then only half as wide as it is today.

What a delight, to get so much from a tiny ball of fuzz glimpsed through binoculars. That heady perspective — measuring our own history against the cosmos, with nothing more than a little bit of steel and glass — crystallizes a lot of my motivation to stargaze. After all, I'm just another curious primate looking up at night.

■ **MATT WEDEL** thinks that binoculars make pretty good time machines — with no risk of getting munched by dinosaurs.

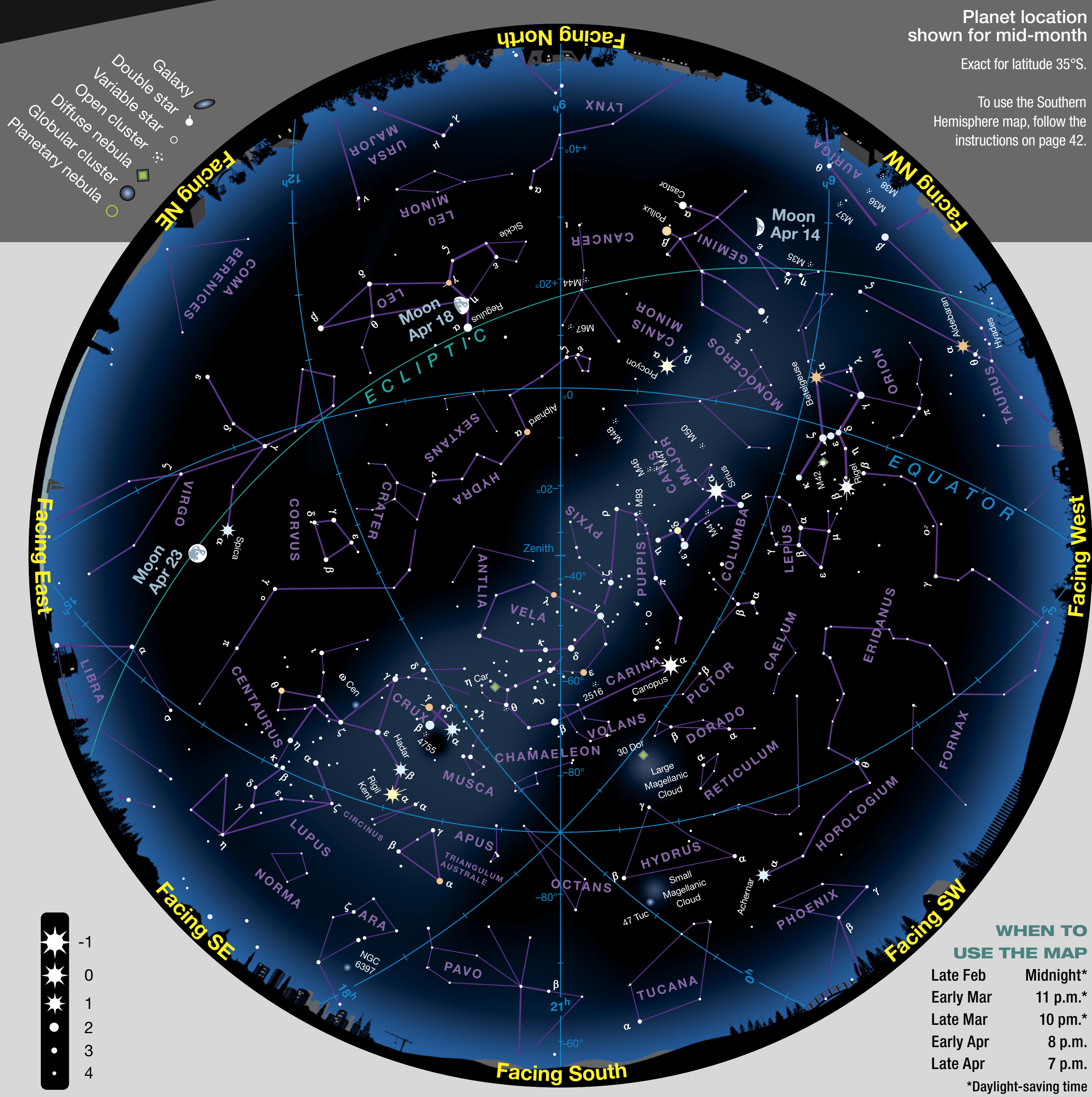
WHEN TO USE THE MAP

Late Feb	Midnight
Early Mar	11 p.m.
Late Mar	11 p.m.*
Early Apr	10 p.m.*
Late Apr	Nightfall

*Daylight-saving time

Southern Hemisphere Sky Chart

by Jonathan Nally



WHEN TO USE THE MAP	
Late Feb	Midnight*
Early Mar	11 p.m.*
Late Mar	10 p.m.*
Early Apr	8 p.m.
Late Apr	7 p.m.

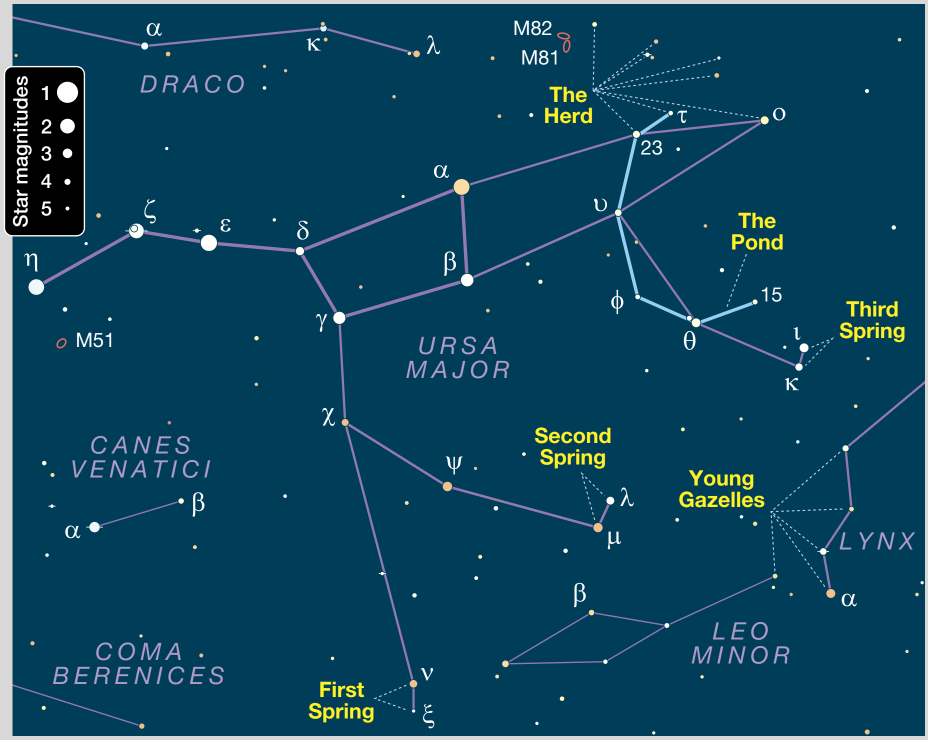
*Daylight-saving time

THERE ONCE WAS a mighty constellation in the southern sky called Argo Navis, named after the ship *Argo* of Greek mythology. In the mid-18th century, it was split into several smaller constellations (*S&T:* Mar. 2020, p. 22): **Vela** (the Sails), **Puppis** (the Stern), and **Carina** (the Keel). All three ride high on April evenings.

Although Vela is rich with deep-sky treasures, at first glance it might seem a bit bare to the naked eye. However, the constellation is traced out with interesting stars. Its brightest light, Gamma (γ) Velorum, is a four-star system that includes the brightest and closest Wolf-Rayet star known; Delta (δ) is a triple-star system that contains an eclipsing binary; Kappa (κ) is a very tight binary; and Lambda (λ) is a solitary supergiant with a lovely orange color. ■

Springs of the Gazelle

On April evenings, try to envision this delightful, animated star pattern.



Of all the ancient star patterns that have vanished from the night sky, one continues to spring into view for modern stargazers: Ḳafzah al Ṭhibā, the Springs of the Gazelle. Early Arab astronomers created the pattern using three attractive pairings of 3rd- and 4th-magnitude stars spread out evenly across 30° of sky. You'll find them on the center star chart as the three pairings of stars at the tips of Ursa Major's paws. But Arab skygazers of old saw each stellar pairing as one spring of the gazelle, which is part of a larger visual story in the stars.

Today it's common to see the Springs of the Gazelle called Three Leaps of the Gazelle. However, "leaps" can bring to mind the long and graceful jumps of a dancer, which does little to convey the bouncy up-and-down jumps that gazelles and other African antelopes (like the springbok) perform in the wild. Also called *pronking*, these movements are anything but graceful. The animal launches itself stiffly upward — lifting off on all four legs with back arched — before propelling itself forward through the air, as if on a pogo stick. This may be a kind of escape response, one that warns a potential predator that the animal has enough power to avoid becoming dinner and would demand a lot of energy to chase.

The 88 official constellations we recognize today are all still-life portraits — figures frozen in time. But the ancient Springs of the Gazelle are individual frames of a motion picture. It's the celestial counterpart of the first movie ever made — a series of still frames of a galloping horse and rider displayed in sequence to create motion. Likewise, by scanning across the Springs of the Gazelle, we can see in the mind's eye the animal pronking across the sky. But in which direction?

In an 1829 *Transactions of the Royal Asiatic Society of Great Britain and Ireland*, Bernhard Dorn describes a Persian celestial globe dating from 1275, on which eight stars in the head of Ursa Major (those indicated on the chart above) represent a herd of gazelle. The globe also depicts their young as five stars between the head of Leo the Lion and the front paw of Ursa Major, as shown in our chart. The Springs of the Gazelle are labelled on the Persian globe, and we can locate their position on the chart. The Gazelle is moving from southeast to northwest: The First Spring is the Bear's left hind paw; the Second Spring is the Bear's right hind paw; and the Third Spring is the Bear's front paw, between the herd of gazelle and their young.

While there is no denying the labelling on the Persian globe, confusion springs forth in Richard Allen's *Star Names*, which introduces a twist to the ancient Persian story. Allen notes that some early Arab skywatchers imagined the celestial Gazelle as Leo Minor, which sprang eastward into Al Haud, the Pond (the stars of Coma Berenices), "for safety at the lashing of the Lion's tail." But Allen goes on to tell us that some skywatchers claimed that this Pond lay not among the stars of Coma Berenices but instead among the stars of the neck, breast, and knees of the Great Bear.

Situating the Pond in Ursa Major makes sense. Arab and Persian astronomers visualized the Lion's tail starting at Denebola, Beta (β) Leonis, and extending all the way to Coma Berenices, whose stars represented the coarse tuft of hair at the tip of the Lion's tail. Seen this way, we can understand how Leo's thrashing tail prompted the gazelle to flee northwest to the celestial Pond, marked by the semicircle on the chart (above; two Pond stars also represent gazelles in the herd). Not to worry — these stars can be imagined as the animals standing at the water's edge, crouching down for a drink.

■ Contributing Editor **STEPHEN JAMES O'MEARA** has been studying the stars and their lore for more than 50 years.

To find out what's visible in the sky from your location, go to skyandtelescope.org.

Planetary Comings and Goings

Jupiter departs at dusk as Mars and Saturn arrive at dawn.

MONDAY, APRIL 1

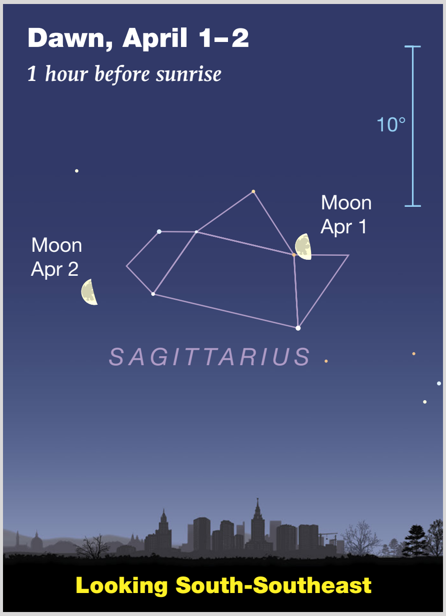
In the past few months, I've mentioned that the **Moon** has been straying off the beaten path of the ecliptic and reaching unusual highs and lows. It's all part of the Moon edging toward next January's *lunistice*, or "major lunar standstill." As this month begins, we find it residing just above the spout of the **Sagittarius Teapot** at dawn. It's an odd sight. The waning gibbous (less than one day ahead of last-quarter phase) has a declination of nearly –29½°. Considering the ecliptic in this part of Sagittarius has a declination of only –23½°, that's *very* far south indeed.

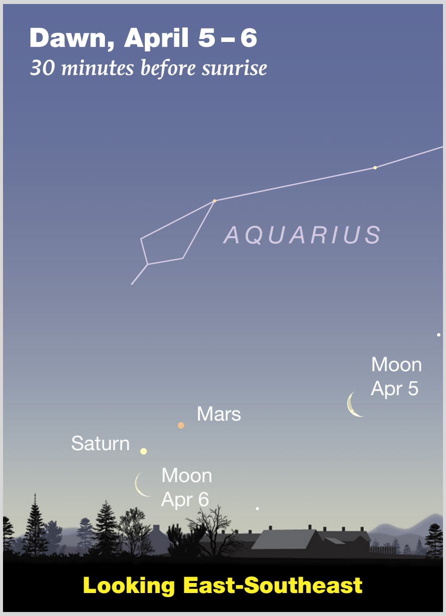
As I described in the February issue, when the Moon's orbital inclination (plus or minus 5°) is added to the extremes of the ecliptic's declination (plus or minus 23½°), you get scenes like this morning's. However, the more observant reader (do we have any other kind?) might have noticed that something doesn't quite add up: –23½° added to –5° gives us –28½°, not –29½°. Where does that extra 1° come from? Call it a "topocentric" bonus. If we observed from the center of the Earth (the "geocentric" perspective), the Moon's declination would never exceed 28½°. But we're on the planet's surface instead, so a certain amount of parallax also comes in to play. In fact, the precise declination of the Moon at any given moment depends on where you are on the globe. It's something to ponder as you gaze at this morning's curious sight.

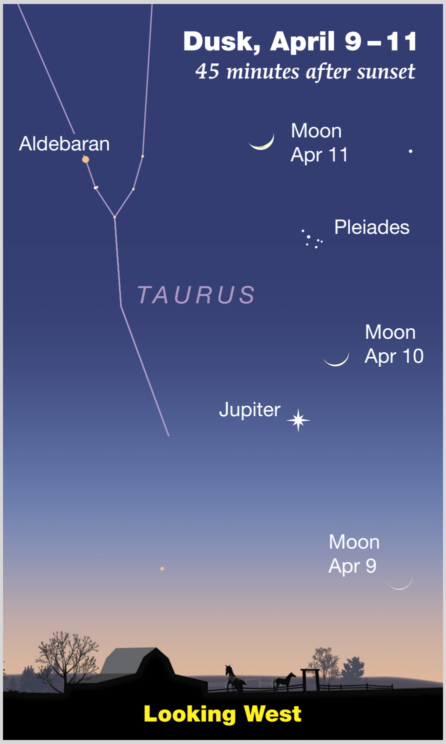
SATURDAY, APRIL 6

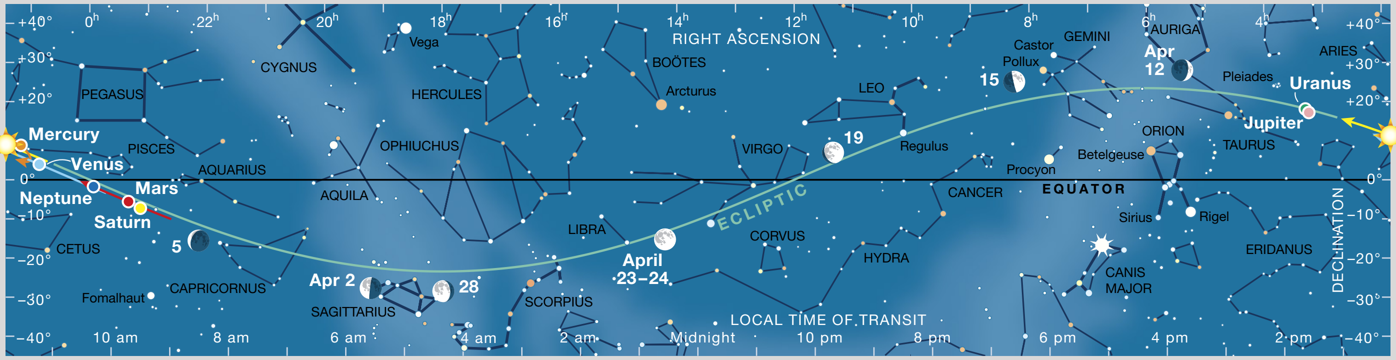
A treat awaits those willing to get up a little early today. If that's you, cast your gaze toward the east-southeast to catch the delightful trio consisting of **Mars**, **Saturn**, and the earthlit waning crescent **Moon**. Mars is the highest of the three and rises first, at around 5:15 a.m. daylight-saving time. It's followed by Saturn, which pops up about 10 minutes later and is situated roughly 3° below left of Mars. Last up is the lunar crescent, just 2° below the Ringed Planet. The triangle they form is a bit more than 4° across at the base, and all three objects will fit in the field of view provided by ordinary binoculars. Indeed, I'd suggest digging out your binos as they will enhance your enjoy-

▼▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist at arm's length.









▲ The Sun and planets are positioned for mid-April; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st and an hour earlier at month's end.

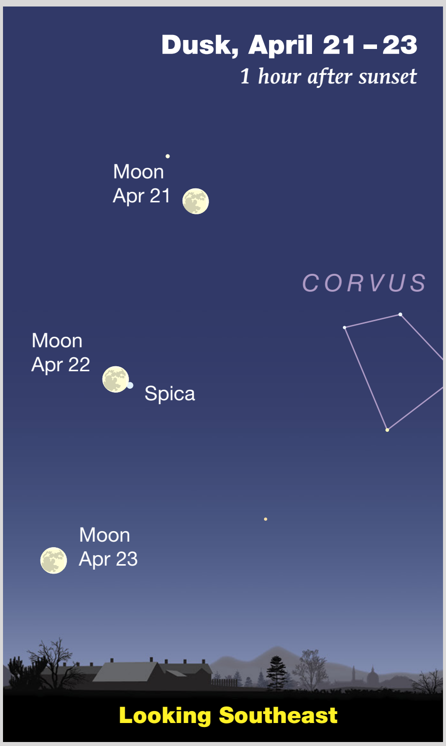
ment of the scene and make it easier to view earthshine illuminating the "unlit" portion of the Moon.

WEDNESDAY, APRIL 10

Although the Moon has vacated the dawn sky, there's still a show to be enjoyed with **Mars** and **Saturn**. The gap between the two planets has been shrinking daily, and this morning they're at their very closest, with just ½° separating them. (They're very nearly the same distance apart the following morning, so if the weather doesn't cooperate today, you have a backup date.) The two planets appear close enough that a small telescope used at low magnification will show them together — and what a contrasting pair they are. Mars is justifiably known as the Red Planet, and its peachy color is obvious next to Saturn's pale-yellow hue. This color contrast grows stronger as the duo climbs higher in the dawn sky and the amount of horizon haze we view them through decreases.

Although they have disparate tints, the planets currently have remarkably similar brightnesses. Mars glows at magnitude 1.2 — just ⅒ magnitude fainter than Saturn. Can you perceive the difference? Probably not. Doing so would challenge even an experienced variable-star observer accustomed to assessing small magnitude differences. Plus, the task is made even more difficult due to the dissimilar hues of the two planets. Still, you'll rarely have a better chance to try!

If you're not too tired from your dawn planet watch, another fine conjunction awaits at dusk. Hanging above the western horizon you'll find the waxing crescent **Moon** about 4° upper right of **Jupiter**, which is glowing gamely at magnitude –2.0. The Moon is a 7%-illuminated sliver — essentially the mirror-reverse of its appearance during its conjunction with Mars and Saturn at dawn on the 6th, when it was an 8% *waning* crescent. The scene is completed by the Pleiades sparkling about 7° above the Moon. As you drink in the view, take an extra moment to appreciate Jupiter. This evening's meet-up with the Moon is essentially the final naked-eye event of Jupiter's current apparition. Soon the big planet will be lost in early twilight's bright glare as it heads toward its May 18th solar conjunction. It will reappear at dawn in early June.



MONDAY, APRIL 22

As twilight fades this evening, cast your gaze toward the east-southeast to watch the **Moon** ascending alongside 1st-magnitude **Spica**, in Virgo. The Moon is 99% illuminated and less than 24 hours from being full. Spica and the Moon will be at their closest around 11 p.m. Eastern Daylight Time, when they're just a bit more than ½° (one Moon diameter) apart.

In binoculars or small telescopes, the neutral gray of the lunar surface contrasts nicely with the star's icy-blue tint. Spica is brightest star in Virgo (hence its Alpha designation), but it's also the third-brightest star along the ecliptic and one of a small handful that can stand up to full-strength lunar glare. The Moon and Spica have a series of close encounters this year, including several occultations, the first of which happens in July. So, you can think of this morning's event as just an appetizer for the main courses yet to come.

■ Consulting Editor **GARY SERONIK** always hates to say goodbye to his favorite planet, Jupiter. Fortunately, his other favorite planet (Mars) is up at dawn.

Time for Totality (Again)

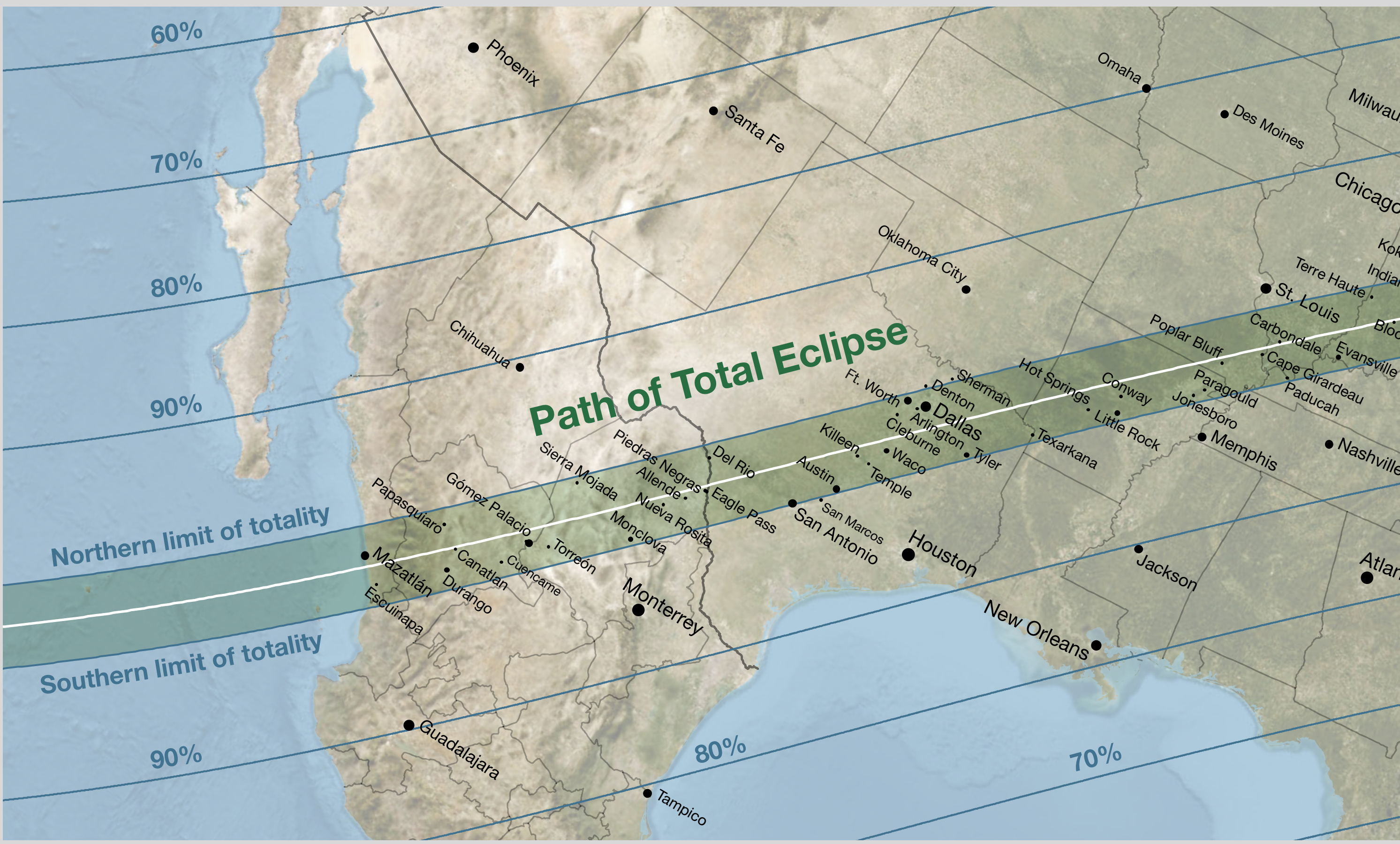
This month's total solar eclipse is the first visible across the U.S. since 2017 and the last of that nature until 2045.

Thirty-two million. That's how many people will be able to see a total solar eclipse on April 8th from home. Weather permitting, of course. Millions more will fly, drive, or connive to make sure they're within the approximately 185-kilometer-wide (115-mile-wide) path of totality that stretches diagonally across Mexico, 15 U.S. states, and the Canadian Maritime provinces. Inside this narrow ribbon of shadow, the lunar disk will completely cover the Sun like a tight-fitting lid on a pot, creating what many consider the most moving sight in nature. And for many, there's an extra degree of motivation this time since the next total eclipse to grace the contiguous U.S. won't occur until August 22, 2044.

The Moon's umbral shadow first touches down at sunrise in the Pacific Ocean, but few will see it until it reaches mainland Mexico near the popular coastal resort city of Mazatlán, where eclipse-watchers will experience 4 minutes 18 seconds of totality starting around 11:08 a.m. local time. Weather prospects here and in the Mexican interior are excellent, with mostly sunny skies being the norm in early spring. A maximum eclipse of 4^{m} 28^{s} occurs near the small Mexican town of Nazas, where the Sun has an altitude of 70°.

As the shadow reaches the Texas border, the chances of cloudy conditions at eclipse time gradually increase, rising from around 25% in Mazatlán to around 45% at Eagle Pass, Texas, where totality begins at 1:28 p.m. CDT and lasts 4^{m} 24^{s}. The Moon's shadow next darkens the large Texas cities of Austin (1^{m} 39^{s} of totality, starting at 1:36 p.m.) and Dallas (3^{m} 53^{s} at 1:41 p.m.).

Clouds along much of the eclipse path in the Lone Star State are relatively common in April, averaging around 55%. According to meteorologist Jay Anderson, the best weather prospects for the entire U.S. lie north of the centerline from Junction to Brady in the Texas Hill Country. Here, April cloudiness hovers around 39%.



Continuing its northeastward advance, the shadow clips southeastern Oklahoma and glides over central Arkansas, where observers in Little Rock get 2^{m} 27^{s} of totality starting at 1:52 p.m. CDT. Across Arkansas and Missouri, cloud cover ranges from 54% to 59%, but as the eclipse path enters Illinois that figure creeps up to 60%, along with increasing chances of spring storms. At lucky Carbondale, Illinois, which will experience its second total solar eclipse in just seven years, totality starts at 1:59 p.m. CDT with 4^{m} 8^{s} of shadow time. Minutes later, at 3:06 p.m. EDT, more than 2 million people in Indianapolis, Indiana, can thrill to 3^{m} 49^{s} of totality.

▼ As shown in this map prepared by Michael Zeiler, during the April 8th total solar eclipse, the Moon's shadow races across Mexico, the U.S., and through eastern Canada. While the eclipse central line may pass close to home for many observers, weather prospects along the path of totality vary widely, with regions in Mexico and Texas being the most favorable. The percentage lines refer to the fraction of the Sun's area covered by the Moon.

Cloudiness varies between 60% and 70% from Illinois to Ohio, where Clevelanders get 3^{m} 48^{s} of precious totality starting at 3:14 p.m. EDT. Cold air over Lake Erie helps to suppress cloud formation, making viewing locations south and southwest of the lake the best in the region.

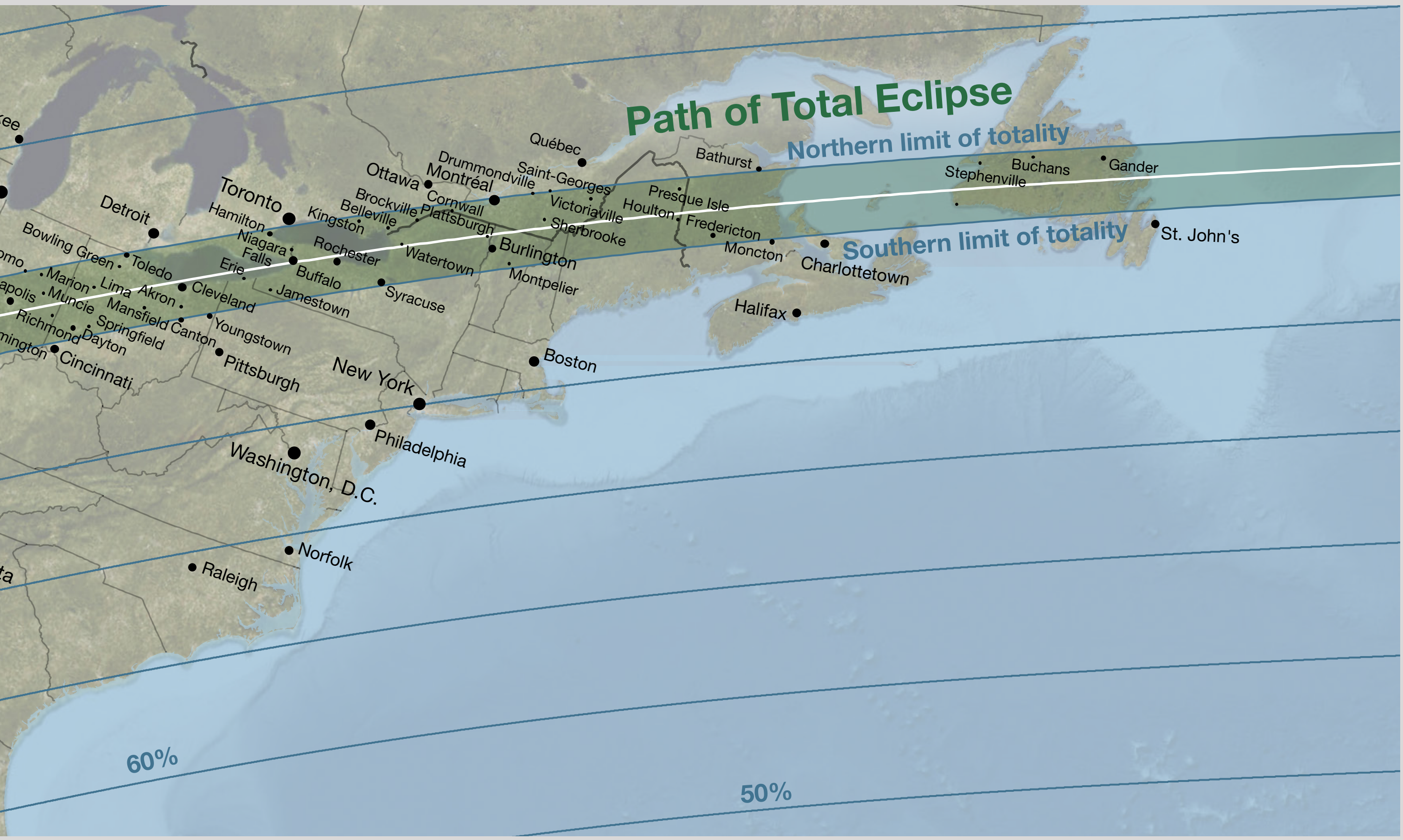
Cloud percentages slowly increase beyond Buffalo and Rochester, New York (where Lake Ontario will moderate cloud cover) as the path enters northern Vermont and Maine. Buffalo, New York, sits squarely on the centerline, with 3^{m} 45^{s} of totality beginning at 3:18 p.m. EDT.

The shadow departs the U.S. and heads to the Canadian Maritime provinces before exiting the continent at Newfoundland and Labrador's Cape Bonavista, at around 5:16 p.m. NDT. From first nibble to last bite, the eclipse lasts about 2½ hours.

Although the view outside the path of totality is far less dramatic, there's still much to see. The amount of Sun obscured varies from near totality of 99% in St. Louis, Missouri, to 90% in New York City, 45% in Key West, Florida, 20% in Seattle, Washington, and to just 2% in Juneau, Alaska.

No matter where you view the eclipse from, be sure to use an approved and undamaged solar filter for all the partial phases of the event — it's *only* during totality that you can safely view without protection. You can watch the partial phases indirectly by using the holes in a colander to cast multiple, tiny images of the Sun on the ground or a sheet of white paper. Alternatively, you can mount binoculars on a tripod and project the Sun's image (turn to page xx for instructions). Telescope users can either cover the front end of the tube with a quality, snug-fitting solar filter, or project the solar image for all to see with a homemade Sun funnel, as described at **https://is.gd/sunfunnel**.

To maximize your chances for clear skies on the big day, consult Jay Anderson's eclipse weather guide at **eclipsophile.com**. For detailed eclipse



timings for any location, visit Xavier Jubier's interactive eclipse map at **https://is.gd/2024eclipse**.

And if this is your first eclipse, here are some highlights to look forward to:

- Spot Venus about 15° to the lower right (southwest) of the Sun 15–30 minutes before totality. Jupiter will be visible closer to the time of totality about three fists (30°) to the Sun's upper left.
- Feel the air temperature drop as the Moon slowly covers the Sun. During most eclipses it dips by about 10°F.
- Experience the eerie half-light as the Sun thins to a crescent.
- Watch for shadow bands — undulating ripples of dark and light flutter on the ground immediately before and after totality.
- Be awed by the spectacle of Baily's beads and the diamond ring effect immediately before and after totality as the Moon's rugged limb breaks the diminishing arc of sunlight.
- Marvel at the silky, ethereal appearance of the solar corona. Since this eclipse occurs close to the peak of the solar current cycle, expect a rounded, crownlike shape.
- Look for strikingly pink solar prominences dotting the Moon's edge. Binoculars are a big help in seeing them so be sure to have a pair at the ready.
- Note the orange color of the distant horizon where the Sun still shines beyond the Moon's shadow.
- Pay attention to the nocturnal behavior of animals. Frogs may start to peep. Birds chirp and chatter more just before totality then fall silent when darkness sets in.
- Embrace the eclipse as a personal syzygy — a rare alignment of the Sun, Moon, Earth . . . and you!

To read more about the eclipse, consult the April 2023 issue (starting on page 26) or pick up a copy of our special publication, *The Great 2024 Eclipse*, which can be purchased on newsstands and directly from **shopatsky.com**.

A Daylight Venus Occultation

APRIL IS A BUSY MONTH for the Moon. The day before it eclipses the Sun, the Moon serves as its own warmup act by covering the planet Venus on the 7th for viewers across the eastern third of North America, much of Mexico and the Caribbean, and Central America. The occultation occurs in broad daylight with the crescent Moon just 1.8%-illuminated and located 15° from the Sun. That combination will make spotting the Moon a challenge.

Your best bet is to find Venus first by using a Go To telescope or one on an equatorial mount fitted with setting circles.

▶ This simulated view shows Venus mere moments before it's occulted by a thin, waning crescent Moon on April 7th, as seen from Atlanta, Georgia.

Attach a solar filter to the telescope, center and focus the Sun, then offset to Venus's position in R.A. and Dec. Finally, remove the filter and view — the planet should be obvious, with the Moon faintly visible nearby.

From Atlanta, Georgia, Venus's gibbous disk will take about 26 seconds to completely disappear behind the advancing illuminated limb of the Moon, starting about 12:17 p.m. EDT. Venus reappears at 1:28 p.m. on the Moon's invisible dark limb, where the planet will seem to materialize from nowhere into a blue sky!

For more details about this occultation, visit the International Occultation Timing website at **www.lunar-occultations.com/iota**.

Action at Jupiter

JUPITER IS NEARING its May 18th conjunction with the Sun, which means telescopic observers have only a few evenings remaining to enjoy viewing the planet. As April opens, it shines at magnitude –2.1 and hangs 26° above the western horizon half an hour after sunset — about the earliest it can be easily viewed. By the end of the month Jupiter's altitude has slipped to just 5° — much too low for there to be any hope of steady seeing conditions. At that point, the planet will be a binocular and naked-eye target. Not to fret, however. Jupiter will return in the morning sky in early June, though it won't be a rewarding sight in telescopes until July.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The moons orbit Jupiter at different rates, changing positions along an almost straight line from our point of view on Earth. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for when Jupiter is at its highest.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

March 1: 8:03, 17:59; **2:** 3:55, 13:51, 23:47; **3:** 9:43, 19:38; **4:** 5:34, 15:30; **5:** 1:26, 11:22, 21:18; **6:** 7:13, 17:09; **7:** 3:05, 13:01, 22:57; **8:** 8:53, 18:49; **9:** 4:44, 14:40; **10**: 0:36, 10:32, 20:28; **11**: 6:24, 16:19; **12**: 2:15, 12:11, 22:07; **13**: 8:03, 17:59; **14**: 3:55, 13:50, 23:46; **15**: 9:42, 19:38; **16**: 5:34, 15:30; **17**: 1:26, 11:21, 21:17; **18**: 7:13, 17:09; **19**: 3:05, 13:01, 22:57; **20**: 8:52, 18:48; **21**: 4:44, 14:40; **22**: 0:36, 10:32, 20:28; **23**: 6:23, 16:19; **24**: 2:15, 12:11, 22:07; **25**: 8:03, 17:59; **26**: 3:54, 13:50, 23:46; **27**: 9:42, 19:38; **28**: 5:34, 15:30; **29**: 1:25, 11:21, 21:17; **30**: 7:13, 17:09; **31**: 3:05, 13:01, 22:56

STELLARIUM

April 1: 5:18, 15:14; **2:** 1:10, 11:06, 21:02; **3:** 6:58, 16:53; **4:** 2:49, 12:45, 22:41; **5:** 8:37, 18:33; **6:** 4:29, 14:24; **7:** 0:20, 10:16, 20:12; **8:** 6:08, 16:04; **9:** 1:59, 11:55, 21:51; **10**: 7:47, 17:43; **11**: 3:39, 13:35, 23:30; **12**: 9:26, 19:22; **13**: 5:18, 15:14; **14**: 1:10, 11:05, 21:01; **15**: 6:57, 16:53; **16**: 2:49, 12:45, 22:40; **17**: 8:36, 18:32; **18**: 4:28, 14:24; **19**: 0:20, 10:15, 20:11; **20**: 6:07, 16:03; **21**: 1:59, 11:55, 21:51; **22**: 7:46, 17:42; **23**: 3:38, 13:34, 23:30; **24**: 9:26, 19:21; **25**: 5:17, 15:13; **26**: 1:09, 11:05, 21:01; **27**: 6:56, 16:52; **28**: 2:48, 12:44, 22:40; **29**: 8:36, 18:31; **30**: 4:27, 14:23

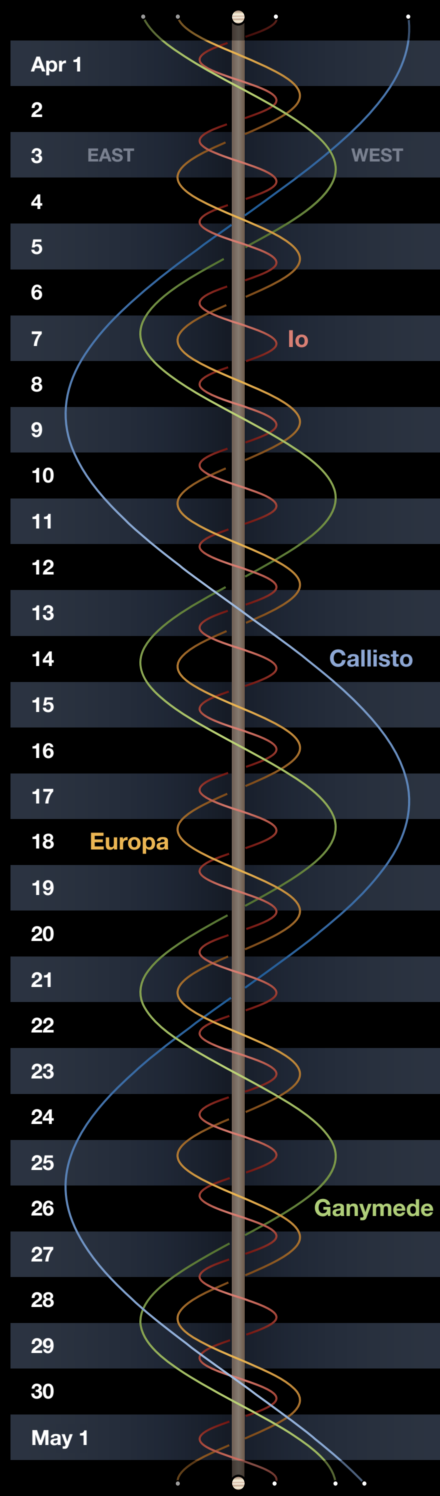
These times assume that the spot will be centered at System II longitude 55° on April 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 55° and $1\frac{2}{3}$ minutes later for each degree more than 55°.

Phenomena of Jupiter's Moons, April 2024

Apr. 1	1:17	I.Ec.R
	6:14	II.Tr.I
	7:49	II.Sh.I
	8:39	II.Tr.E
	10:11	II.Sh.E
	19:41	I.Tr.I
	20:28	I.Sh.I
	21:52	I.Tr.E
	22:37	I.Sh.E
	23:25	III.Tr.I
Apr. 2	1:26	III.Tr.E
	2:44	III.Sh.I
	4:23	III.Sh.E
	16:49	I.Oc.D
	19:46	I.Ec.R
Apr. 3	1:24	II.Oc.D
	5:21	II.Ec.R
	14:11	I.Tr.I
	14:57	I.Sh.I
	16:22	I.Tr.E
	17:06	I.Sh.E
Apr. 4	11:20	I.Oc.D
	14:15	I.Ec.R
	19:38	II.Tr.I
	21:07	II.Sh.I
	22:04	II.Tr.E
	23:30	II.Sh.E
Apr. 5	8:42	I.Tr.I
	9:25	I.Sh.I
	10:53	I.Tr.E
	11:35	I.Sh.E
	13:22	III.Oc.D
	15:26	III.Oc.R
	16:28	III.Ec.D
	18:09	III.Ec.R
Apr. 6	5:50	I.Oc.D
	8:44	I.Ec.R
	14:49	II.Oc.D
	18:39	II.Ec.R
Apr. 7	3:12	I.Tr.I
	3:54	I.Sh.I
	5:23	I.Tr.E
	6:04	I.Sh.E
Apr. 8	0:21	I.Oc.D
	3:12	I.Ec.R
	9:03	II.Tr.I
	10:26	II.Sh.I
	11:29	II.Tr.E
	12:48	II.Sh.E
	21:43	I.Tr.I
	22:23	I.Sh.I
	23:54	I.Tr.E
Apr. 9	0:33	I.Sh.E
	3:54	III.Tr.I
	5:55	III.Tr.E
	6:46	III.Sh.I
	8:25	III.Sh.E
	18:51	I.Oc.D
	21:41	I.Ec.R
Apr. 10	4:14	II.Oc.D
	7:58	II.Ec.R
	16:13	I.Tr.I
	16:52	I.Sh.I
	18:24	I.Tr.E
	19:02	I.Sh.E
Apr. 11	13:21	I.Oc.D
	16:10	I.Ec.R
	22:28	II.Tr.I
	23:44	II.Sh.I
Apr. 12	0:54	II.Tr.E
	2:06	II.Sh.E
	10:44	I.Tr.I
	11:21	I.Sh.I
	12:55	I.Tr.E
	13:31	I.Sh.E
	17:51	III.Oc.D
	19:53	III.Oc.R
	20:29	III.Ec.D
	22:10	III.Ec.R
Apr. 13	7:52	I.Oc.D
	10:39	I.Ec.R
	17:39	II.Oc.D
	21:16	II.Ec.R
Apr. 14	5:14	I.Tr.I
	5:49	I.Sh.I
	7:25	I.Tr.E
	7:59	I.Sh.E
Apr. 15	2:22	I.Oc.D
	5:08	I.Ec.R
	11:53	II.Tr.I
	13:02	II.Sh.I
	14:19	II.Tr.E
	15:25	II.Sh.E
	23:45	I.Tr.I
Apr. 16	0:18	I.Sh.I
	1:56	I.Tr.E
	2:28	I.Sh.E
	8:23	III.Tr.I
	10:24	III.Tr.E
	10:47	III.Sh.I
	12:27	III.Sh.E
	20:53	I.Oc.D
	23:36	I.Ec.R
Apr. 17	7:05	II.Oc.D
	10:35	II.Ec.R
	18:15	I.Tr.I
	18:47	I.Sh.I
	20:26	I.Tr.E
	20:57	I.Sh.E
Apr. 18	15:23	I.Oc.D
	18:05	I.Ec.R
Apr. 19	1:18	II.Tr.I
	2:20	II.Sh.I
	3:44	II.Tr.E
	4:43	II.Sh.E
	12:46	I.Tr.I
	13:16	I.Sh.I
	14:57	I.Tr.E
	15:26	I.Sh.E
	22:21	III.Oc.D
Apr. 20	0:23	III.Oc.R
	0:30	III.Ec.D
	2:12	III.Ec.R
	9:54	I.Oc.D
	12:34	I.Ec.R
	20:30	II.Oc.D
	23:53	II.Ec.R
Apr. 21	7:16	I.Tr.I
	7:45	I.Sh.I
	9:27	I.Tr.E
	9:55	I.Sh.E
Apr. 22	4:24	I.Oc.D
	7:03	I.Ec.R
	14:43	II.Tr.I
	15:39	II.Sh.I
	17:10	II.Tr.E
	18:02	II.Sh.E
Apr. 23	1:47	I.Tr.I
	2:13	I.Sh.I
	3:58	I.Tr.E
	4:23	I.Sh.E
	12:54	III.Tr.I
	14:49	III.Sh.I
	14:54	III.Tr.E
	16:29	III.Sh.E
	22:55	I.Oc.D
Apr. 24	1:32	I.Ec.R
	9:56	II.Oc.D
	13:11	II.Ec.R
	20:17	I.Tr.I
	20:42	I.Sh.I
	22:28	I.Tr.E
	22:52	I.Sh.E
Apr. 25	17:25	I.Oc.D
	20:00	I.Ec.R
Apr. 26	4:09	II.Tr.I
	4:57	II.Sh.I
	6:35	II.Tr.E
	7:20	II.Sh.E
	14:48	I.Tr.I
	15:11	I.Sh.I
	16:59	I.Tr.E
	17:21	I.Sh.E
Apr. 27	2:51	III.Oc.D
	6:13	III.Ec.R
	11:56	I.Oc.D
	14:29	I.Ec.R
	23:21	II.Oc.D
Apr. 28	2:30	II.Ec.R
	9:18	I.Tr.I
	9:40	I.Sh.I
	11:29	I.Tr.E
	11:50	I.Sh.E
Apr. 29	6:26	I.Oc.D
	8:58	I.Ec.R
	17:34	II.Tr.I
	18:15	II.Sh.I
	20:01	II.Tr.E
	20:39	II.Sh.E
Apr. 30	3:49	I.Tr.I
	4:08	I.Sh.I
	6:00	I.Tr.E
	6:18	I.Sh.E
	17:25	III.Tr.I
	18:49	III.Sh.I
	19:24	III.Tr.E
	20:30	III.Sh.E

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.

▲The sinuous lunar rille Vallis Schröteri as seen from the orbiting Apollo 15 command module

NASA / JSC / ARIZONA STATE UNIVERSITY

Understanding Sinuous Rilles

The origin of these meandering lava channels is surprisingly complex.

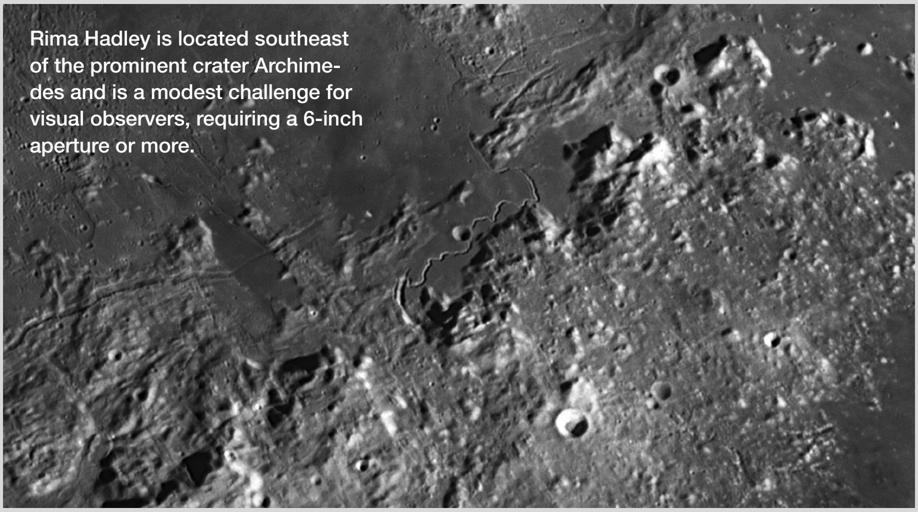
Of all the landforms on the lunar surface, sinuous rilles are among the most intriguing. We know that flowing fluid must be involved in their formation by their meandering tracks, but what was the liquid? In the 1960s, some scientists suggested that sinuous rilles were evidence that the Moon once had flowing water, as that's the liquid that creates bends in terrestrial rivers. Sometime earlier, it was even proposed that craters were circular coral reefs, but the theory was swiftly rejected. There was no significant evidence that liquid water had existed on the Moon.

A key observation that constrains theories of the origin of sinuous rilles is that they occur on maria, which scientists have generally recognized since the 1960s to be volcanic lava flows. In the mid-1960s and early '70s, the theory that these narrow, snaking depressions originated as volcanic lava channels emerged based on investigations of lava flows on Earth. In 1972, my University of Hawai'i colleague Dale Cruikshank and I contributed to this theory by publishing our observations of active lava channels and lava tubes in Hawai'i.

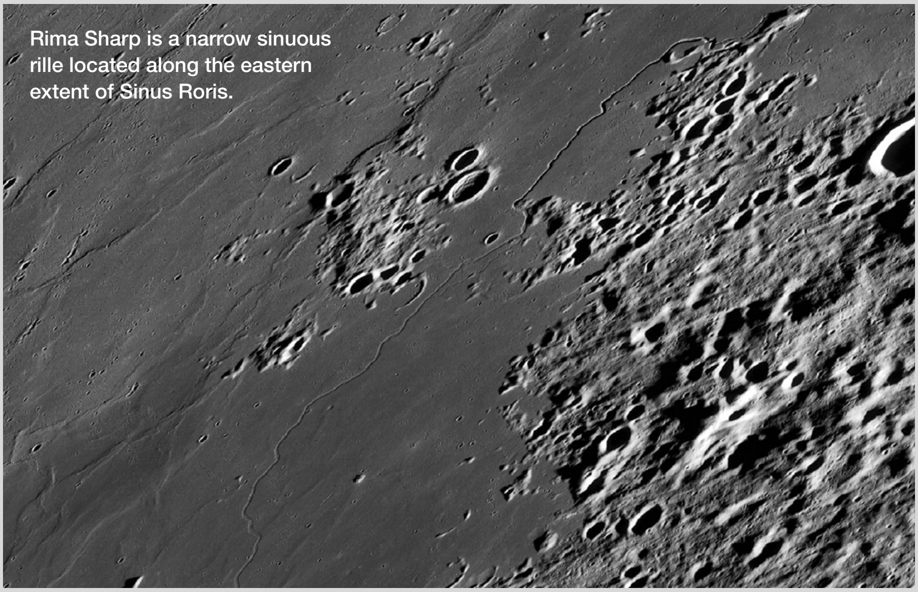
As lava flows downslope, the edges of the stream cool faster than the center, forming levees while the hotter middle part of the flow keeps moving. Ultimately, the eruption slows and stops, leaving a sinuous channel if the lava flowed across ground with a gentle slope, and a straight channel on areas with a steeper slope. Since the 1970s, geologists realized that although channeling such as we observed on the Hawaiian Islands occurred on the Moon (as evidenced by levees along flow margins of some sinuous rilles), the dominant mechanism for creating sinuous rilles is actually *thermal erosion* of the lava channel floor.

Thermal erosion occurs when the temperature of a lava flow is hot enough to melt the underlying material, which is then carried away in the flowing lava, deepening the channel. It was also recognized at the time that thermal erosion is more effective if lava flows turbulently, which occurs when a fluid frequently changes direction and speed. These changes bring the hottest lava from the interior of the stream into contact with the substrate material while also exerting more stress on the substrate, increasing the lava's erosional effectiveness and melting ability.

Several variables contribute to the effectiveness of thermal erosion. Over the past 40 years, lunar scientists Lionel Wilson of Lancaster University in the U.K. and James Head at Brown University in the U.S. have studied the physical,



Rima Hadley is located southeast of the prominent crater Archimedes and is a modest challenge for visual observers, requiring a 6-inch aperture or more.



Rima Sharp is a narrow sinuous rille located along the eastern extent of Sinus Roris.

CLOSE-UP OF HADLEY RILLE: SEAN WALKER; RIMA SHARP: NASA / GSFC / ARIZONA STATE UNIVERSITY

geochemical, and thermodynamic processes controlling the formation of lunar lava flows and sinuous rilles. In a recent publication (**https://is.gd/lavarilles**) they combine their research, others' theories, and observations of active lava flows in Hawai'i to derive equations that describe the details of the formation of sinuous rilles. Most influential are the temperature and composition of the flowing lava, the erodibility of the substrate material, and the duration that hot lava is in contact with the substrate (it takes days to heat the substrate enough to melt). The duration depends on the volume and the speed of erupted lava.

The most unusual sinuous rille is **Vallis Schröteri**, which cuts through the Aristarchus Plateau. Schröter's Valley is 168 kilometers (104 miles) long, 6 km across at its widest point, and has an average depth of 500 meters. According to calculations by Wilson and Head, to thermally erode Schröter's Valley, 300,000 cubic meters of lava must have erupted each second for 10 to 15 months. A total volume of 8,000 cubic kilometers of lava flowed down the rille and emptied onto Oceanus Procellarum. The modeling is consistent with the 1.6-km-high Cobra Head volcano, whose deep crater is the vent for the cone, the rille itself, the vast eruption of lava, and the widespread pyroclastic deposits that blanket the Aristarchus Plateau — all created by a single, continuous eruption. It must have been a spectacular, yearlong event that occurred some 3.3 billion years ago.

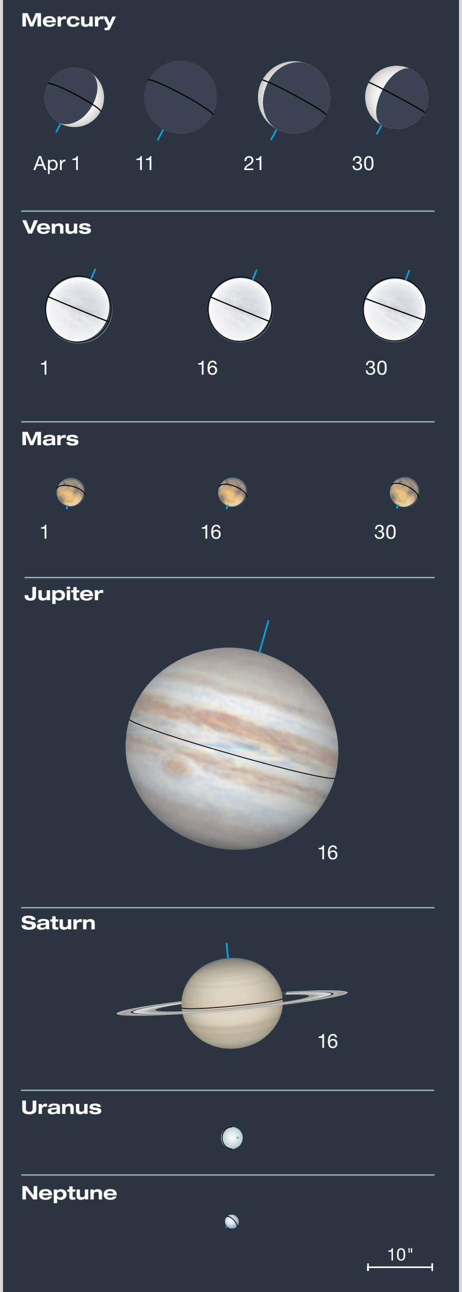
A second famous sinuous rille is the Apollo 15 landing site that astronauts explored in 1971. **Rima Hadley** is 144 km long, 1.2 km wide, and has an average depth of 220 meters. According to Wilson and Head, it formed over a period of 4 months, with an average lava eruption rate of 70,000 cubic meters per second, and deposited 770 cubic kilometers of hot lava in **Palus Putredinis**.

Other sinuous rilles on the Moon formed faster with less lava. According to a catalog of 195 sinuous rilles compiled by Debra M. Hurwitz (then at Brown University) and her colleagues, the average sinuous rille is 68 km long, 637 m wide, and 72 m deep. With these dimensions, a typical sinuous rille formed in 3 months, with an eruption rate of 12,000 cubic meters of lava each second.

From an observer's perspective, sinuous rilles are a great challenge. Only Schröter's Valley is wide enough to easily see with small telescopes. With larger apertures and high magnification, imagers can photograph Hadley Rille, but its 1.2-km width makes visual detection difficult unless the lighting is just right. Similarly, the 320-km-long **Rima Sharp**, whose vent is thought to be the source for the 2-billion-year-old mare lavas sampled by the Chinese Chang'e 5 sample-return mission, is only 840 m wide. And finally, **Rima Marius**, found just north of the Marius Hills, is about 630 m wide and 310 km long.

You can image the Hadley, Sharp, and Marius rilles with 6-inch telescopes, and although Hadley has often been spotted visually, in this age of electronically assisted observing there are few reports of direct visual observations for Sharp and Marius. However, British observer Percy Wilkins did include the Marius Rille in his 1951 map of the Moon, and German selenographer Johann Friedrich Julius Schmidt included the Prinz Rilles in his 1866 catalog of 278 rilles. Can you match the observing feats of 70 to 150 years ago?

■ Contributing Editor **CHUCK WOOD** often looks to Earth for insights into the origin of lunar features.



▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

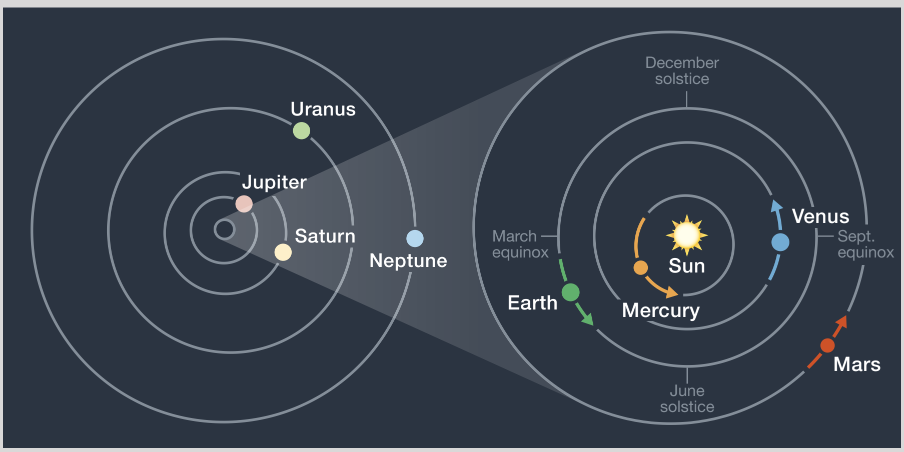
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during April. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk on the 1st and lost in the Sun's glare the rest of the month • **Venus** visible at dawn to the 7th • **Mars** visible at dawn all month • **Jupiter** visible in the west at dusk • **Saturn** emerges at dawn starting on the 5th.

April Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	0^h 42.0^m	+4° 31′	—	–26.8	32′ 01″	—	0.999
	30	2^h 29.6^m	+14° 45′	—	–26.8	31′ 45″	—	1.007
Mercury	1	1^h 34.8^m	+13° 22′	16° Ev	+1.4	9.3″	17%	0.726
	11	1^h 21.1^m	+11° 10′	3° Ev	—	11.4″	0%	0.589
	21	1^h 01.1^m	+6° 19′	15° Mo	+2.8	11.3″	8%	0.596
	30	1^h 04.0^m	+4° 27′	23° Mo	+1.1	9.8″	24%	0.685
Venus	1	23^h 42.2^m	–3° 31′	17° Mo	–3.8	10.3″	96%	1.623
	11	0^h 27.6^m	+1° 21′	14° Mo	–3.8	10.1″	97%	1.653
	21	1^h 13.1^m	+6° 13′	12° Mo	–3.9	9.9″	98%	1.679
	30	1^h 54.6^m	+10° 24′	10° Mo	–3.9	9.8″	99%	1.699
Mars	1	22^h 35.5^m	–10° 12′	35° Mo	+1.2	4.5″	96%	2.090
	16	23^h 19.1^m	–5° 46′	38° Mo	+1.2	4.6″	95%	2.033
	30	23^h 59.0^m	–1° 30′	41° Mo	+1.1	4.7″	94%	1.980
Jupiter	1	2^h 59.2^m	+16° 08′	36° Ev	–2.1	34.1″	100%	5.783
	30	3^h 25.5^m	+17° 55′	14° Ev	–2.0	32.9″	100%	5.984
Saturn	1	23^h 00.9^m	–8° 07′	28° Mo	+1.1	15.7″	100%	10.581
	30	23^h 12.0^m	–7° 03′	54° Mo	+1.2	16.2″	100%	10.267
Uranus	16	3^h 15.5^m	+17° 48′	25° Ev	+5.8	3.4″	100%	20.501
Neptune	16	23^h 55.0^m	–1° 52′	28° Mo	+7.9	2.2″	100%	30.783

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit **skyandtelescope.org**.



Astrophotography With a Portrait Lens

Creating more detailed astrophotos requires a boost in focal length.

Portrait lenses are popular among professional photographers because they create a flattering perspective of people's faces while simultaneously blurring the background, helping separate the subject from its surroundings. Such lenses typically have focal lengths between 70 and 200 mm, with appealingly fast apertures often starting at f/1.2 to f/2.8. These specifications also make portrait lenses excellent options for a lightweight, high-performance astrophotography system. However, before you invest in a new lens, consider both its advantages and disadvantages for the types of images you want to create.

I'm a big fan of taking a structured approach to astrophotography. This means only buying additional gear if it makes sense for your budget and level of experience. Don't underestimate what you can accomplish with only a budget camera, a kit lens, and a sturdy tripod. (I described such an approach in the February 2023 issue, page 54.) Once you have some real-world experience imaging under the night sky, you'll be better able to evaluate what additional gear you might need.

A Speedy Upgrade

A first purchase is often a better lens. The main problem with the inexpensive lens that your camera came with is that it's probably fairly slow at the upper end of its zoom range — typically f/5.6 or narrower. This limits its light-gathering ability, which leads to significantly longer exposures.

A faster lens not only allows shorter exposures, it produces a much brighter image, which makes focusing on faint objects easier. The auto-focus systems on some cameras struggle with the dim light of the stars. Often, you'll need to switch your lens to manual mode and

▲ **85-MM NORTH AMERICA** The Canon EF 85mm f/1.8 USM lens is one of the author's favorite, budget-friendly astrophotography options. When mounted on an APS-format, or cropped-sensor camera (such as the astro-modified Canon 60D used for this photo), it offers sky coverage equal to a 136-mm lens on a full-frame camera. For this 2-minute exposure of the North America Nebula, the camera was set to ISO 3200 with the lens wide open, while an iOptron iEQ30Pro equatorial mount tracked the night sky.

◀ **STELLAR VALUES** Three of the author's favorite portrait lenses for astrophotography are (left to right) Canon's EF 85mm f/1.8 USM lens, the EF100mm f/2.8 Macro USM, and the EF 70-200mm f/2.8L USM zoom lens (shown here attached to a Canon EOS R7 mirrorless camera with an EF-EOS R Mount Adapter. All three are available at deep discounts on the used equipment market.

use *live view* to zoom in and focus on a bright star or planet. The brighter image of a fast, high-quality lens simply makes it that much easier to achieve perfect focus. And sharp focus is critical for satisfying photos.

A fast lens is good, but you have to give some thought to the type of images that you want to create before you can figure out what focal length is going to be most useful. If you're mainly interested in wide-field astrophotography, such as landscapes with the Milky Way or an auroral display, you'll benefit most from an ultra-wide-angle lens. This will enable you to shoot short exposures (less than 30 seconds) from a fixed tripod without getting star trails. However, if you want to zoom in on specific deep-sky objects, such as nebulae and galaxies, you should look at something with a longer focal length. This is where portrait lenses excel.

Stellar Portraits

Portrait lenses sit in a kind of Goldilocks Zone — they produce a sufficient image scale to show details in individual objects, without being so large that they require a heavy-duty tracking mount. Plus, their typically wide apertures make them ideal candidates for imaging in the low-light conditions that typify night-sky photography.

Used on a full-frame camera, the 70-mm end of the portrait-lens range lets you capture entire constellations and large deep-sky objects, such as the North America and Pelican nebulae. At the longer focal lengths (up to 200 mm), individual clusters, nebulae, and the nearest galaxies start to reveal a surprising amount of detail.

Keep in mind that if your camera has the smaller APS-C-sized sensor, you'll need to do a little math to figure out the equivalent focal length a given lens will yield. Simply multiply the actual focal length of the lens by your camera's crop factor. The 1.6× crop factor of Canon cameras means that a 100-mm lens provides the same field of view as a 160-mm model on a full-frame camera. (For Nikon, Sony, and Fuji cameras, the conversion factor is 1.5×.)

In fact, if you own an APS-C camera body you can get into portrait-lens territory with the popular 50-mm prime lens. Often referred to as a "nifty fifty," these are often the most inexpensive option in a manufacturer's lineup. And despite its low price, a standard 50-mm lens delivers exceptional optical performance and offers aspiring astrophotographers an ideal starting point. Importantly, with a typically wide f/1.8 aperture, such lenses deliver over 10 times more light than a f/5.6 optic. The only downside is that a 50-mm lens lacks the magnification of longer-focal-length lenses, meaning they don't deliver as much detail in deep-sky objects.

Traditional Values

Because portrait lenses are so widely used by professional photographers, they can usually be found on the used market at reasonable prices. This is especially true if you're willing to use an adapter ring to mount an older model on systems that have changed their lens mounts in the past few years. You can save even more by avoiding options like image stabilization and auto-focus. These features are great for actual portrait photography, but you don't need them for imaging the night sky.

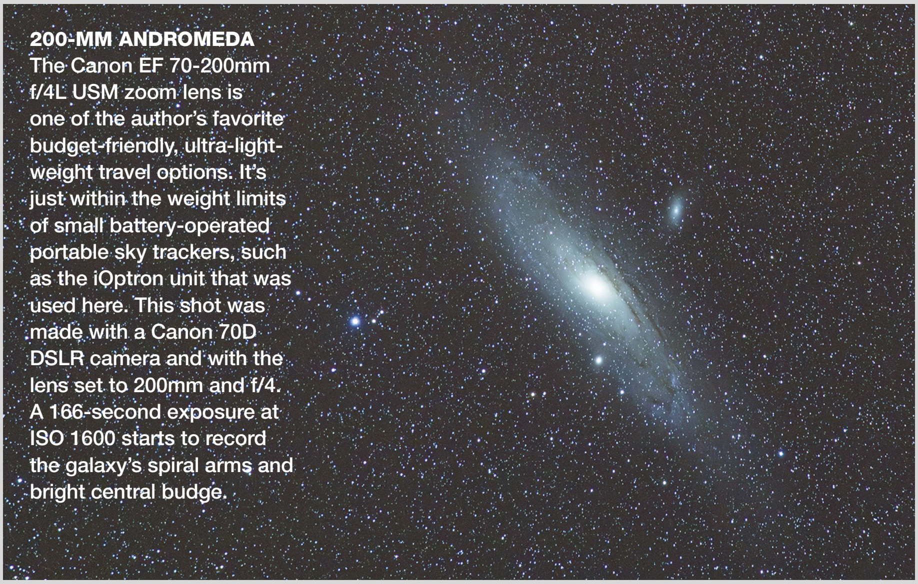
Although I've emphasized how useful fast optics are, you probably should stay away from ultra-fast portrait lenses (such as f/1.2). Not only are these models extremely expensive, but they typically suffer from poor image quality off-axis. This flaw is difficult to spot in portraits with their blurry backgrounds, but it's obvious in astrophotos. An aberration, called *coma*, turns stars near the edges of the frame into comet-like streaks — and it can't be fixed with image-editing programs like *Photoshop*. The only way around the problem is to reduce the aperture by a stop or two, but then it's no use paying a premium for an f/1.2 lens if you can only use it at f/2.8. You might as well save money and buy a lower-priced, slower model that performs just as well at the apertures you actually shoot with.

As a Canon user, two of my favorite portrait lenses are the Canon EF 85mm f/1.8 USM and the EF 100mm

▶ **ALONG FOR THE RIDE** If your telescope has an equatorial mount, chances are the optical tube assembly can be replaced by a camera attached to a dovetail bar (such as the short version manufactured by ADM shown at right). Here, the author's Canon EOS 60D is attached to a Canon EF 70-200mm f/2.8L USM zoom lens riding on an iOptron iEQ30Pro equatorial mount.

f/2.8 Macro USM. The Sigma 85mm F1.4 DG HSM Art lens is also a strong performer. Happily, these models can usually be found on the used market at substantial savings.

Longer-focus lenses operating at 135 to 200 mm are some of the most compelling options for astrophotography with their ability to reveal significant detail in many deep-sky targets. The Canon EF 135mm f/2L USM lens is an excellent choice, as is the Sigma 135mm F1.8 DG HSM Art lens. At the upper end of the portrait range, older lenses like the Canon EF 200mm f/2.8L II USM are available used at hefty discounts.



200-MM ANDROMEDA The Canon EF 70-200mm f/4L USM zoom lens is one of the author's favorite budget-friendly, ultra-lightweight travel options. It's just within the weight limits of small battery-operated portable sky trackers, such as the iOptron unit that was used here. This shot was made with a Canon 70D DSLR camera and with the lens set to 200mm and f/4. A 166-second exposure at ISO 1600 starts to record the galaxy's spiral arms and bright central budge.

Stop the Earth

Of course, as the focal length increases, Earth's rotation becomes an increasingly significant factor. Shooting from a stationary tripod restricts exposures to a few seconds or less to preserve pinpoint stars. While short shutter speeds might be sufficient to capture conjunctions of the Moon and planets, photos of galaxies, nebulae, and clusters require much longer exposures. This means you'll need some way of tracking the stars.

If you own a telescope on a motorized equatorial mount, you can buy (or make) an inexpensive piggyback adapter that allows your camera to come along for the ride as your scope tracks the stars. The main downside to this approach is that it adds extra weight, which may impair your mount's tracking performance. Alternatively, assuming your mount has a standard dovetail system, you can simply remove the telescope and attach your camera in its place via a small aluminum dovetail plate, which you can acquire from most telescope vendors.

Another route to pinpoint stars is to purchase a dedicated, battery-operated sky tracker (*S&T:* Feb. 2022, p. 54). There are several different makes and models to choose from, and they're all much smaller and lighter than a typical telescope mount. Because of this, star trackers make excellent travel companions when a full-sized mount might be impractical. These units will fit in your carry-on bag for a winter vacation, or in your backpack for a summer camping trip.

Either option will allow you to record images for up to several minutes at portrait-lens focal lengths, opening a universe of deep-sky imaging possibilities. Even if you plan to bring your telescope with you, sometimes it's nice to have a separate mount dedicated to astrophotography. That way you can enjoy viewing objects in your scope while your camera clicks away nearby.

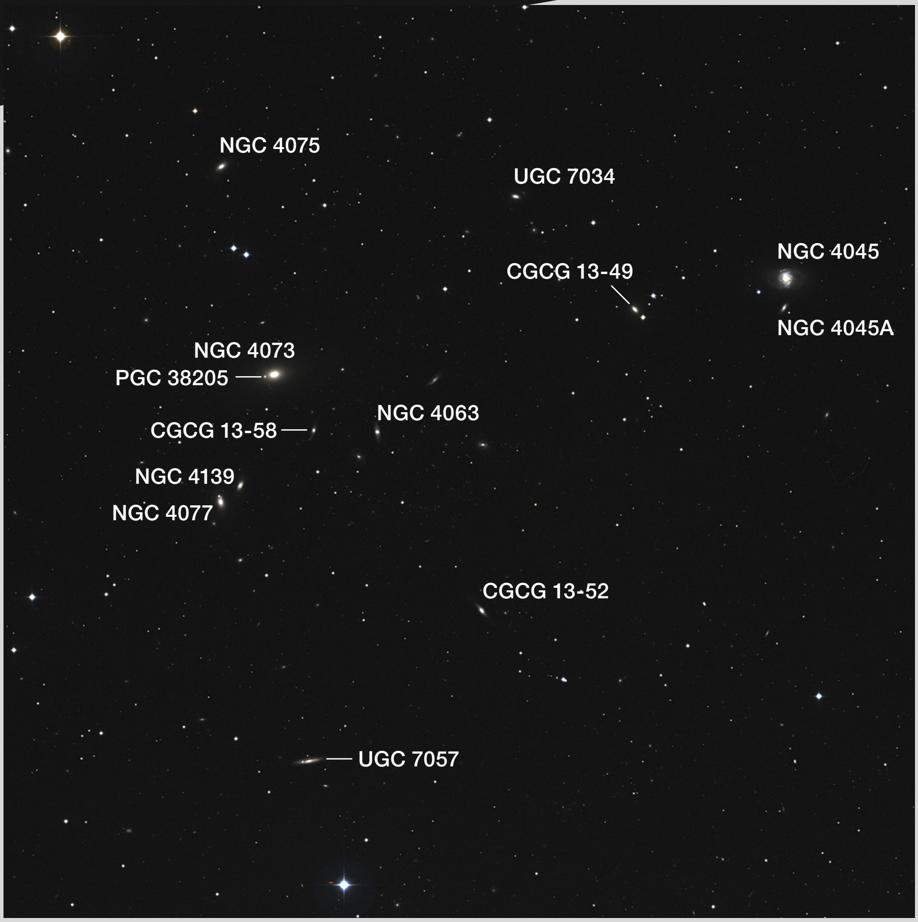
▶ **SKY TRACKER** A portable, battery-operated tracking mount, such as the iOptron SkyTracker Pro shown here, permits the use of lenses that have longer focal lengths without the risk of star trails. The tracker mounts in between your existing tripod and ball head, to create an ultra-portable system.

Cosmic Zooms

Finally, while most of my recommendations are fixed-focal-length primes, there are other notable options. Many manufacturers offer extremely high-quality zoom lenses that work well over their entire range. For example, the Canon EF 70-200mm f/2.8L USM (the version without image stabilization) is an excellent value for astrophotography. You can save even more money (and weight) by selecting the f/4 version of this lens. In fact, because of its high-quality optics and versatility, this is one of my all-time favorite lightweight travel lenses to pair with a small tracking mount.

Using a portrait lens for astrophotography presents some additional challenges compared to a simple, wide-angle lens used with a fixed tripod. But the reward for your efforts is stunning images that reveal rich detail and color in your celestial subjects.

■ **TONY PUERZER** is a retired professional photographer and an avid amateur astrophotographer. He loves exploring the subtle details hidden in night-sky images.



◀ **TODD'S TARGETS** In his search for a planet beyond Neptune, American astronomer David Todd discovered numerous faint galaxies. He also missed some. Use the image at left to locate the galaxies described in the text.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

David Todd's Accidental Deep-Sky Discoveries

While searching for a distant planet, this American astronomer stumbled upon several galaxies in Leo and Virgo.

On February 6, 1878, David Peck Todd discovered the 14th-magnitude galaxy IC 591 using the U.S. Naval Observatory's 26-inch Clark refractor. The galaxy's location is surprising, just 23′ northwest of 1.4-magnitude Regulus, or Alpha (α) Leonis. But Todd wasn't seeking new nebulae — his aim was to discover a planet beyond Neptune! He conducted a little-known visual search and, as we'll see, in the process dug up some intriguing galaxies.

Todd wasn't the first to predict a new, distant planet. In 1848, just two years after the discovery of Neptune, French scientist Jacques Babinet proposed a trans-Neptunian planet. He arrived at this conclusion by analyzing perturbations in Neptune's motion using the predicted orbital elements by French mathematician Urbain Le Verrier and English astronomer John Couch Adams. Babinet dubbed the unseen world Hyperion.

Two years later, James Ferguson, an astronomer at the Naval Observatory, measured the asteroid Hygiea's position relative to a nearby 9th-magnitude star. English astronomer John Russell Hind created a stir when he looked for the reference star and came up empty. Ferguson took up the search but also failed to retrieve it, leading to speculation it might instead be an unknown planet. In 1878, asteroid hunter Christian Heinrich Friedrich Peters solved the mystery of the missing star. A mislabeled micrometer wire caused Ferguson to measure an errant position. By this date, however, the prospect of a trans-Neptunian world had captured other astronomers' imaginations.

Todd reanalyzed the residuals for the positions of Uranus and Neptune in 1877. His calculations pointed to a trans-Neptunian planet of magnitude 13 or fainter at a distance of 52 astronomical units (a.u.). Based on an expected longitude of 170°±10°, Todd began a visual search in Leo on November 3, 1877. He carefully examined each field at 400× to 600×, covering 40° along the ecliptic, and checked any nonstellar objects for movement. The project ended unsuccessfully on March 6, 1878.

Did he stand a chance in his pursuit? As far as stumbling upon Pluto, it was in Taurus at the time, a full 14° south of the ecliptic and far beyond his search region. Furthermore, he was looking for a tiny but distinct disk, estimated at 2.1″ in diameter. Pluto, of course, appears stellar in a telescope.

So, what did he find? A modern analysis shows Todd netted 28 galaxies, including several previously known. Many others, though, were unidentified, as his rough positions using the refractor's setting circles landed on empty patches of sky. But by reviewing his sketches and positional offsets from nearby stars, catalog sleuths Harold Corwin, Wolfgang Steinicke, and others (including myself) recovered 16 of the 28 as original discoveries.

"Suspected Object"

Let's examine the evidence for **IC 591**, which Todd described as a "Suspected object faint and diffused." A finder diagram includes Regulus and Uranus, which happened to be very nearby. His eyepiece sketch from February 6th (below) shows an oval object labeled xxii b, along with a star (xxii a) preceding (west) by 86 seconds of time, or 21′.

How can we confirm Todd's observation of IC 591 without a precise position? Although he only included five stars in his diagram, they match up perfectly with the sky, and a 13.4-magnitude star 21′ to the west of the galaxy's core is the clincher. He missed Leo I, which is only 15′ east of IC 591. With a magnification of 400×, his scope's narrow field was too small to frame this large, low-surface-brightness dwarf galaxy (see *S&T:* Oct. 2023, p. 57). John Louis Emil Dreyer skipped Todd's nebula when he compiled the *New General Catalogue of Nebulae and Clusters of Stars*, published in 1888. However, French astronomer Stéphane Javelle rediscovered it in 1892, and he received discovery credit in the *Index Catalog*.

"Large and Nebulous"

In late December 1877 and early January 1878, Todd perused star fields in western Virgo, about 3½° east of Beta (β) Virginis, and ran across the galaxy group now called MKW 4. A redshift survey published in 2002 lists 50 members within a circle 2.4° in diameter. William Herschel first swept this region in 1784 with his 18.7-inch speculum-metal reflector and discovered **NGC 4073**, at magnitude 11.5 the brightest member of the group, along with 12th-magnitude **NGC 4045** and 13th-magnitude **NGC 4077**.

Todd first picked up 13.5-magnitude **NGC 4075** (object xi) on December 27, 1877, noting "a small, but poorly defined disk." My 18-inch Dob shows it as a modest oval tipped toward the southwest with a starlike nucleus. The following week, he encountered NGC 4073 (xii a) and called it "large and nebulous." Through my 18-inch, this 11.5-magnitude giant elliptical is well concentrated and increases to a small, prominent nucleus. Nearby, he uncovered **NGC 4063** (xii d), a 14th-magnitude galaxy with a weak concentration. Once again, Todd lost out on discovery recognition, this time to French astronomer Édouard Stephan (of Stephan's Quintet fame), who spotted it four months later but measured a precise position.

On January 2, 1878, Todd shifted his gaze less than ½° west-northwest and came upon more nonstellar objects. NGC 4045 (xiii b) is a foreground, 12th-magnitude spiral with active star formation in the nucleus and a circular inner ring. I noticed a roundish core and distinct stellar nucleus within a slightly elongated envelope. Todd's drawing shows a faint star (xiii a) about 1½′ south of NGC 4045. Apparently, he mistook the 14th-magnitude galaxy **NGC 4045A** (CGCG 13-45) for a star, though I saw it as small, pale, and somewhat elongated. Todd discovered another faint nebula, the lenticular galaxy **CGCG 13-49** (xiii e), 8′ east of NGC 4045 and just northeast of an 11th-magnitude star (xiii d). My 18-inch reveals a fuzzy 25″ oval extending in the star's direction with a string of three 11th- to 13th-magnitude stars trailing to the northwest.

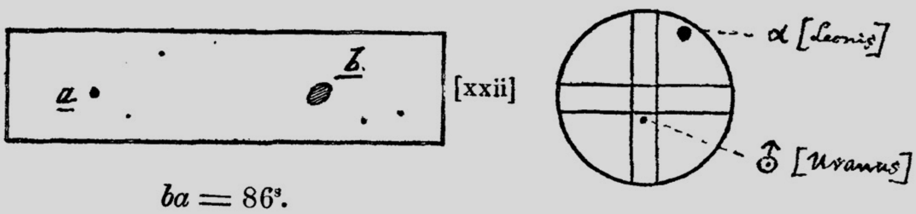
Three nights later, Todd returned to this field and recorded NGC 4077 (xiv a) as a potential candidate. When the seeing improved the next night, he noted "a star with faint nebulous border." The "star" is likely the galaxy's nucleus. I logged NGC 4077 as elongated north-to-south with a 14.7-magnitude star pinned to the north edge of its halo. In addition, he found **NGC 4139** (xiv b), a smaller and fainter lenticular (magnitude 13.8) only 1.3′ to the northwest. In my 18-inch, the oval halo spans 30″ in diameter and intensifies at the center. Astronomers sometimes identify this galaxy as IC 2989 — a designation resulting from an erroneous NGC position.

LISTENING TO MARS

Todd was a vocal advocate for the notion of intelligent life on Mars. On August 21–23, 1924, with Mars in opposition, he promoted a "National Radio Silence Day," which urged citizens to maintain radio silence for the first five minutes of every hour during a 36-hour period. Army radio stations listened for signals, and a cryptographer was even on hand to translate any messages from the Red Planet. Needless to say, none arrived.

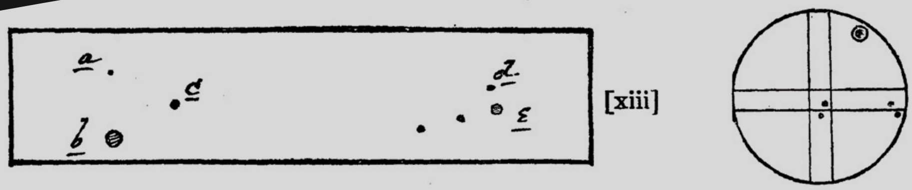
Todd's Misses

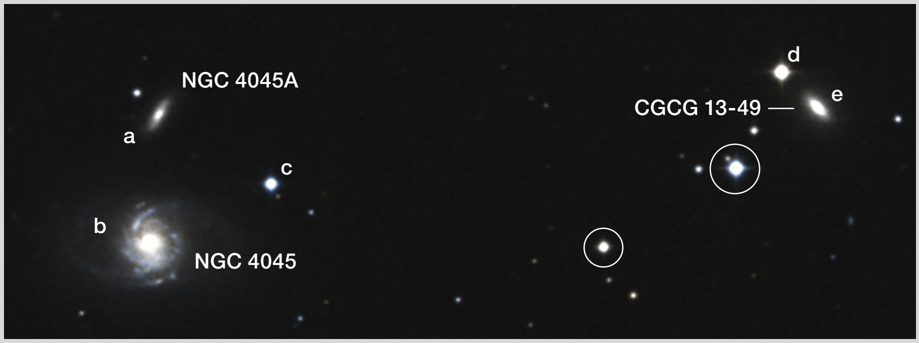
Last April, I revisited this cluster with my 24-inch f/3.8 reflector at 375× and viewed several galaxies that Todd missed in his survey. The brightest is **UGC 7034**, situated 14′ east-



▲ **STUMBLING UPON IC 591** This sketch and the one on page 60 are taken from an article Todd wrote describing his search for the elusive trans-Neptunian planet (published in the *Proceedings of the American Academy of Arts and Sciences* in 1885, vol. 21). His diagrams are all south up, and the accompanying images have the same orientation.

TODD, DAVID P. / *PROCEEDINGS OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES* / 1885; SDSS: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY





▶ **NGC 4045 AND FAINT COMPANIONS**
Todd took meticulous notes during his months-long search for the distant planet. He drew detailed diagrams that he'd return to later when he'd reobserve the field, to check if any target had moved in the intervening time.

northeast of NGC 4045. This small, 14th-magnitude lenticular bulges slightly from west to east. **CGCG 13-58** is a 14.6-magnitude patch only 3.5′ southwest of NGC 4073. Shifting 13′ farther southwest, I located 14th-magnitude **CGCG 13-52**, a thin, low-surface-brightness slash with its central axis pointing back towards NGC 4073. The narrow edge-on galaxy **UGC 7057** is on the southern side of the cluster, less than 7′ north-northeast of a 7.7-magnitude star. With the star placed outside the field, the 13.6-magnitude galaxy was a ghostly, uniform streak.

One member of the cluster is quite easy to overlook. Virtually stellar, **PGC 38205** is camouflaged in the halo of NGC 4073, just 30″ east-southeast of center. This 15th-magnitude compact elliptical may be the remnant core of a much larger galaxy that was stripped of its outer stars by NGC 4073. M32 (M31's much smaller companion) is considered the prototype of this rare class.

Two years after Todd finished his search, George Forbes, an astronomy professor at Glasgow University in Scotland, proposed two new outer planets at 100 and 300 a.u. Forbes argued these planets diverted several known comets into elliptical orbits with similar aphelion distances. Todd was excited to read that Forbes's predicted position for the interior planet differed by only 4° from his position. He wrote a general account of his investigation in 1880 and a detailed report in 1885, expressing hope it would inspire a thorough, deeper survey with a telescope equipped for dry-plate photography. Pioneering Welsh astrophotographer Isaac Roberts took up the cause in 1890 from his new observatory in Crowborough, Sussex (England). He compared two sets of 18 photographic plates taken at least a week apart in the same region, but also struck out.

In 1881, Todd was appointed Director of Massachusetts's Amherst College Observatory, where he remained a professor of astronomy until retiring in 1917. While at Amherst, he became friends with Percival Lowell, who financed an expedition led by Todd to observe the May 28, 1900, total solar eclipse from Tripoli, Libya. Lowell recruited Todd again in 1907 to head an expedition to Chile's high desert, hoping to obtain photographic proof of Martian canals. In return, Todd's visual pursuit of a ninth planet perhaps motivated Lowell, who recalculated a theoretical position and began his first photographic search for a trans-Neptunian world in 1905.

■ The history of deep-sky discovery continues to fascinate Contributing Editor **STEVE GOTTLIEB**, who has been writing for *Sky & Telescope* for the past 25 years. You can reach him at **astrogottlieb@gmail.com**.

Todd's Targets and More

Object	Type	Todd desig.	Mag(v)	Size	RA	Dec.
IC 591	Barred sp.	xxii	14.0	1.0′ × 0.7′	10^h 07.5^m	+12° 16′
NGC 4073	Elliptical	xii a	11.5	3.2′ × 2.3′	12^h 04.4^m	+01° 54′
NGC 4045	Spiral	xiii b	12.0	2.7′ × 1.9′	12^h 02.7^m	+01° 59′
NGC 4077	Lenticular	xiv a	13.2	1.3′ × 0.9′	12^h 04.6^m	+01° 47′
NGC 4075	Lenticular	xi	13.5	1.2′ × 0.6′	12^h 04.6^m	+02° 04′
NGC 4063	Lenticular	xii d	14.0	1.1′ × 0.5′	12^h 04.1^m	+01° 51′
NGC 4045A	Lenticular	xiii a	14.3	0.6′ × 0.4′	12^h 02.7^m	+01° 57′
CGCG 13-49	Lenticular	xiii e	13.7	0.8′ × 0.6′	12^h 03.2^m	+01° 57′
NGC 4139	Lenticular	xiv b	13.8	1.0′ × 0.5′	12^h 04.6^m	+01° 48′
UGC 7034	Lenticular	—	13.9	1.0′ × 0.4′	12^h 03.6^m	+02° 03′
CGCG 13-58	Lenticular	—	14.6	0.8′ × 0.3′	12^h 04.3^m	+01° 51′
CGCG 13-52	Spiral	—	13.8	1.0′ × 0.4′	12^h 03.7^m	+01° 42′
UGC 7057	Spiral	—	13.6	1.9′ × 0.4′	12^h 04.3^m	+01° 34′
PGC 38205	Elliptical	—	~15	—	12^h 04.5^m	+01° 54′

Angular sizes are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

TODD, DAVID P. / *PROCEEDINGS OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES* / 1885; SDSS: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

A Total Delight

TOTALITY: *The Great North American Eclipse of 2024*

Mark Littmann & Fred Espenak
Oxford University Press, 2023
384 pages, ISBN 9780198879084
US$18.95, softcover

TOWARDS THE MIDDLE of this richly authoritative yet eminently accessible book, the authors ask, "What is this sight that lures people to travel to the ends of the Earth for a brief view at best, a substantial possibility of no view at all, and with no rain check?" This book is their answer.

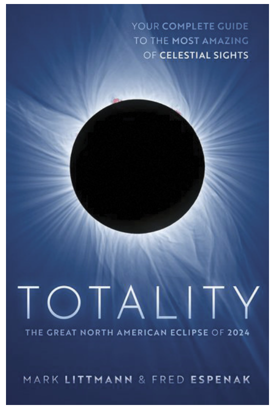
Totality: The Great North American Eclipse of 2024 provides everything you need to appreciate what a total solar eclipse (TSE) is all about and to prepare yourself for witnessing the event. Even if you've read a lot about TSEs and experienced totality yourself, you might find much of interest here because of the sheer depth and breadth of the authors' expertise. Fred Espenak, aka Mr. Eclipse, is one of the world's top experts on eclipses, and his coauthor Mark Littmann has written award-winning books about solar eclipses, giant meteor storms, and Halley's comet, among other literary accomplishments.

After an initial chapter on the experience of totality, they explore the complex celestial mechanics involved in an eclipse. But they quickly caution the reader: "If for any reason your eyes begin to glaze over, stop reading this chapter immediately and go right on to the next." The chapter does get fairly technical, and they don't want that to dampen the reader's enjoyment of "the wild, wacky, and wonderful things" that people have said about and experienced with TSEs.

Tales from eclipsophiles other than the authors themselves is one of the book's highlights. Littmann and Espenak insert amusing anecdotes that some of the most dedicated eclipse-chasers over the past half-century have shared with them. There's the story of the airline cleaning woman who accidentally remained on a chartered plane leaving to chase an eclipse after the door had closed and shouted to be let off — only to be "flabbergasted" by what she was forced to observe. Or of the woman who, once totality began, "began hammering on [her] husband's back with both fists and screaming" — and later had no recollection of her reaction.

History provides other entertaining stories. For the 1724 eclipse, for one, Jacques Cassini, director of the Paris Observatory, invited a marquis and his silk-stocking lady friends to observe the eclipse with him. When they absent-mindedly showed up *after* the eclipse had ended, the marquis said, "Never mind, ladies . . . M. Cassini is a great friend of mine and he will be delighted to repeat the eclipse for you."

It's not all light and fluffy, of course. The authors go thoroughly and engagingly into ancient mythology and historical eclipse-chasing as well as key things to remember when attending a total eclipse. They provide valuable advice and tips on safety, photography, weather conditions, and much more — all to help readers prep themselves for and fully relish the April 2024 eclipse. The information is useful for *any* TSE, of course, but as the authors remind us, even though the Moon will eclipse the Sun 48 times between 2024 and 2045, the next TSE to cross most of the contiguous U.S. won't occur until that final year, 2045.



The authors pepper *Totality* with fascinating facts about solar eclipses. They explain how totality itself can actually reduce certain types of cloud cover, for example, and how even when only 1% of our star remains uncovered by the Moon during totality, the Sun is still 10,000 times brighter than the full Moon.

They also remind us of the curious behaviors animals may display in a TSE. During a 1715 totality, an observer in London noted how horses working in the high roads lay down and refused to get up. In 1976, as totality began, eclipse-chasers in Australia suddenly heard thousands of cows mooing at once in confusion, a cacophony that ended as soon as totality did. In 1999, eclipse-chaser Mike Simmons watched hordes of ants stream out of the ground at the height of a TSE in Iran; they vanished when the Sun returned.

Humans have their own memorable reactions, naturally. Glenn Schneider recalls watching the Moon's shadow approaching in the west during a 1979 eclipse in Montana. When it suddenly was upon him, he instinctively ducked. Then there's the ineffable response. The authors quote David Makepeace, a veteran eclipse-chaser: "People expect a total solar eclipse to be a curiosity. They don't expect it to move their souls."

Altogether, no matter your experience, if you want to take your understanding of TSEs to a new level, you need no other source than this book.

■ **PETER TYSON** joined the worst traffic in Wyoming history after co-leading an *S&T* tour there for the August 2017 TSE.

Observe April's Eclipse with Your AM Radio

As the Moon's shadow glides across North America, you'll have a chance to hear the eclipse as it happens.

Total solar eclipses are more than a jaw-dropping visual phenomenon — they're pretty interesting in wavelengths beyond the visible spectrum, too. And at certain wavelengths, clear skies aren't necessary to detect the event. Should overcast skies prevail over your location on eclipse day, you can still make some interesting observations using a device you probably already own. That device is an AM radio. The humble AM radio offers a great way to experience the event on a cloudy day and even share it with vision-impaired friends.

How Sunlight Affects Radio Reception

Dramatic changes in AM radio reception often take place when the day turns into night and reverts to normal at sunrise. Perhaps you've had the experience of driving in your car at night, listening to some program on the AM

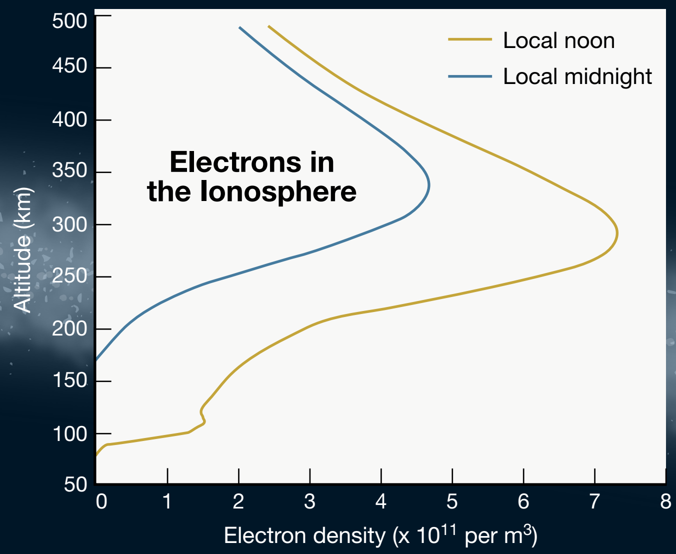
dial, when the announcer identifies the station as WBBM in Chicago. This might seem odd if you are listening from, say, Albany, New York, more than 1,100 kilometers (700 miles) from the Windy City. Yet this happens every night.

A total solar eclipse produces a broad, round area of darkness that greatly reduces sunlight as it sweeps across Earth's surface in a relatively narrow path. Its effect on the local intensity of sunlight is remarkably similar to what happens at night. Distant radio stations along and near to the path of totality might briefly experience enhanced propagation, thus making long-distance reception possible during a solar eclipse. Why is this so?

We can thank Earth's ionosphere for this extended long-distance radio reception. Radio waves are merely one part of the electromagnetic spectrum and therefore are affected by electrical charges. Since ions are electrically charged, radio waves and ions interact.

The *ionosphere* is an upper atmospheric zone composed of tenuous, electrically conductive layers consisting of both neutral and charged particles. It extends from an altitude of approximately 50 km to more than 400 km. The ions present in this region interact with radio waves in two ways. They can either absorb (or deplete) radio signals, thus reducing their intensity and signal strength, or they can reflect (or refract) the waves, changing their direction. Conceptually, this is akin to a radio-wave "mirror" analogous to a telescope mirror.

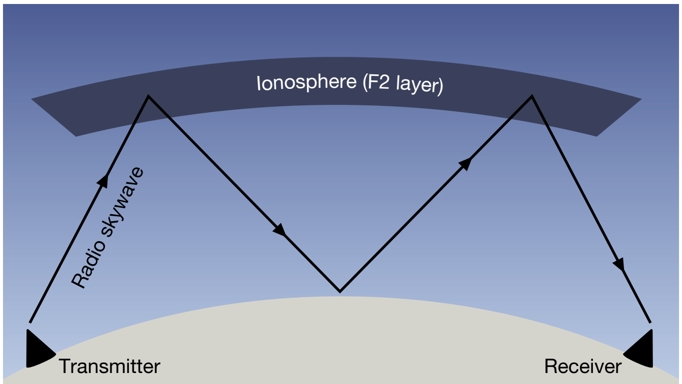
The main reflecting layer in the ionosphere, called the F2 layer, is about 290 km above Earth's surface and is present both day and night. But at a height of about 50 to 100 km lies the D or depletion layer, which absorbs energy from radio signals passing through it to the F2 layer, weakening them and limiting their transmission range.



▲ **EXTENDED RANGE** The density of electrons in the ionosphere varies dramatically between day and night, greatly extending the range of AM radio transmissions. Note that at altitudes lower than about 170 km (105 miles), the count essentially drops to zero.

But as sunset approaches, the D layer rapidly loses its ionization and essentially vanishes, allowing the F2 layer to reflect signals over much greater distances. In other words, radio waves are absorbed only during daylight hours and at night easily reach the F2 layer, where they are reflected back toward the ground. Likewise, on the way back down, the D layer's usual obstruction is gone, so the waves reach the ground in a well-preserved state — often over far greater distances from the transmitting station than is possible during daylight hours (as illustrated on page 64).

ILLUSTRATION: BEATRIZ INGLESSIS / S&T; GRAPH: DIETER BILITZA ET AL / *JOURNAL OF GEODESY* (2011)



▲ **BOUNCING WAVES** Electrons in the ionosphere's F2 layer reflect radio waves broadcast by AM stations when the Sun isn't visible, allowing receivers to pick up those waves at great distances. This schematic shows the ionosphere reflecting the waves, though they actually are refracted along curved arcs when passing through the ionosphere.

Ironically, the F2 layer is actually a better reflector during the daytime, despite the fact that long-distance radio reception is better at night. The reason for this is that there are more ions during the day. Since the atoms are split into ions by the Sun's ultraviolet (UV) radiation but are constantly recombining into atoms, the number of ions decrease at night because there's no sunlight and increase again every day as the Sun's UV radiation does its daily work.

Utilizing AM Radio for the Eclipse

Medium wave, or AM (amplitude modulation), is the oldest system of commercial broadcast transmission. The pioneer AM broadcast service started operation on the frequencies it still uses, 540 to 1600 kilohertz (kHz). In 1993, its range was extended to include frequencies up to 1700 kHz. AM broadcast stations use powers ranging from 250 watts to 50 kilowatts (50,000 watts) — the maximum permitted in the U.S.

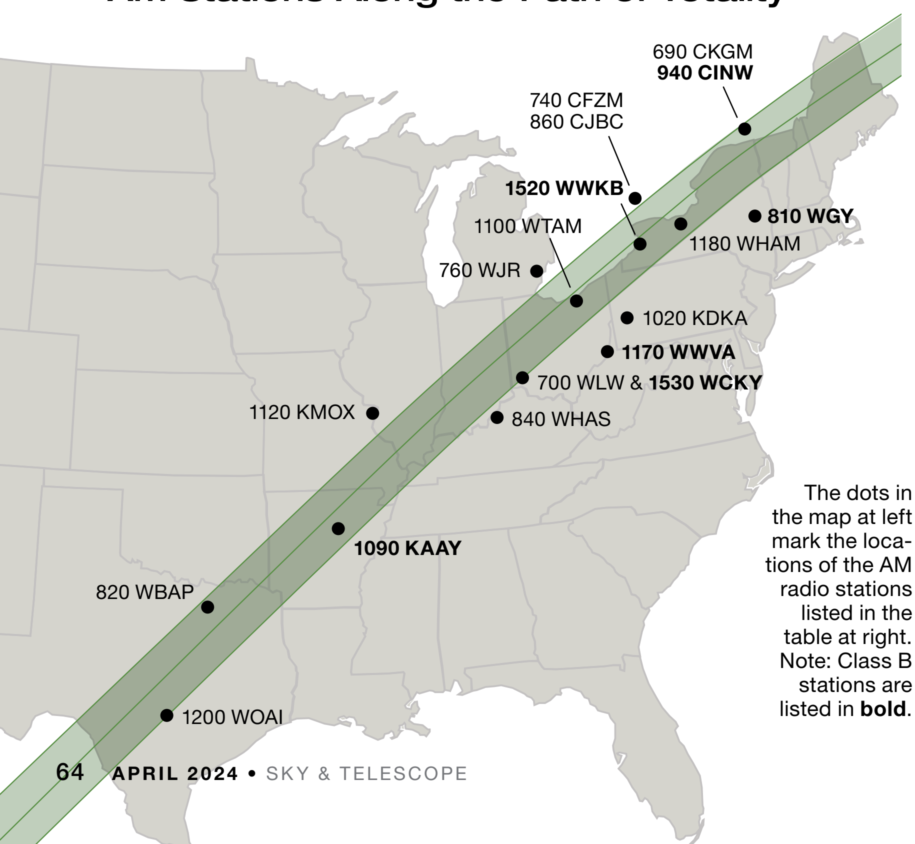
Listening to distant radio signals is an interesting hobby that amateur radio enthusiasts refer to as "DX'ing." As already pointed out, transmissions in the commercial 540–1700 kHz AM radio band can be heard for hundreds — and sometimes even thousands — of kilometers under the cover of darkness. This is especially true of the so-called "clear channel" (Class A) radio stations. *Clear channels* are frequencies set apart by international agreement for use primarily by high-powered stations. They are designed to cover wide areas with line-of-sight "groundwave" service and, at night, "skywave" service, particularly for remote, rural areas. Skywave service takes advantage of the reflective capabilities of the ionosphere's F2 layer to propagate the signal great distances.

When the Moon's shadow sweeps across our planet on April 8th, some of the best receptions should occur for people within about 600 km to 1,300 km of the narrow path of totality from AM stations that are likewise near or within that path. As maximum darkness approaches a station's transmitter, the D layer should weaken. The F2 layer then becomes increasingly able to reflect the radio signal and support long-distance reception, at least for a short period before, during, and after totality.

Listeners within a few hundred km of a transmitting station residing in or near the path of totality might hear the signal of a distant station begin to materialize. The broadcast

BOUNCING WAVES: ADAPTED FROM SEBASTIAN JANKE / WIKIPEDIA COMMONS; MAP: MAHEMUD HUSAIN / SHUTTERSTOCK / BEATRIZ INGLESSIS / S&T

AM Stations Along the Path of Totality



The dots in the map at left mark the locations of the AM radio stations listed in the table at right. Note: Class B stations are listed in **bold**.

Frequency (kHz)	CallSign	City
690	CKGM	Montreal
700	WLW	Cincinnati
740	CFZM	Toronto
760	WJR	Detroit
810	**WGY**	**Schenectady**
820	WBAP	Fort Worth
840	WHAS	Louisville
860	CJBC	Toronto
940	**CINW**	**Montreal**
1020	KDKA	Pittsburgh
1090	**KAAY**	**Little Rock**
1100	WTAM	Cleveland
1120	KMOX	St. Louis
1170	**WWVA**	**Wheeling**
1180	WHAM	Rochester
1200	WOAI	San Antonio
1520	**WWKB**	**Buffalo**
1530	**WCKY**	**Cincinnati**

will build in strength until the area of maximum darkness passes over the station, at which time signal strength should be at its peak. Then, as the area shadow moves away from the station, its signal will begin to fade.

One example of this occurred on March 7, 1970, as the path of a total solar eclipse swept northeastward from northern Florida, up the Atlantic coast, to just off of Cape Cod, Massachusetts. An amateur astronomer stationed at Greenville, North Carolina, was able to hear WABC in New York, New York (broadcasting at 770 kHz) for about 20 minutes, centered on the time that 96% of the Sun's diameter was eclipsed as seen from the Big Apple. The distance from Greenville to WABC's transmitter is 650 km.

During the total solar eclipse of August 11, 1999, British radio enthusiasts undertook a nationwide program for monitoring enhanced propagation over a wide range of radio frequencies, including shortwave transmissions. More than 1,700 people participated, and the project found that the eclipse definitely had an effect on distant transmissions.

Tuning in to Totality

The table below lists 18 AM stations that lie either within the April's eclipse path or close enough to have at least 95% of the Sun's disk obscured by the passing Moon. Twelve are clear-channel stations, and the other six of these are Class B stations, which direct their signal diametrically away from another station at night that occupies the same frequency, so that it won't interfere. Case in point: KAAY in Little Rock, Arkansas, does this to protect WBAL in Baltimore, Maryland. But these stations only perform this pattern change at night.

State/Province	Mid-Eclipse (UT)	Mid-Eclipse (Local)
Quebec	19:27	3:27 p.m.
Ohio	19:09	3:09 p.m.
Ontario	19:20	3:20 p.m.
Michigan	19:14	3:14 p.m.
New York	**19:26**	**3:26 p.m.**
Texas	18:41	1:41 p.m.
Kentucky	19:07	3:07 p.m.
Ontario	19:20	3:20 p.m.
Quebec	**19:27**	**3:27 p.m.**
Pennsylvania	19:17	3:17 p.m.
Arkansas	**18:52**	**1:52 p.m.**
Ohio	19:15	3:15 p.m.
Missouri	19:00	2:00 p.m.
West Virginia	**19:16**	**3:16 p.m.**
New York	19:21	3:27 p.m.
Texas	18:35	1:35 p.m.
New York	**19:20**	**3:20 p.m.**
Ohio	**19:09**	**3:09 p.m.**

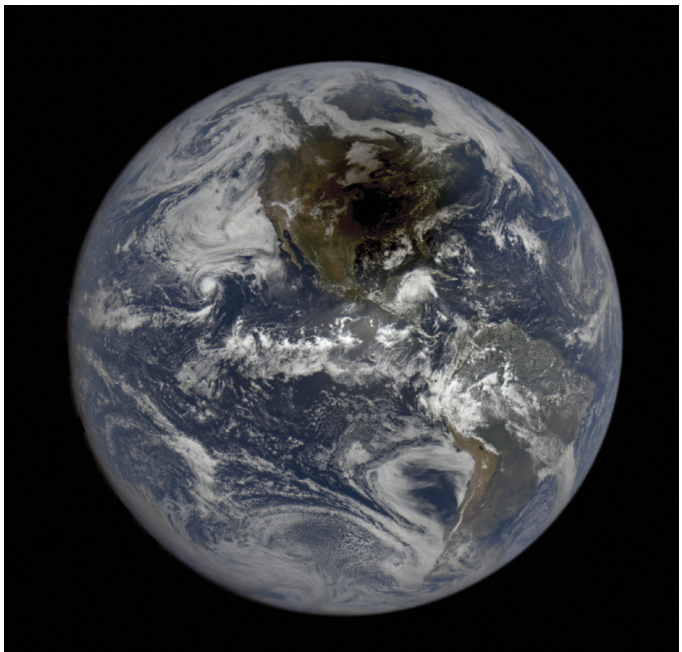
In these cases, you might pick up overlapping transmissions from two stations simultaneously.

If you are listening for a particular station that is transmitted from within 1,300 kilometers away, you might be able to hear it near the time that maximum eclipse is occurring over that station's transmitter. The map on the facing page shows the distribution of the stations in the table. The equipment needed couldn't be simpler. Any AM receiver can be pressed into service — if you don't have one around the house, most all cars and trucks still include an AM/FM radio. If the calibration of your radio isn't very accurate, try tuning in a particular distant station at night before the eclipse, and sweep through the AM band to determine what reception conditions are like. If your receiver has multiple memory channels with a scanning feature, you're in luck — that's ideal for checking a lot of frequencies in a hurry. Then, on eclipse day, tune in to the station you've selected and listen for its signal to improve as the Moon's shadow passes by the transmitter.

This is also a great project that can enhance the experience of anyone with a visual impairment. Everyone within earshot will know when totality is nearing for the station you're tuned in to as totality approaches.

I welcome your observations at **skywayinc@aol.com**. Please include the station call sign you heard and the time that you heard it, along with your location. I'll compile all the results and report the outcome of this experiment at a later date.

■ For the first 17 of his 41 years as a broadcast meteorologist, Contributing Editor **JOE RAO** syndicated weathercasts that were heard in more than 200 radio markets.



NASA / DSCOVR EPIC TEAM

BRIEF DARKNESS Here's how the Moon's shadow looked as it crossed the United States during the eclipse of August 21, 2017, as seen from space.

Unistellar's eQuinox 2 Smart Telescope

This 4½-inch observing station offers generous aperture and the ability to contribute to research.

▲ The Unistellar eQuinox 2 is a 114-millimeter (4½-inch) reflector containing everything necessary to record images of deep-sky objects and deliver them to your smartphone or tablet.

Unistellar eQuinox 2

U.S. Price: $2,499
unistellar.com

What We Like

Portable and robust design

Large object database and ability to directly input coordinates

Support for "Citizen Science" research

What We Don't Like

Complicated procedure to acquire FITS files

Lack of IR-blocking limits science potential

I'VE WATCHED the "smart" telescope market rapidly expand over the past five years. These devices are completely self-contained, self-aligning imaging platforms designed to produce color astrophotos with the least amount of effort and deliver the results directly to your smartphone or tablet. The French company Unistellar was among the first to introduce a smart telescope to the public with their eVscope (reviewed in *S&T:* Dec. 2020, p. 66). Since then, several companies have produced their own versions, often with smaller apertures, such as the ZWO SeeStar S50 reviewed last month.

The latest iteration from Unistellar is the eQuinox 2, a 114-mm (4.5-inch) f/4 reflector that retains much of the design of the original eVscope model while shedding parts — such as the electronic "eyepiece" of the eVscope — to offer a more affordable package to potential users.

I've been curious how these devices perform, so *Sky & Telescope* arranged the loan of an eQuinox 2 so I could put it to work under the stars. When first received the device, I assumed I would be reviewing what essentially is a telephoto lens and camera riding on a Go To mount. But the longer I worked with it, the more I understood it to be a fully integrated system that achieves easy Electronically Assisted Astronomy (EAA) as a way to bring budding amateur astronomers into the hobby. It also provides a great tool for doing real astronomical research.

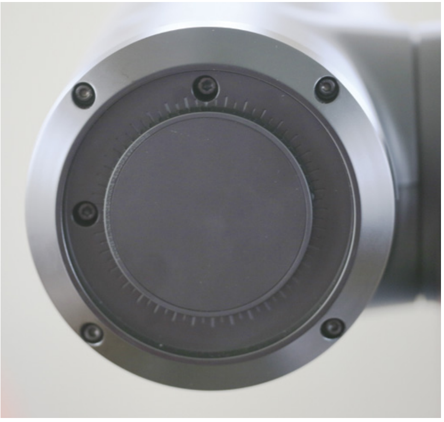
First Experience

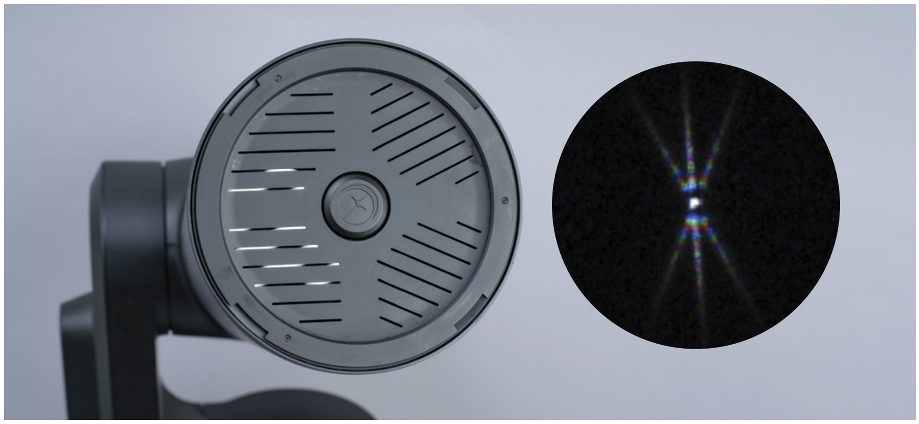
The eQuinox 2 arrived double-boxed with a custom-cut Styrofoam insert holding everything securely. Other than the optical tube assembly (OTA) with its drive base and the tripod, the only other items included are a tool for collimating the system, several hex wrenches, a USB-C charger, and an AC power plug adapter for European users. The USB-C charger cable is about 1 mm longer than the typical USB-C connector and clicks into place more securely than the standard USB-C cable. The telescope with the tripod attached weighs 9 kilograms (20 lbs). I could easily carry the fully assembled scope, but it's bulky enough that I preferred separating the mount from the OTA when moving it into the backyard.

The eQuinox 2 is the 2nd-generation Unistellar automated telescope. The only notable changes from the 1st generation (aside from the lack of an eyepiece) is its imaging sensor, a Sony Starvis IMX347 color CMOS detector with a standard Bayer array to produce color images. This provides a 34 × 47 arcminute field of view, large enough to image the full Moon. The camera lacks an infrared blocking filter, which has some effect on the images it produces. (More on this later.)

TELESCOPE, TOOLS: SEAN WALKER / S&T

▶ The telescope includes several hex wrenches to tighten parts on the tripod and tube assembly, and a Torx wrench used for adjusting collimation. The two knurled knobs are for securing the drive base to the tripod. Not shown are the USB-C charger cable and European standard charging cable.





▲ *Left:* The back end of the eQuinox 2 includes a large, knurled disk that you turn by hand to focus. The two inset bolts located at the 9- and 12-o'clock positions are used to adjust the primary mirror collimation. The four outer bolts allow users to remove the primary mirror when it requires cleaning. *Right:* Located just beneath the lens cover is a slotted plastic disk called a Bahtinov mask. This device aids in focusing the telescope by adding six diffraction spikes to stars in the field of view (inset). When the spikes appear symmetrical, the optics are in focus.

Before my first imaging session with the eQuinox 2, I had to download the free *Unistellar* app from the Google Play store. (Apple users can find it on the Apple App Store.)

Once outside, I leveled the tripod using the built-in bubble level, as the device's internal computer relies on this to ensure good tracking. Next, I installed the telescope's wide mounting base on the tripod and locked down both tripod screws. Installing the scope was a bit awkward the first time but quickly became more intuitive as I repeated the process. It would be nice if Unistellar offered an adapter to permit connecting its scopes to standard camera tripods or telescope piers, though I found the provided tripod sturdy.

The eQuinox 2 is powered up by pressing the start button on the fork arm. The button first lights up purple while starting and then changes to red when the scope is ready to operate. At this point you can connect to the scope via your phone or tablet's Wi-Fi, where it will be listed under available networks. Opening the *Unistellar* app should show the system status as operating.

The first order of business after startup is to perform a Sensor calibration with the dust cap on. This records a 10-second dark frame, which the app's software will then subtract from each exposure throughout the night. Note that this dark frame isn't stored for use in future imaging sessions, so you'll need to perform this task each time you restart the system. Once this is done, point the scope to the sky and click on the ***Orientation*** button so the system can determine where it's looking. In a few moments, it gets its bearings by recording short exposures and comparing the star patterns with its internal database in a process called *plate solving*.

When the telescope is ready, click on the ***Catalog*** tab and choose a bright star visible above the horizon to use for checking collimation and adjusting focus. If the camera assembly mounted at the front of the tube (where the secondary mirror would be in a conventional Newtonian reflector) appears off-center on a greatly out-of-focus star, adjust the two hex screws at the 9- and 12-o'clock positions on the rear of the OTA until it's centered. With collimation accomplished, install the included Bahtinov focusing mask (built into the telescope cover) and then turn the large focusing dial on the back of the scope until the diffraction spikes visible around the brightest stars in the field look symmetrical. The entire setup process took only a few minutes, and then I was ready to start observing.

I found there was a need at least to check focus each night, but only a

▲ *Left:* The secondary supports are thicker than in a conventional Newtonian reflector to conceal the wires connecting the onboard computer to the telescope's CMOS detector. *Right:* Instead of a secondary mirror that diverts light to an eyepiece, the telescope's primary mirror reflects starlight directly to a Sony Starvis IMX347 color CMOS detector with a diagonal measurement of 9.04 millimeters.

FOCUSER, SPIKED STAR: PETER BEALO; TELESCOPE DETAILS: SEAN WALKER / S&T

minor tweak of the focus knob was usually required. The only issue with focusing turned out to be user error — I tried to focus on a double star, showing two overlapping Bahtinov diffraction patterns. At first, I thought the scope was grossly out of collimation, but I quickly determined that double stars are not good focusing targets!

Collimation held very well, even after driving with the system in my car some 320 kilometers (200 miles) to the Stellafane Telescope Making Convention in Springfield, Vermont, with the last mile being bumpy dirt roads. Indeed, collimation held rock-steady for the several months I used the scope.

With a focal length of 456 millimeters, the eQuinox 2 is suited to many deep-sky objects, except perhaps small planetary nebulae. While it can record the entire lunar disk, the OTA's focal length is too short for satisfying planetary imaging. It can resolve Saturn's rings and two bands on Jupiter, but not much more than that.

Because the telescope has an alt-azimuth mount, over time the imaging field rotates. So, when taking a series of exposures over an extended period, the corners of the images may not receive light from all exposures. As a result, these parts of the frame will be noisier than the center. All this is hidden when the user chooses ***Frame*** on the Observation page, which appears as a circular frame that covers the noisier corners of the field.

Electronically Assisted Astronomy in Action

The *Unistellar* app's catalog has a generous list of objects, with lots of details for each. It also includes the ability to move the system to any location manually entered in either by RA and declination or by alt-azimuth coordinates, and even manually using the ***Joystick*** feature. Slewing to a selected object never took more than about 30 seconds. The scope plate-solves a field or two along its way to the chosen target by moving for a few seconds, stopping to take a pointing exposure, and then slewing off to its final destination. It rarely took more than three steps to reach the desired object.

Only two things seemed to confuse the eQuinox 2 when it attempted to slew to a target. The first is a partly cloudy sky. If the scope stopped on a cloud through which no stars were visible, it wouldn't continue on, and I had to re-launch the slew. The other impediment was slewing to the Moon. As the scope approached, the imaging field was filled with lunar glare that overwhelmed the stars and stopped the device in its tracks. When this happened, I could use the Joystick in manual mode to nudge the scope on target.

When a deep-sky object is acquired, you can tap the ***Enhanced Vision*** button to begin stacking images. After 10 or 15 seconds the image seen on your handset transforms from just a few stars to many stars plus your target. As time goes on, more images are stacked, and the image becomes less noisy and displays fainter stars. Users need to manually determine total exposure times required and press a ***Camera*** button to save an image of an object. Unless you manually intervene, the system continues to stack additional frames. I often saved pictures at several points while on a target.

I found the Wi-Fi connection of the eQuinox 2 to be very reliable up to a distance of about 30 meters (100

▲ *Left:* The Sony Starvis IMX347 CMOS detector within the eQuinox 2 has a generous field of view — large enough to reveal any miscollimation and even coma in the corners of the frame, as this image of M45 reveals. Careful attention to collimation can preclude many of these issues. *Right:* The circular ***Frame*** option in the Observation section can mask some of these deficiencies.

PETER BEALO (2)

feet), unless a large mass of metal (like my car) was in the line of sight. I could set up in the driveway and run the telescope for hours from a comfy chair inside my house, with three walls between me and the eQuinox 2. The only limiting factor was battery life. A full charge lasts about 11 hours, and you can charge the device while imaging, though it's recommended you activate the ***Limit rotation*** function in the ***My telescope*** section of the app to avoid straining the charging cable.

Up to 10 devices may connect to the eQuinox 2 simultaneously. One user controls the telescope while the others are observers who can see and save the resulting images on their handsets.

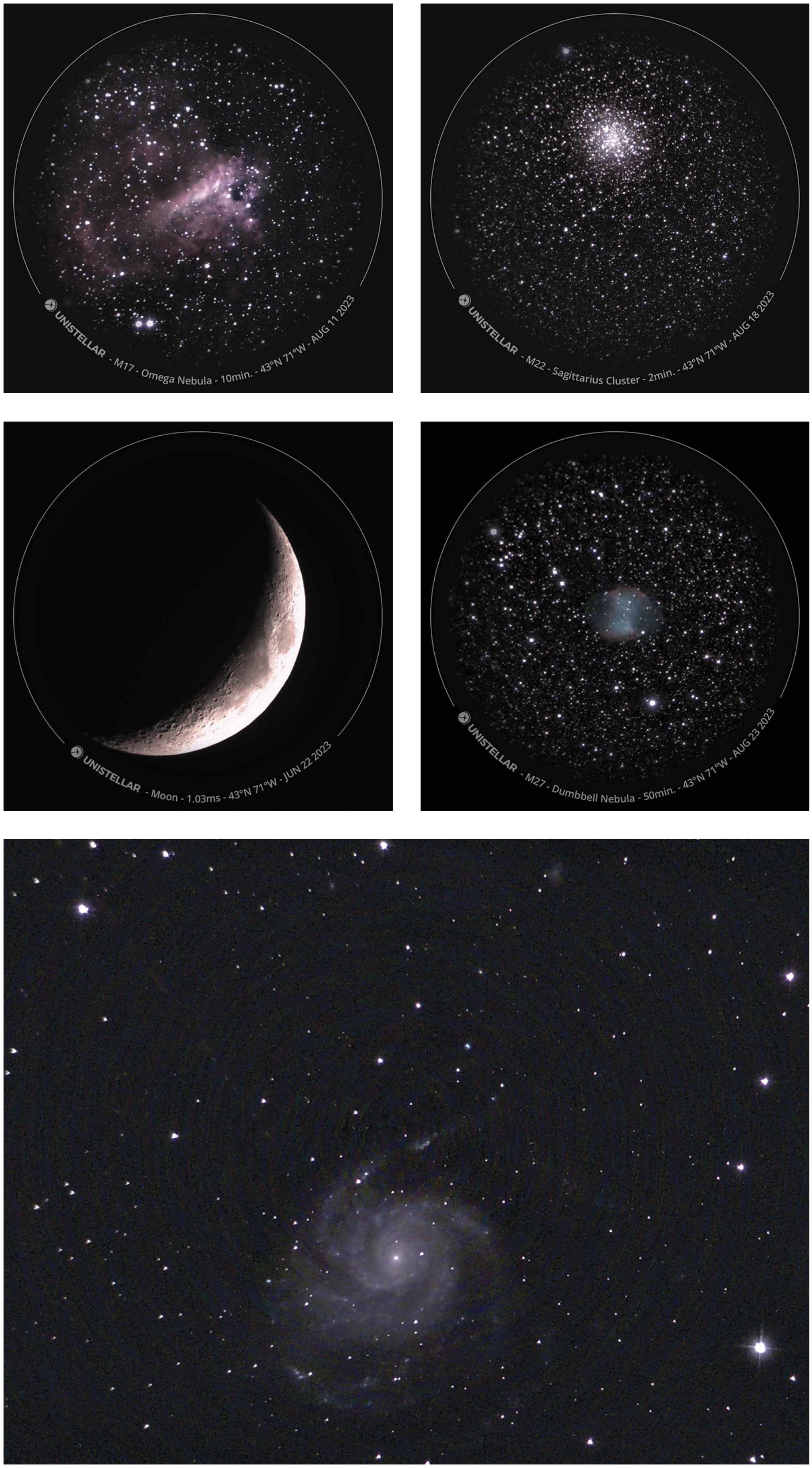
I tried out the group observing feature at Stellafane last year. I had concerns that some attendees wouldn't welcome newer automated technology at this hallowed and historic event, but upon firing up the eQuinox 2 I quickly had four observers connected and requesting objects to observe.

Later, at home, I invited my astro-curious neighbor to observe with me. We hopped from object to object, discussing the differences between globular clusters, nebulae, and galaxies as well as their various sizes and distances — all while relaxing in comfortable camp chairs.

How Many Megapixels?

Pictures recorded with the eQuinox 2 are saved as 8-bit color PNG files, a lossless-compression format. But if you want access to the raw, unprocessed images, Unistellar provides a somewhat complex method to retrieve them.

After an observing session, command the device to connect to your home network and the scope will then automatically upload your images to the company's server. You then email a request for either FITS or TIFF files of the uploaded pictures. A day or so later, you'll receive a link to download a ZIP file. Just be warned that the resulting file is likely to be huge (dozens of gigabytes), because they send you the stacked results as well as every exposure used to create them. But why would you



▲ *Top rows:* The eQuinox 2 records pleasing color images of deep-sky objects with enough resolution to resolve small details, such as these pictures of M17, M22, the Moon, and M27. The image of M101 (above) resolves several star-forming regions within the galaxy's spiral arms.

PETER BEALO (5)

want the unprocessed data in the first place? The camera produces 12-bit data, or 4,096 levels of brightness per color channel. This is desirable because with practice you can produce a better image by processing the FIT file, rather than attempting to enhance the 8-bit PNG files sent to your smart device.

One odd discrepancy between the original PNG files and the FITS (or TIFF) files returned by Unistellar is the size of the images. The Sony IMX347 sensor is a 4.17-megapixel detector, yet the images produced with the eQuinox 2 are 6.2 megapixels. This means the system's internal processing is enlarging the pictures, possibly to generate finer detail using a stacking technique called *drizzling*. Unistellar doesn't divulge the technique it uses to achieve this larger image scale.

Citizen Science

If the eQuinox 2 telescope and its EAA capability are the "steak", then its citizen-science capabilities are the "sizzle." And a fine sizzle it is.

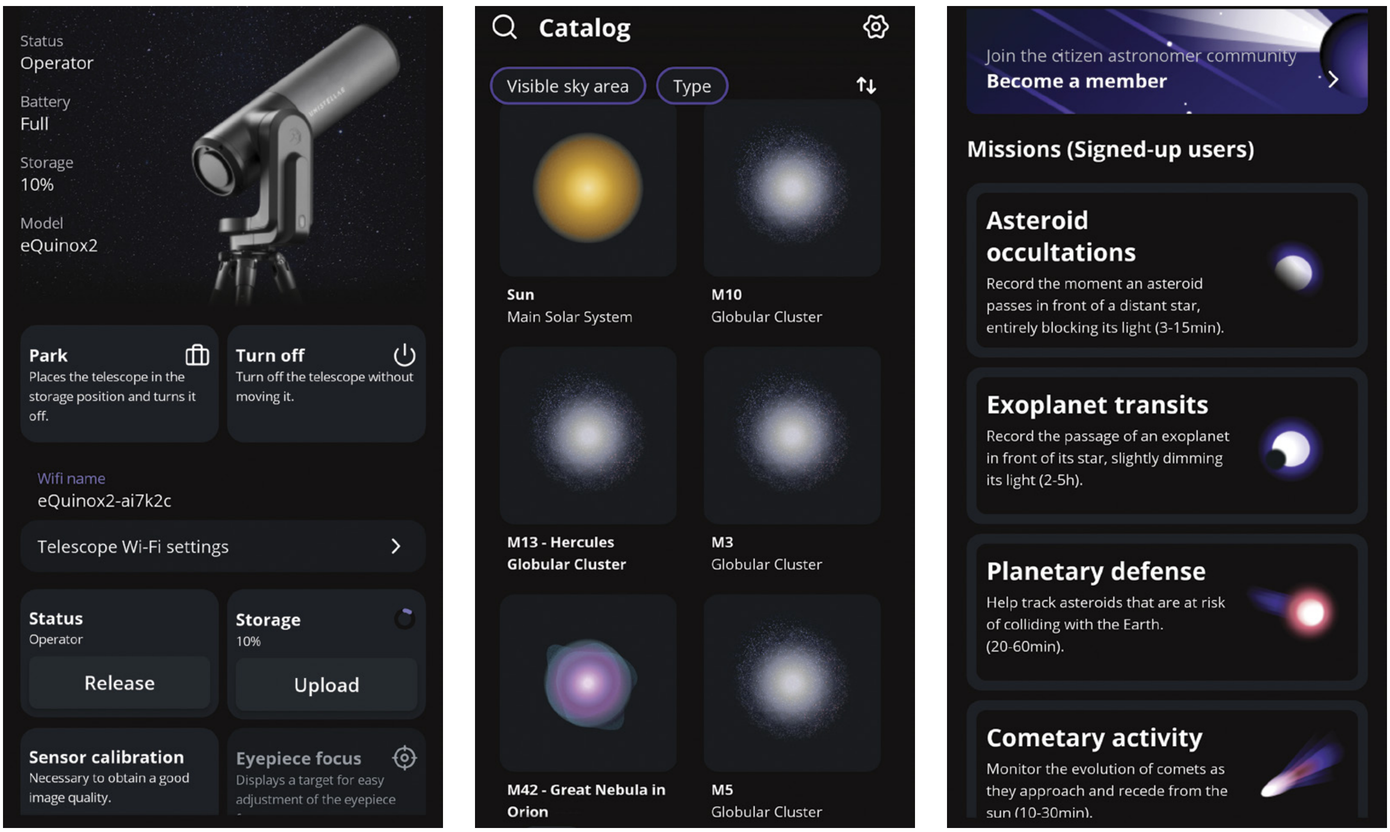
Unistellar employs a staff of several astronomers who provide science project ideas to Unistellar users. The astronomers collect user image data and even publish papers in journals using this crowd-sourced data. Users providing images for these projects get the satisfaction of knowing they're helping perform actual scientific research and are even listed on accepted papers as coauthors. How cool is that? An eQuinox 2 can be put to excellent use by a high-school teacher or even an undergraduate professor by having their students participate in a research project.

But there is a slight handicap that limits some of the eQuinox 2's scientific potential. The camera's sensor does not have an infrared-blocking filter. As a result, infrared light pollutes all the color channels of the sensor, making some science, such as photometric measurements of variable stars (particularly red ones) and other objects, less accurate.

Final Thoughts

The eQuinox 2 is an excellent introduction to astronomy that goes well beyond the ability to capture nice pictures. As a telescope for beginners, it hits the mark for being easy to learn and capable of producing good images. And for more experienced telescope enthusiasts, it fills more than a small niche role. As a telescope for educators, even those with relatively little astronomical knowledge, the device can provide students with many evenings of enjoyment and learning.

■ **PETER BEALO** enjoys observing the night sky from his backyard observatory in Plaistow, New Hampshire.



▲ *Left:* The eQuinox 2 is controlled via the *Unistellar* app that users download from the Apple or Google Play stores. In the ***My telescope*** screen, you can connect to the device via Wi-Fi, perform a sensor calibration, or park the telescope before shutting it down for the evening. *Middle:* The catalog within the *Unistellar* app contains a database of more than 5,000 objects. Users can slew to these or can manually slew to any location. *Right:* Clicking on the Science button brings users to a selection of projects they can contribute to. For example, Unistellar telescope owners contributed valuable observations for NASA's DART mission, which impacted asteroid Didymos on September 26, 2022.

▲ RIDE-ALONG CONTROLLER

Mount manufacturer iOptron adds a microcomputer to its line of products designed to make astronomy and astrophotography easier. The iMate Astronomy Control Box ($219) is a single-board, ride-along computer featuring a powerful 64-bit ARM processor to run your astro-imaging gear. The device includes 2 gigabytes of LPDDR3 RAM and 32GB of EMMC flash memory to ensure smooth operation of all your imaging equipment. It has a single USB 3.0 and a pair of USB 2.0 ports to connect your camera, autoguider, and other electronic accessories. Its internal storage is expandable up to 64GB courtesy of a MicroSD port. The computer comes pre-loaded with *KStars* planetarium software and the *Ekos* control and automation tool, as well as many drivers for compatible hardware from multiple manufacturers. Users connect to the computer with their Apple or Android devices via its built-in Wi-Fi. The device secures to your telescope or mount with a 31-mm dovetail shoe and other threaded ports.

iOptron
6F Gill St., Woburn, MA 01801
781-569-0200; ioptron.com

▲ SOLAR SMARTPHONE AID

Just in time for the total solar eclipse this month, filter manufacturer American Paper Optics releases the Solar Snap Eclipse App Kit ($14.99). The kit pairs the *Solar Snap* smart-device app (available for both Android and Apple devices) with a convenient solar-filter card that is secured to your smartphone or tablet with Velcro to provide a safe and easy method to photograph the eclipse. The app enables you to quickly adjust the exposure and zoom on your device to ensure a good image in moments as you enjoy the view. The filter material is ISO-certified so as to be safe for both your camera and your eyes. Each purchase includes two Solar Snap camera filters, two solar eclipse glasses, and two Velcro sets. The *Solar Snap* app is available free on both the Google Play and Apple store.

American Paper Optics
2995 Appling Rd, Suite 106, Bartlett, TN 38133
901-381-1515; eclipseglasses.com

◀ SMART ASTROGRAPH

Celestron rolls out its first smart telescope designed to remove the complexity from astro-imaging. The Celestron Origin ($3,999) is a 6-inch (150-mm) f/2.2 Rowe-Ackermann Schmidt Astrograph paired with the company's Evolution alt-azimuth Go To mount containing everything necessary to take images of the night sky and send them directly to your smart device. The scope contains a built-in, 6.4-megapixel, back-illuminated, color Sony IMX178 CMOS camera; together, the scope and camera provide 1.48-arcsecond-per-pixel resolution. The unit includes an internal electronic focuser and built-in dew prevention system powered by an on-board, rechargeable battery. The Origin automatically determines where it is pointing using the company's patented Star-Sense technology and is controlled via the *Celestron Origin* app (available free for Apple and Android devices). The scope comes with an adjustable-height steel tripod, dust cap, and USB wall charger.

Celestron
2835 Columbia St., Torrance, CA 90503
310-328-9560; celestron.com

New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope assumes no responsibility for the accuracy of vendors' statements. For further information contact the manufacturer or distributor. Announcements should be sent to nps@skyandtelescope.org. Not all announcements can be listed.

Make an Eclipsinator

View the Sun in style.

▶ Tom and Lori O'Berg got a great view of the October 14, 2023, annular eclipse with Tom's Eclipsinator.

APRIL IS NEARLY UPON US, and with it the big eclipse that everyone has been eagerly anticipating. In our December 2023 issue, I described a nifty projector you could make that would give you a large solar image about 70 to 125 feet away. But what if you didn't jump right on grinding that lens, or what if you don't have a big enough space? Are you out of luck?

Thankfully, no. If you have a pair of binoculars that you don't mind getting a little hot inside (Goodwill is great for these), you can project a decent image on a white card a few feet away. Simply aim the binoculars at the Sun and project the image into the binoculars' shadow. If you hold them a few feet away from the screen, you can get an image two or three inches across.

What if you want a bigger image? That's easy: Just hold the binoculars farther away from the screen (and refocus). Except it's not so easy to do by hand. The image will bounce around all over the place, and if the Sun is high in the sky, then you'll have to climb a ladder to project it farther than your own height. Plus, you'll need a big shade around the binoculars to provide a large enough shadow for the solar image to be projected within.

Enter Tom O'Berg and his "Eclipsinator" (named in homage to Dr. Doofenshmirtz of the "Phineas and Ferb" cartoon). Tom reasoned that a length of PVC pipe could hold his binoculars well away from the screen, and he could clamp the pipe to his bicycle maintenance stand, which would serve as a rough polar mount.

Tom quickly learned that PVC pipe is a little too flexible on its own. He wound up reinforcing the top end with an additional pipe inside the first one, and even then he had to add outriggers and tensioning strings. The setup worked quite well, though, during the October 14th annular eclipse last year.

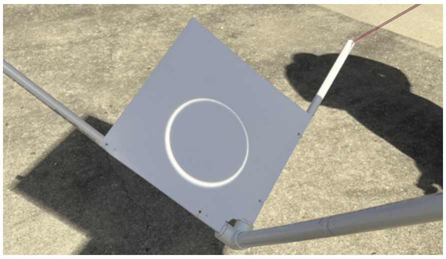
When I heard about Tom's Eclipsinator, I realized I had to make one. My astronomy club puts on "Solar Sundays" during which we show people the Sun through hydrogen-alpha and white-light-filtered telescopes, but we often have a large enough crowd that a projected image would be nice so more people could see the sunspots at once. Plus, I'm in the above camp of people without a good space to set up a long-range projector.

I've got a beefy equatorial mount, so weight isn't an issue. My immediate thought was to use a two-by-four for the spine, but that seemed like overkill. So I tried a two-by-two and a one-by-two. The one-by-two was a bit wobbly, but the two-by-two was plenty stiff.

I used a binocular tripod bracket to

▶ Kathy Oltion observes sunspots with Jerry's version of the Eclipsinator, which uses an 8-foot-long two-by-two for the pole. Bright-colored yarn keeps people from sticking their heads in the light path.

PVC VERSION OF THE SOLAR PROJECTOR: BETH ABRAHAM; WOODEN VERSION OF THE SOLAR PROJECTOR: JERRY OLTION



LORI O'BERG

▲ The annular eclipse of October 2023 was clearly projected for all to see by Tom O'Berg's Eclipsinator.

mount the binoculars to the top end of the pole, and I put a white screen at the bottom end. The screen is just a piece of foam-core posterboard taped to a couple pieces of lath that are screwed to the bottom end of the pole. I made a shade on top out of the same material, with a hole for one lens of the binocular to look through. I mounted a dovetail bar at the pole's balance point, which turned out to be about three feet down. That puts the screen low enough to the ground that kids can see it easily.

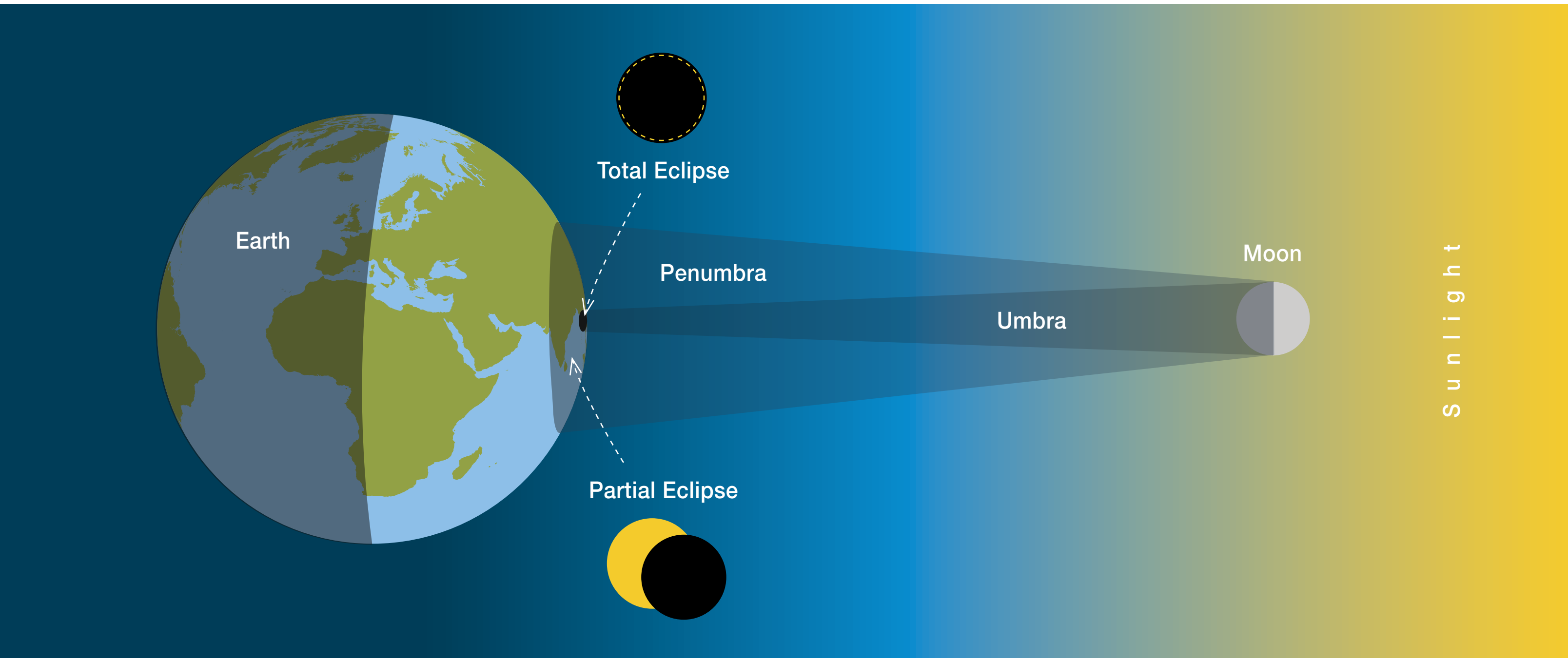
To use the Eclipsinator, I polar-align the mount, aim the binoculars at the Sun, and nudge the mount until the image is in the center of the screen. I then focus the binoculars, and that's it.

Different binoculars will provide different-size images. I use an old pair of 8×42s, which give me a 6½-inch solar disk. You don't want to use an expensive pair of binoculars for this. While you're refining your aim at the Sun, you're liable to melt internal parts, especially if the eyepieces' field stops are plastic. The outgassing from the molten plastic can also fog the inside surfaces of the lenses, essentially giving the binoculars cataracts. You can minimize the chances of this by making sure the binoculars are always aimed straight at the Sun, but there will inevitably be a little off-centeredness as you're setting up.

With a total solar eclipse in the offing, it's worth a few bucks for a pair of secondhand binoculars, some PVC pipe or a wooden two-by-two, and a white screen. An Eclipsinator will make a great addition to any solar viewing party.

■ Contributing Editor **JERRY OLTION** plans to use his Eclipsinator to view the Sun on a regular basis.

Why Do Solar Eclipses Happen?



▲ When the Moon casts its shadow onto Earth, people on the ground see the Moon eclipsing the Sun. The shadow's umbra is the dark central part where the eclipse is total. In the penumbra the Moon covers only some of the Sun, for a partial eclipse. (Not to scale!)

SURE, YOU KNOW THE BASIC IDEA: A solar eclipse happens when the Moon passes between you and the Sun, hiding part or all of the Sun from view. It's weird, it's unearthly, and it scared the bejeezus out of our ancestors, who didn't know what was going on. The stories they made up to explain eclipses were hair-raising.

The drive to actually *understand* eclipses — well enough to predict them! — was one of the drivers of ancient astronomy, and thus one of the drivers for the whole idea of science itself.

One breakthrough was grasping the scene from another viewpoint: The Moon is a sunlit ball and casts a shadow, and we see an eclipse of the Sun when the Moon's shadow sweeps over us, like in the diagram above.

But there's more to it than that — and if you want a fuller picture of what's going to occur this year on April 8th, read on.

Celestial Geometry

First off: The Moon orbits around Earth about once a month. This repeating journey brings the Moon close to our line of sight to the Sun at the time of "new Moon." At that time the sunlit side of the Moon faces directly away from us; the Moon shows us only its darkened nightside. And we can't *see* even that — because when the Moon is near our line of sight to the Sun, it's hidden in the Sun's dazzling glare in the bright blue daytime sky.

Usually the Moon misses the Sun in these monthly near-lineups (for reasons I'll get to later). But about every six months on average, at least part of the new Moon crosses at least part of the Sun's face as seen from somewhere on Earth. Hence a solar eclipse.

If the Moon crosses the Sun off-center as seen from your location, you get only a *partial* solar eclipse, with the Moon's silhouette making a "dent" in the Sun's brilliant face. A deep partial eclipse, when the dent is big, turns the Sun into a dazzling crescent.

But the really good stuff happens if the Moon crosses the Sun nearly dead center as seen from your location. Then you may get a *total* solar eclipse, blacking out the Sun completely for anything from a few seconds up to 7½ minutes.

A total eclipse also has partial-eclipse phases before and afterward. The partial phases take their time; the whole event usually runs about 3 hours from beginning to end.

What to Expect

A total eclipse is much more spectacular than a partial — not only because the

EARTH: SHUTTERSTOCK / FLUIDWORKSHOP, ILLUSTRATION: PATRICIA GILLIS-COPPOLA / S&T

sky and land get much darker, but especially because during totality we get a rare look at the Sun's intricate, feathery *corona*: its outermost atmosphere, made mostly of free electrons and protons that are trapped in the Sun's loopy, streaky magnetic field.

The partial phase of a solar eclipse can be seen from a large swath of the world. On April 8th that will include nearly all of North America, Central America, and the top of South America.

But totality is reserved for a much smaller area. The dark center of the Moon's shadow, the part where the Sun is completely blocked (the shadow's *umbra*) is never more than about 260 km (160 miles) wide by the time it reaches Earth, usually less. On April 8th, the narrow shadow-patch of totality will sweep across the Pacific, Mexico, the U.S., and a bit of Canada (see page 48). That's the part for which so many people are traveling.

The Same Size?

By an amazing coincidence, the Sun and Moon both appear about the same size as viewed from Earth. That's because the Sun, which is really about 400 times bigger than the Moon, also happens to be about 400 times farther away. So they both *appear* about the same size in the sky (½° wide, about the size of your little fingernail held at arm's length).

However, their apparent sizes do vary a bit. The Sun appears smallest in early July every year, when Earth is farthest away from the Sun in our orbit (at what's called *aphelion*). The Sun appears largest in early January when we're closest to it (at *perihelion*). But the difference is only 3.3%, 1 part in 30.

The Moon varies by a greater amount. It looks smallest when it's at the *apogee* of its orbit around Earth, and it looks largest at *perigee*. This difference can sometimes amount to as much as 14%.

As a result, we can get two types of "central eclipses" of the Sun. If the Moon appears a little bigger than the Sun, the Sun gets completely covered and the eclipse is total. If the Sun appears a bit bigger than the Moon, its brilliant edge shows all around the Moon's rim and the eclipse is *annular*, meaning ring-like.

The Workings in 3D

So why don't we get a solar eclipse at *every* new Moon? How does the Moon usually sneak by unseen?

The answer is that the solar system is not perfectly flat. In particular, the orbits of the Moon and Earth do not lie in quite the same plane. If you drew Earth's orbit around the Sun on a flat sheet of paper, the Moon's orbit around Earth would be tilted 5° out of the paper, floating a little above and below it except where the planes intersect. Eclipses happen only when both the Sun and Moon are close to this intersection, along what's called the *line of nodes*.

A 5° tilt might not seem like much. But it's 10 times the ½° width of the Sun as we see it in the sky. So, when new Moon happens somewhere other than at the line of nodes, the Moon has plenty of room to pass north or south of the Sun without crossing it. That's why solar eclipses are uncommon.

Your Eyes Are Worth Keeping

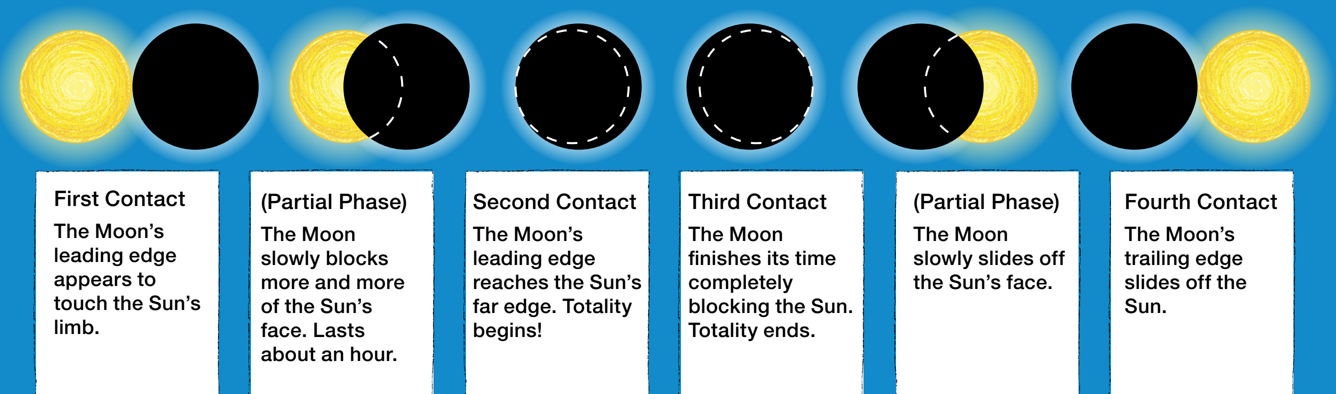
As you've probably heard many times, staring at the Sun's blazing surface, even when only part of it is in view, can damage your eyes and leave a permanent blind spot in your vision. Never stare at the bright Sun, whether a partial eclipse is in progress or not.

Instead, during the partial phases you need to look through a safe solar filter. One example is the kind that's made to go over the front of a telescope. For viewing just by eye, the inexpensive little "eclipse glasses" that we have tested do just fine.

Or you can watch an image of the Sun as projected onto a piece of paper — using either a pinhole, which gives a very small, dim, crude image, or a pair of binoculars or a telescope, which project a much bigger, brighter, and sharper image onto paper. See page 72.

While the Sun is hidden during totality, no filter is needed! ■

Sun & Moon Dance Steps



The stages of a solar eclipse, from partial to total to partial, begin and end when the edges of the Moon and Sun appear to make contact with each other. This happens four times from start to finish, as labeled above.

LEAH TISCIONE & GREGG DINDERMAN / *S&T*

DUSTY CROWN

Steve Leonard

This colorful image is centered on the northern portion of the emission nebula IC 1396 in Cepheus. The dark nebulosity at center is slowly dispersing due to ultraviolet radiation from a hot, young star outside the field of view. The bluish planetary nebula IRAS 21394+5844 is seen at the top.

DETAILS: *Astro-Tech AT115EDT refractor and ZWO ASI1600MM Pro camera. Total exposure: 16 hours through narrowband filters.*

◁ SPECTACULAR SHRAPNEL

Fred Herrmann

The Vela Supernova Remnant is the aftermath of the explosion of a massive star that occurred some 11,000 years ago. The bluish filaments are the outer layers of the progenitor star expanding out into the interstellar medium.

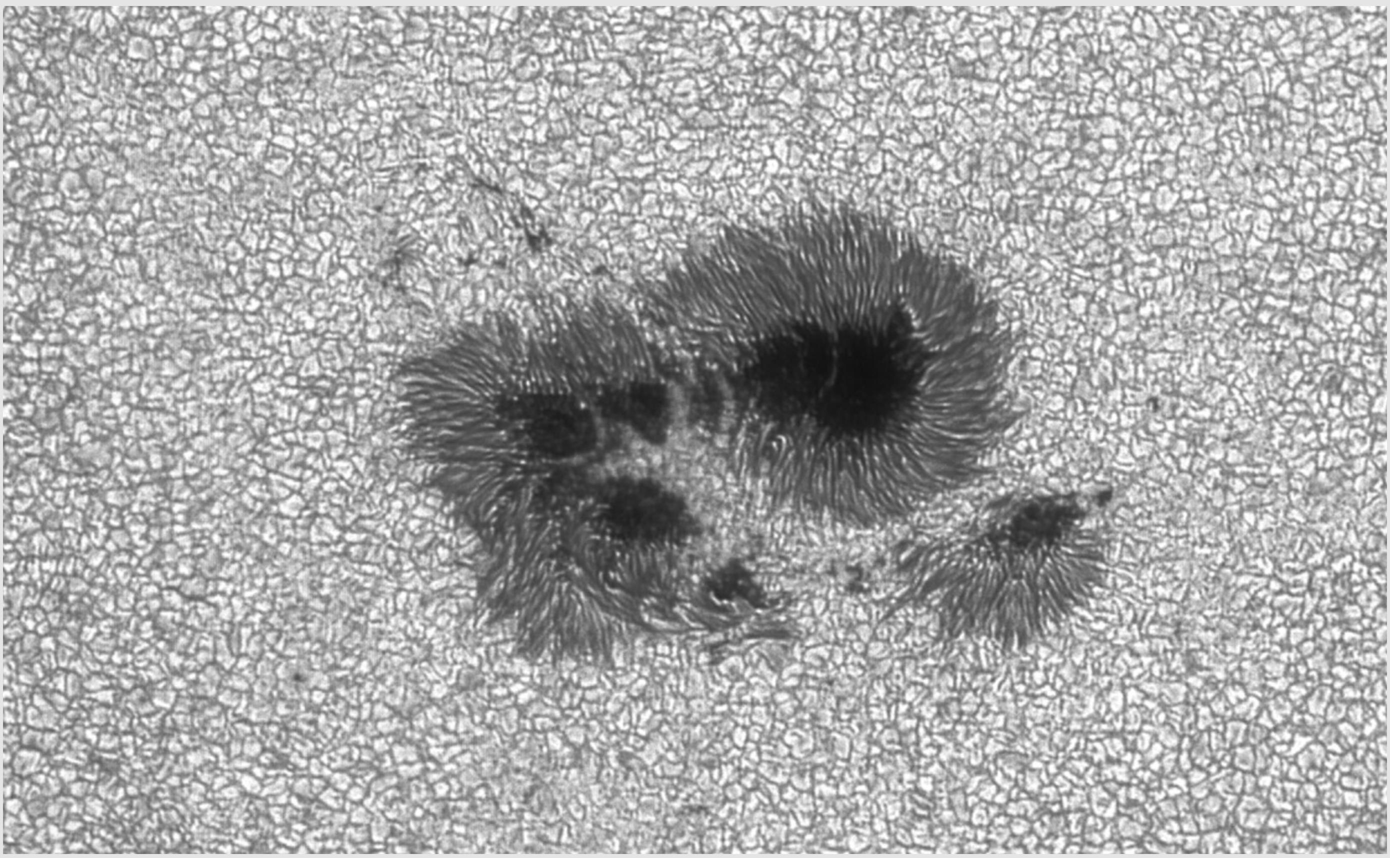
DETAILS: *Takahashi Epsilon E-180 astrograph and ZWO ASI2600MM camera. Mosaic of 13 panels taken through narrowband filters.*

▽ SOLAR CLARITY

Daniel Brousseau

Feathery penumbrae circle sunspot group AR 3435 in this very-high-resolution image from September 22, 2023. The deceptively delicate-looking solar granules surrounding the sunspots are the tops of convective cells of plasma, with some as large as the state of Alaska. These cells form, brighten, and then darken and dissipate within a period of roughly 20 minutes.

DETAILS: *Sky-Watcher Quattro 250P 10-inch Newtonian reflector and ZWO ASI290MM camera. Stack of multiple video frames through both a Baader solar filter and an Astronomik O III filter.*



◁ BLOOMING SPIRAL

Bob Fera and Eric Coles

Messier 63, also known as the Sunflower Galaxy, is a 9th-magnitude flocculent spiral located roughly 27 million light-years away in Canes Venatici. Its tightly wound spiral arms are riddled with dust punctuated by many reddish star-forming regions.

DETAILS: *PlaneWave CDK20 corrected Dall-Kirkham telescope and Moravian C3-61000 Pro camera. Total exposure: 8 hours through LRGB filters.*

▽ NEBULOUS ORION

Gerald Rhemann

Sharpless 2-278 (right in image) is a faint mix of dust and emission nebulosity in Orion. To its left is the diffuse, blue reflection nebula LBN 964.

DETAILS: *AstroSysteme Austria 12-inch astrograph and ZWO ASI6200MM Pro camera. Total exposure: 9 hours through Hα and LRGB filters.*

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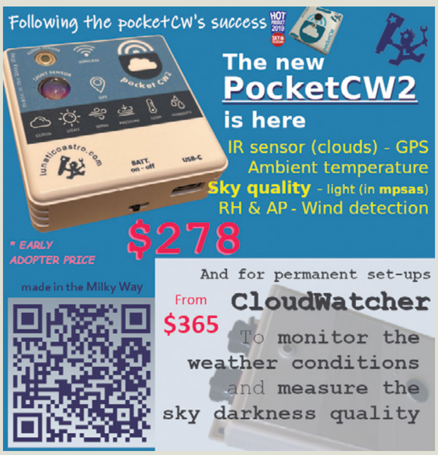

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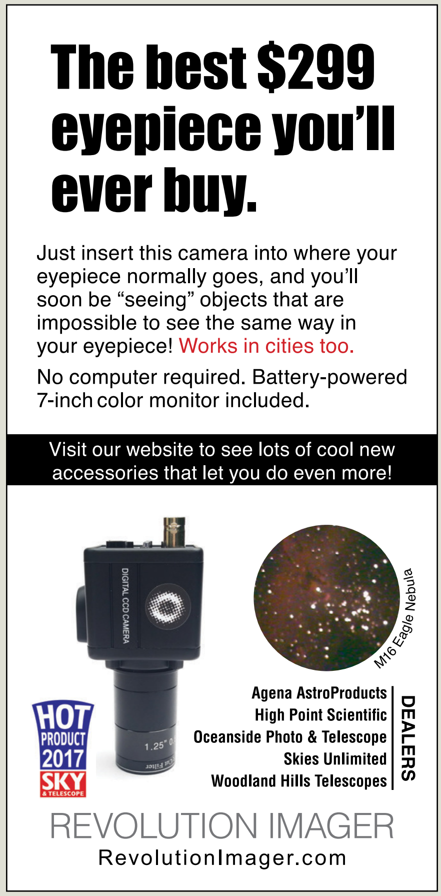

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During the July 1963 eclipse, clouds were the least of the author's worries — and actually benefited him. Here, the diamond ring enhances the 2010 Easter Island eclipse.

A Teenager's First Eclipse Chase

The author had no idea what an adventure he'd be on, including a close brush with disaster.

MY VERY FIRST issue of *S&T* (April 1963) showed the path of that year's July 20th total solar eclipse running through Quebec — and I, a keen 16-year-old amateur astronomer living in the neighboring province of New Brunswick, was determined to go.

I arranged to join a group organized by the Montreal Centre of the Royal Astronomical Society of Canada. I'd meet them at their Montreal observatory the evening before the eclipse, and the next day they'd drive me to their observing site at Plessisville, a town two-thirds of the way to Quebec City.

But en route the train that I'd boarded in my hometown of Moncton collided with another train around 4 a.m. at the trestle across the Miramichi River. Just past the trestle, a freight train that had been traveling ahead of our passenger train had lost several flatcars, which had rolled down to the riverside. Our train's locomotives rear-ended the remaining flatcars and derailed, also rolling down the slope.

Our passenger cars fortunately remained on the bridge, so we all survived. The crew in the locomotives and some passengers were hospitalized with injuries such as broken legs. I was uninjured, in part because the night before something had told me to turn my seat around so that I wouldn't be thrown out of it in the event of an accident!

The 14 hours it took to clear the train wreck and send a replacement train to pick us up meant that I couldn't make it to Montreal in time to join the eclipse-chasers. So I jumped off the new train as it slowly pulled out of the town of St. Hyacinthe and hitchhiked to Plessisville. (Sixty years ago, that's how Canadian teenagers got around.)

I arrived at the observing site three hours before first contact and was thrilled to see scopes like Questars, Unitron refractors, and 8-inch Newtonian equatorials — wondrous things I'd only ever drooled over in *S&T* ads.

In the 1960s, you couldn't just go eclipse-chasing; you were expected to "do science." My assigned job was to use my 60-mm refractor to search for comets near the Sun during totality rather than simply view totality itself! Fortunately for me in a way, the Sun entered altocumulus clouds about 15 minutes before totality. We did see the pearly inner corona and a large pink prominence through the thin cloud — both never-forgotten firsts for me.

After the eclipse, I boarded a train near Quebec City for my trip home. The next morning at a stop in French-only rural Quebec, I briefly hopped off and went across the tracks for breakfast. During my meal, the train started to move. Instead of just throwing $5 on the counter and running for it, I tried using my high-school French to establish how much the bill was. It was a long, cool, foggy 12 hours until the next train, and I had to call home collect to get my father to rescue my suitcase and telescope off the now-departed train.

Since that trip, I've been 10 out of 10 in successfully chasing totality. I'd learned my lesson: When it comes to eclipse-chasing, only three things matter: mobility, mobility, and mobility.

■ Retiring Contributing Editor **ALAN WHITMAN** thanks his favorite magazine for publishing 35 of his articles since 1998. (And his favorite magazine warmly thanks him. —*The Editors*)

DENNIS DI CICCO / *S&T*