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AUGUST 2026

Dark Clouds of the Summer Milky Way

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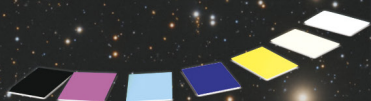
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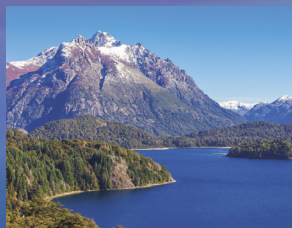
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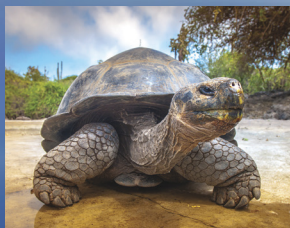
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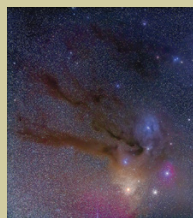
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ON THE COVER



The Rho Ophiuchi region teems with various nebulae.

PHOTO: ALAN DYER

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In Flux

CHANGE CAN BE a force for good or bad. In the past year, we've experienced plenty of both. We often can't control the changes that buffet us — but we can control how we adapt to them.

Many U.S. scientists had to dig deep into themselves in 2025 in order to find ways to tackle the changing world of science funding. The federal government was swinging the budget hatchet. At *Sky & Telescope*, we heard stories of the tumult directly from our contributors, sources, and friends, including astronomers whose space missions were placed on the chopping block.

Emotions ran high as scientists scrambled to advocate on Capitol Hill. The charged atmosphere made diligent, fact-based reporting all the more imperative. Science writer Hannah Richter kept pace with the year's events, penning several news articles for us on the whiplash changes. Now, she has deftly collated the chaos into the in-depth article starting on page 22, in which she outlines step-by-step how the year unfolded.



▲ Easy-to-use scopes are a great way to start in astronomy.

Change doesn't only have consequences on a large, national scale. Changes at home or in the workplace can profoundly affect how we operate as a family or as a team. Around the turn of the year, key departures and additions to the staff of *S&T* and our parent organization, the American Astronomical Society, conspired to show that we, too, are vulnerable to the forces of change.

The staffing shifts were happening as we were putting together the April and May 2026 issues. Many of you have already noticed that our meticulousness slipped during this time. The May 2026 issue carries two diagrams from 2025: the lunar libration diagram (page 42) and the planets chart (page 47). We apologize for the errors. These mistakes did not transpire out of a lack of caring, but out of mild chaos. (You'll find corrected diagrams on our errata page online: skyandtelescope.org/errata.)

Nevertheless, we must look to the future with hope. And that's something I'd like to invite you to do. Think about someone you know who might have expressed a budding interest in astronomy, then turn to page 70 for a review of affordable and easy-to-use scopes, penned by former-*S&T*-editor-turned-high-school-teacher Joshua Roth. The roundup might inspire you to ignite the passion in someone who's just setting out in the hobby.

Let's focus on those celestial objects we all delight in, while sparing a thought for the scientists whose lives have been turned upside down. We hope that they, too, find serenity by looking up.

Dinner
Editor in Chief

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Contributing Photographers

P. K. Chen, Robert Gendler, Babak Tafreshi

ART, DESIGN & DIGITAL

Creative Director Terri Dubé
Technical Illustrator Beatriz Inglessis
Illustrator Leah Tiscione

ADVERTISING

Director of Strategic Partnerships Rod Nenner
ads@skyandtelescope.org

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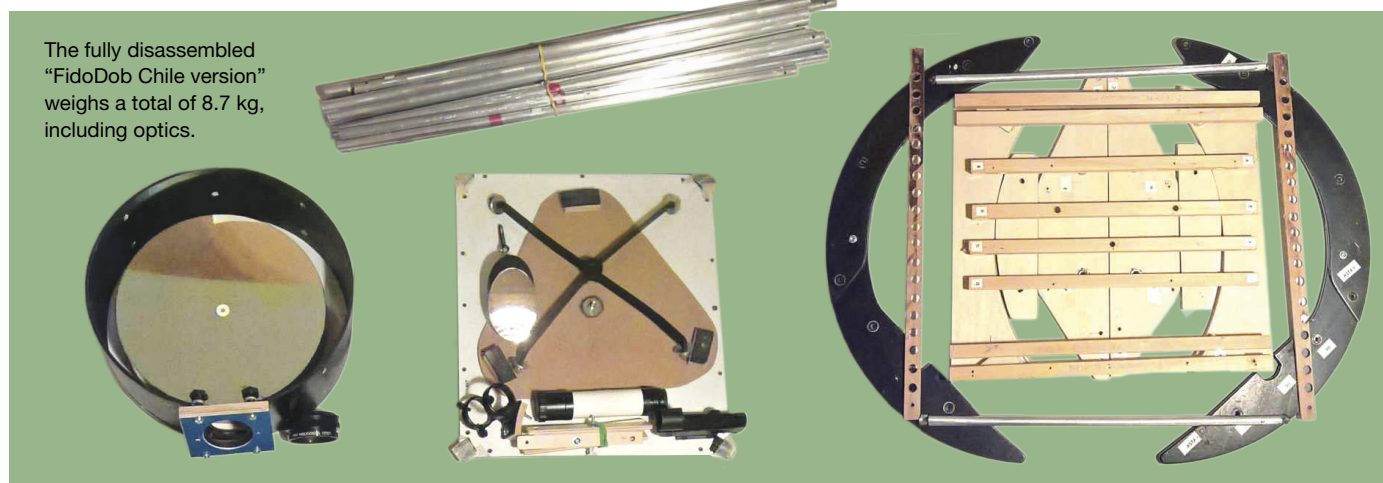
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The fully disassembled “FidoDob Chile version” weighs a total of 8.7 kg, including optics.

Pack-a-Scope

Reading and enjoying Jonathan Kissner’s “An Ultracompact Carbon-Fiber Travel Scope” (*S&T*: June 2026, p. 74), I could not resist sharing a complementary experience of my own.

In 2019, I was the only visual observer in a group of astrophotographers traveling to Chile for the July 2nd total solar eclipse. My task was simple: Bring a telescope that could fit into a standard suitcase alongside clothing and essential gear.

Starting from the optics of an old Meade Starfinder 10-inch Dobsonian and with the invaluable help of a retired craftsman, I built a truss structure using inexpensive materials that could be fully disassembled. The result — my “FidoDob Chile version” — weighed 8.7 kg (19 lbs), including optics, and packed entirely into half a Samsonite suitcase.

While Laurent Bourasseau’s design achieves a remarkable 7.4-kg scope using carbon fiber and advanced engineering, I was struck by how close

a more “proletarian” approach could come. Using wood, simple tools, and a good deal of improvisation, I arrived within 1.3 kg of his feat.

Under the Atacama sky, the telescope performed beautifully, reminding me that portability is not only a matter of materials and optimization but also of ingenuity, constraints, and purpose.

In the end, both approaches share the same spirit: making the sky accessible, anywhere.

Lorenzo Burti
Verona, Italy

Poignant Passages

When I first pick up my newest copy of *Sky & Telescope*, I always immediately flip to the back page to read Focal Point. There’s something about these columns that hit me spot-on every time. Vanya Agrawal’s “Music From Numbers” (*S&T*: June 2026, p. 84) is a poignant example of the mixture of science and human awe that I have joyfully found here. This mix is echoed in the recent voyage of Artemis 2, when the mission — aside from its astonishing science and images — also inspired us with “Moon joy” through the shared human senses and spirit communicated by the crew and what they witnessed.

Jeff Hino
Albany, Oregon

Perennial Birds

I greatly enjoyed Javier Barbuzzano’s “Animal Navigators” (*S&T*: June 2026,

p. 20). It rang a faint bell, and then it dawned on me: Stephen T. Emlen wrote an article on his studies of the indigo bunting for *S&T* in 1969 (*S&T*: July 1969, p. 4). It’s a full-circle “migration” of nearly 57 years!

Fred Veretto
Oceanside, California

Perfectly Pragmatic

Bravo! Paul Sutter’s “Cracks in Cosmology” (*S&T*: Mar. 2026, p. 34) is the article I’ve been waiting to read for decades. Let the magic thinking end and understanding begin.

E. Iain McConaughy
Algonquin Park, Canada

Practically Fundamental

Christopher M. Graney and Dennis Danielson’s “Lord Kelvin and Space Seeds” (*S&T*: Mar. 2026, p. 28) and Paul Sutter’s “Cracks in Cosmology”

confirmed a life decision I made some 60 years ago — to not pursue a career in astrophysics.

Indeed, *Sky & Telescope* is my sole connection to the study of the skies today. I remain fascinated, and this publication is probably to blame. But after being informed by the chairman of the astronomy department at a major university that once I had obtained my PhD, most of my time would be spent teaching the discipline, I balked. With the pace of scientific discovery, I just could not bear to spend my life teaching any subject whose knowledge base was advancing so rapidly that the material would be a perpetually moving target.

In the cosmology article, Sutter submits, “95% of the universe is made up of stuff that we don’t really know how to describe on a fundamental level.” And Graney and Danielson assert, “Never in the history of science have

we been so in the dark as we are today about the fundamental question of how life came into existence.” Though we know so many more facts than we did in the 1970s, it seems that we have not advanced far at all on what these authors refer to as the fundamentals: How did the universe come to be and how did life originate?

William J. Wilkins
Hudsonville, Michigan

Picturesque Rings

Kudos to Beatriz Ingleess and the design team for the ingenious illustration accompanying Arwen Rimmer’s “Rings Around the Solar System” (S&T: Mar. 2026, p. 14) in which the relative positions and sizes of the rings and satellites of four separate planets were represented on a single page with a single frame of reference. It’s a diagram surely worth a thousand words or more.

Kenneth A. Heisler, M.D.
Falmouth, Massachusetts

Poetic Galaxy

Howard Banich’s “Leo I: A Small Galaxy with a Big Story” (S&T: Mar. 2026, p. 22) really resonates with me for a couple of reasons. It does a great job of illustrating how understanding some of the scientific background enhances a visual observation. This concept is one of the principles I highlight in my outreach programs, so I feel validated by Banich’s story.

I sense that since the American Astronomical Society took over, *Sky & Telescope* has experienced an influx of technical expertise and writing, but I applaud your continued inclusion of visual astronomy, in addition to imaging and space science.

Howard Banich’s articles are valuable and appreciated.

Jim Gasser
Maumee, Ohio

Pairing Planets

Spotted ‘em! A warm thanks to Gary Seronik for highlighting the Mercury and Venus pairing on February 2nd in “Lunar Hits and Near Misses” (S&T: Feb. 2026, p. 46) — I always flip to the Sun, Moon & Planets column first when the latest issue arrives.

I took my Canon 10×42 L IS binoculars to the hillside drive leading to the Ronald Reagan Presidential Library and Museum — the best low-western horizon near my home.

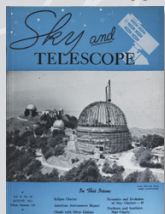
Guiding off of Venus (itself visible maybe 10 minutes before), I could distinctly make out Mercury at around 5:42 p.m., with Venus less than 1° above a local ridge line. Together they were a beautiful pair that easily fit in the field of view.

Bob Wieting
Simi Valley, California

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 Sabrina Garvin

1951



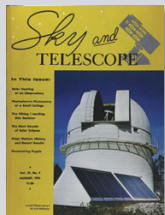
August 1951

Neutral Hydrogen “Seven years ago, Dr. H. C. van de Hulst, of Leiden Observatory, predicted the existence of the 21-cm. emission line from interstellar hydrogen, and the Radio Astronomy Research Group in Holland, [has been working on the] project for the past two years. Dr. van de Hulst reported that C. A. Muller had observed the long-wave hydrogen emission on May 11th . . .

“Nearly seven weeks earlier, however, on March 25, 1951, Dr. Harold I. Ewen, of Harvard’s Lyman Laboratory, detected this hydrogen radiation from the Milky Way. Dr. Ewen described his horn-type radio antenna of about 12 degrees half-power beam width, rigidly mounted at declination -5° . . .

“[Van de Hulst] considers one of the important uses of this discovery to be the ability of the radiation to penetrate clouds that are opaque to visible light.”

1976



2001



August 1976

Cataloging Variables “The number of stars officially designated as variable has now risen to 25,838, by the addition of 699 new ones in the *Third Supplement to the Third Edition of the General Catalogue of Variable Stars*, just published by B. V. Kukarkin and his colleagues at the Sternberg State Astronomical Institute, Moscow. . . .

“Generally speaking, the recent discoveries tend to be very faint objects found in photographic surveys of the Milky Way, or else naked-eye stars of very small amplitude whose variability has been discovered photoelectrically. . . .

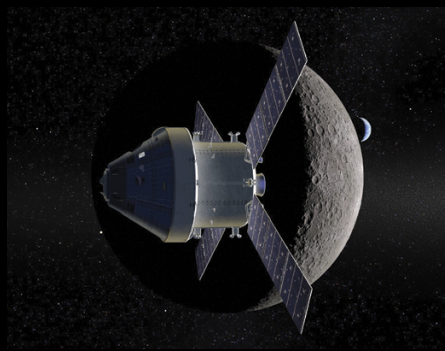
“The Moscow publication also provides new information on 3,923 previously known variable stars. In addition, there are lists of pulsars, optically variable quasars and radio sources, and galaxies with variable nuclei. This is a clear indication of the enormous widening of the horizon of variable star astronomy in recent years.”

August 2001

Metal Stars “With more than 60 extrasolar planets now safely in their catalogs, astronomers are beginning to draw some statistical conclusions about planetary systems in general and the stars that host them. One trend was spotted early. Stars that have planets — at least the giant, close-in planets that can be detected so far — tend to be ‘metal rich.’ That is, the stars usually show above-average proportions of elements heavier than hydrogen and helium in their spectra. . . . Exoplanet hunters increasingly consider a heavy-element-rich spectrum to be a red flag indicating a star where they’re likely to score a hit.”

Recent studies have confirmed that gas giants are far more common around metal-rich stars. But small, rocky planets like Earth don’t seem to require high metallicity to form. System architecture, or the configurations of planets in their orbits, has more to do with the system’s unique history.

The Artemis 2 crew took this photo just before they passed behind the Moon.



▲ This artist's concept takes an outside perspective, showing the *Integrity* module as it passed behind the Moon relative to Earth.



▲ From the crew's perspective, the Moon appeared much larger on the sky than the Sun, creating almost an hour of totality during a total solar eclipse. The glow around the Moon seen here is the zodiacal light; however, the astronauts also glimpsed the solar corona at totality's start and end. See more photos at skyandtelescope.org/Artemis2.

SPACE

NASA's Artemis 2 Mission Goes to the Moon

AFTER MORE THAN a decade of planning and delays, the boosters on NASA's Space Launch System (SLS) Block 1 rocket roared to life on April 1st, sending Artemis 2 on a path around the Moon.

The mission — the first crewed flight of both the SLS rocket and the Orion capsule — marks the first human journey beyond low-Earth orbit since the Apollo program more than half a century ago. The crew includes NASA astronauts Reid Wiseman, Victor Glover, and Christina Koch as well as Canadian Space Agency astronaut Jeremy Hansen. They were the first Moon-bound crew to include both a Black astronaut and a woman. Canadian Hansen is also the first non-U.S. citizen to leave low-Earth orbit.

The 10-day mission took the crew looping around the Moon on a “free return” trajectory. They broke the record for spaceflight's farthest distance, traveling 400,171 km (248,655 mi) from Earth. All along the way, the crew sent back images of Earth and Moon alike — including more than 7,000 images captured during the lunar flyby on April 6th. The astronauts dimmed the cabin lights to aid their official sightseeing, watching craters pass by both visually and with cameras angled just so to minimize reflections from the windows.

As Artemis 2 passed behind the Moon from Earth's perspective, radio contact cut off for 40 minutes. The crew then witnessed a solar eclipse, experiencing 54 minutes of totality. On the dark farside, the crew saw six flashes of light, likely medium-size meteorite impacts. (See skyandtelescope.org/lunarflashes.)

Just before the flyby, Hansen noted a bright crater on the boundary between the Moon's near and far sides. In an emotional message, Hansen proposed to ground control that the crater be named for his crewmate's late wife, Carroll Taylor Wiseman, who passed away in 2020. Carroll Crater is to the northwest of Glushko, at the same latitude as Ohm Crater, the crew noted. The crew also requested another unnamed crater — almost directly between Orientale and Ohm — be named for their capsule, *Integrity*. Both names are awaiting approval by the International Astronomical Union.

On April 10th, the mission ended with *Integrity* splashing down in the Pacific Ocean. Next up: Artemis 3, due in 2027, will remain in low-Earth orbit to test maneuvers between the Orion capsule and a commercial lunar lander, ahead of the Moon landing tentatively planned for 2028.

■ DAVID DICKINSON

THE MOON

How Much Water Ice Do the Lunar Poles Hold?

PERMANENTLY SHADOWED regions at the Moon's poles might contain less water ice than previously thought, concludes a study in *Science Advances* from Shuai Li (University of Hawai'i, Mānoa) and collaborators.

Scientists have long looked for such ice deposits at the Moon's poles, where topographic lows never receive direct sunlight and remain extremely cold, potentially trapping water molecules. But searches for this ancient ice have returned mixed results.

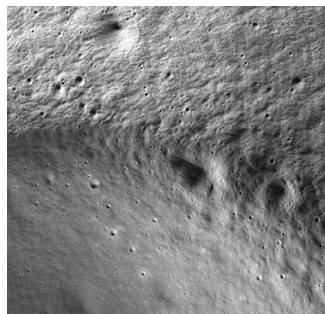
Now, a new set of observations lowers the threshold for how much water the lunar poles might hold. Using images from NASA's ShadowCam, a camera flying on the Korea Pathfinder Lunar Orbiter (KPLO), researchers peered into these dark areas and found no evidence of widespread ice deposits on the surface. The team concluded that, at most, 20% to 30% of lunar

surface regolith is water (by weight).

ShadowCam relies on faint, scattered sunlight to image permanently shadowed areas. Water ice reflects most of the visible light that hits it, yet the team did not find ice deposits rich enough to distinguish themselves from other brighter features such as boulders.

Nor did imaging the same areas from different angles turn up much evidence of ice. Dry lunar regolith reflects light back toward the source, while water ice scatters light forward. Li and colleagues found only a few small areas that scattered more light than dry regolith. Most of these were associated with freshly exposed material, such as at meteorite impacts. Water ice might therefore be more plentiful below the surface.

As it stands, the finding is a setback for human lunar exploration, which might have relied on surface water ice.



◀ This and other high-resolution images of permanently shadowed regions near the lunar south pole, illuminated by faint scattered light, show little evidence for water ice.

But Simeon Barber (Open University, UK), who wasn't involved with the study, says conclusive observations

are difficult to make from orbit. We need ground-truth tests, he says.

Barber is involved in the European Space Agency's Package for Resource Observation and In-Situ Prospecting for Exploration, Commercial Exploitation, and Transportation (PROSPECT), which will drill beneath the lunar south pole's surface. NASA might also deploy the Volatiles Investigating Polar Exploration Rover (VIPER) to the lunar south pole in the coming years (*S&T*: Feb. 2026, p. 11). These future missions will help settle the question of how much water ice is at and under the Moon's poles.

■ JAVIER BARBUZANO

PLANET FORMATION

Possible Planet Collision Around a Young, Sun-like Star

IN AN INFANT SYSTEM more than 11,600 light-years away, two primordial planets might have crashed into each other, creating a dusty disk of debris that's now blocking the star's light.

Giant impacts likely played a role in sculpting our own solar system, from creating the Moon to explaining Uranus's tilt and Saturn's rings. "What's exciting about this [event] is that we're actually seeing it happen in real time," says Anastasios Tzanidakis (University of Washington), who led the observations published in the March 20th *Astrophysical Journal Letters*.

The European Space Agency's Gaia telescope first flagged the dimming of a Sun-like star now called Gaia-GIC-1. But when Tzanidakis and team imaged it at infrared wavelengths, it was glowing more brightly than expected.

A planet collision could create the signatures they observed. Dust from

the collision would dim Gaia-GIC-1's light at visible wavelengths, while heat radiating off the collision's dusty aftermath — at a temperature of 900 kelvin (1160°F)— would cause infrared emission to spike. To explain the observations, the cloud of debris would have to span a whopping 19 million km across (12 million mi, or about one-third of the way from the Sun to Mercury).

The Gaia observations initially showed the star's visible light dimming every 380 days or so, suggesting that the putative dust cloud was orbiting its star at a little more than the distance between Earth and the Sun. Over time, though, the dust cloud heated up and expanded, elongating along its orbit. As a result, the star's visible light started flickering irregularly as the expanding dust cloud covered up more of the star.

This system isn't the first one to have evidence of a cataclysmic colli-



▲ An artist's rendering shows a planetary crash around a young, Sun-like star

sion. In 2023, a team led by Matthew Kenworthy (Leiden University, The Netherlands) discovered a similar signature from what they think was a crash between a pair of ice giants.

"We're starting to get lots of little pieces of evidence coming together that collisions are happening at all scales," Kenworthy says, who discovered a similar signature from what his team concluded was the collision of a pair of ice giants. "I'm really looking forward to seeing what they find when they investigate it further."

■ ARIELLE FROMMER

SOLAR SYSTEM

Many Waters May Have Mixed on Mars

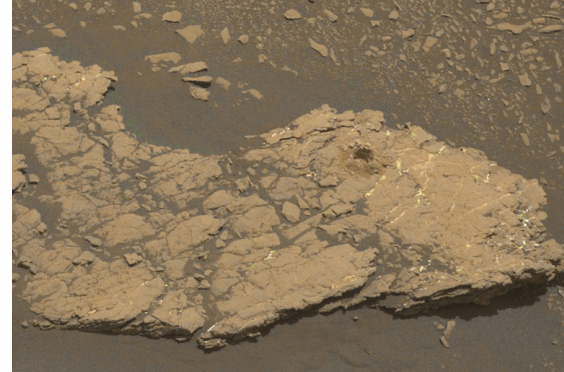
IF EVERY ROCK tells a story, then the drill sample that NASA's Curiosity rover took from the Martian ground in 2019 tells a saga. Sample analysis suggests that alkaline and acidic water mixed beneath the Martian surface, said graduate student Taiko Hirai (Institute of Science Tokyo), who presented his results at the 57th Lunar and Planetary Science Conference. He concluded that a subsurface environment once existed where complex organic molecules could have formed.

Even from orbit, the Glen Torridon region in Gale Crater exhibits a strong signature of clay minerals, which form in neutral to alkaline water — unlike the acidic waters that made the sulfate-rich rocks explored by Curiosity's predecessors, Spirit and Opportunity. Curiosity drilled at two locations in Glen Torridon and gave one sample to its Chemistry and Mineralogy instrument, which uses X-ray diffraction to identify minerals.

But the chemistry of this sample was a puzzle, Hirai explained. In most respects, its mineral makeup suggested it was once buried deep underground. There, the groundwater filling its pores must have been slightly alkaline, because the rock contains siderite (iron carbonate) and the unusual clay minerals greenalite and minnesotaite — all of which could have formed by crystallizing out of the alkaline groundwater.

But two pieces of chemical evidence didn't quite fit in this alkaline scenario. The sample does have some sulfate, which hints at chemistry in acidic water. Yet siderite would dissolve if dunked in enough acidic water. What's more, the sample's iron concentration was unexpectedly high.

Gale Crater's water became more acidic later in its history. So as a new lake formed in the crater, after the sampled rock was already buried beneath the ground, acidic surface water could have mixed with the more



▲ Curiosity drilled into the Martian ground to extract a sample from the clay-rich Glen Torridon region in Gale Crater.

alkaline groundwater already in the rock. The mixture could explain the unusual combination of alkaline-preferring minerals alongside the presence of acid sulfates. Brief exposure (that is, less than 100 years) to the acidic lake water, and the chemical reactions that would ensue, could also explain the excess iron.

The mixing of these two flavors of water is an exciting prospect, Hirai said at the conference. Where they meet, there's a gradient in the chemical environment that's ideal for the creation of complex organic molecules — the kind that's necessary for life.

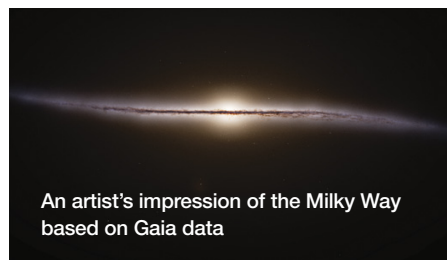
■ EMILY LAKDAWALLA

MILKY WAY

Astronomers Find the Edge of the Milky Way

ASTRONOMERS HAVE LOCATED the edge of the Milky Way's star-forming disk, showing that new star formation is focused within 40,000 light-years of our galactic center.

Disk galaxies like the Milky Way tend to form stars in an "inside-out" pattern, starting from the center and working outward through the disk. So, as a general rule, as astronomers look farther out in the galaxy, they see younger stars.



An artist's impression of the Milky Way based on Gaia data

But there's a point where this pattern changes, finds a team led by Karl Fiteni (then at University of Malta). Carrying out research under the supervision of Joseph Caruana and Victor Debattista (also at Malta), Fiteni analyzed the precise ages of and distances to more than 100,000 giant stars, using data from the LAMOST and APOGEE spectroscopic surveys as well as measurements from the European Space Agency's Gaia satellite. Coupling observations with simulations, Fiteni showed that the Milky Way's inside-out pattern reverses at 35,000–40,000 light-years from the Milky Way's center: Beyond that point, stars are *older* the farther we look.

The team concludes that the reversal marks the edge of the Milky Way's star-forming disk. The stars beyond 40,000 light-years probably didn't form in situ, but they didn't come from infalling satellite galaxies, either. "The stars in the outer disk . . . are on close-to-circular orbits, meaning that they had to have

formed in the disk," Debattista says.

Those stars likely rode our galaxy's spiral waves like surfers riding swells to shore (*S&T*: Mar. 2023, p. 14). Ultimately, they were dumped in the outskirts of the Milky Way. Since it took the outermost stars longer to travel farther, they are also the oldest. The results are published in the April issue of *Astronomy & Astrophysics*.

Astronomers have seen similar U-shaped age profiles in simulated disk galaxies and inferred their presence in observations of other galaxies beyond our own, so the Milky Way appears to be following a common pattern in disk evolution. But it's unclear what stymies star formation farther out. It's possible that the Milky Way's central bar corrals gas at preferred radii (*S&T*: June 2026, p. 28). Or our galaxy's warped shape might disrupt star formation in the outer reaches. Upcoming spectroscopic surveys may help paint a clearer picture.

■ COLIN STUART

SOLAR SYSTEM

Uranus's Outermost Rings Are Made of Two Different Things

THE JAMES WEBB SPACE TELESCOPE (JWST) has found water ice in one of Uranus's outer rings and carbon dust in another. While we've known the two rings have different colors since their discovery, the new observations suggest a surprisingly large role for a tiny ice moon.

Like Saturn, Uranus has a main ring system, with tiny moons shepherding ring edges (*S&T*: Mar. 2026, p. 14). Also like Saturn, Uranus has faint rings far beyond the main system, two of which weren't spotted until 2003 in Hubble Space Telescope observations. The nu (ν) ring is narrow, sandwiched between the orbits of ring moons Portia and Rosalind, while the outer mu (μ) ring is broader and contains the orbit of Mab, another ring moon.

Near-infrared observations of the inner ν ring showed that it appeared red, likely due to micrometeoroid bombardment kicking up material from Portia and/or Rosalind. The outer μ ring did not show up in those data, though it

had appeared in the shorter-wavelength Hubble observations, suggesting the ring was bluer in color and therefore composed of water ice.

Now, longer-wavelength JWST observations from between 2023 and 2025, as well as archival data from the Keck Observatory and Hubble, have confirmed a mixture of rocky and carbon-rich material in the ν ring, exactly as expected for particles knocked off the ring moons. The spectra also confirm tiny, sub-micron grains of water ice in the μ ring. Imke de Pater (University of California, Berkeley) and collaborators published the results in the April *Journal of Geophysical Research: Planets*.

But while the new data confirm the origins of the colors, they also raise new questions. How can a tiny fleck of a moon like Mab produce enough ice grains to populate an entire ring? How do those ice particles leave the moon's surface? And why is Mab so icy in the first place?

Mab is much too small for geologic activity, between 12 and 24 km (7 to 15 mi) in diameter. For comparison, Saturn's Enceladus is about 500 km across and still considered small for a geologically active moon. So Uranus's μ

ring likely comes from the moon's micrometeoroid bombardment. But it's unclear why Mab turned out to be icier than the other ring moons.

Unfortunately, Webb can't tell us anything about Mab's geology; the moon is simply too small to image. Only an orbiter, such as European and American scientists have repeatedly proposed, could tell us more.

■ EMILY LAKDAWALLA

IN BRIEF

First Science from Sun-Observing Proba 3

The European Space Agency's Proba 3 mission, launched in December 2024, flies two spacecraft in precise formation to watch the solar wind as it leaves the Sun. The craft do so by creating an artificial eclipse. One spacecraft blocks the solar circumference using a 1.4-meter (4.6-foot) disk. The other spacecraft observes the Sun from 144 meters away, keeping that separation to within 1 millimeter. After a year of operations, Proba 3 has provided its first science results: In the March 10th *Astrophysical Journal Letters*, Andrei Zhukov (Royal Observatory of Belgium) and colleagues describe structures in the solar atmosphere just 70,000 km (43,000 mi) from the Sun's surface — a region no other space-based coronagraph can observe. Images taken on a 30-second cadence reveal flows within those structures. "The time resolution and the spatial resolution of the images they're getting are really impressive," says Mathew Owens (University of Reading, UK), who was not involved in the research. "[The solar atmosphere] is proving to be a lot more structured and messy than previous studies have shown."

■ JAVIER BARBUZANO

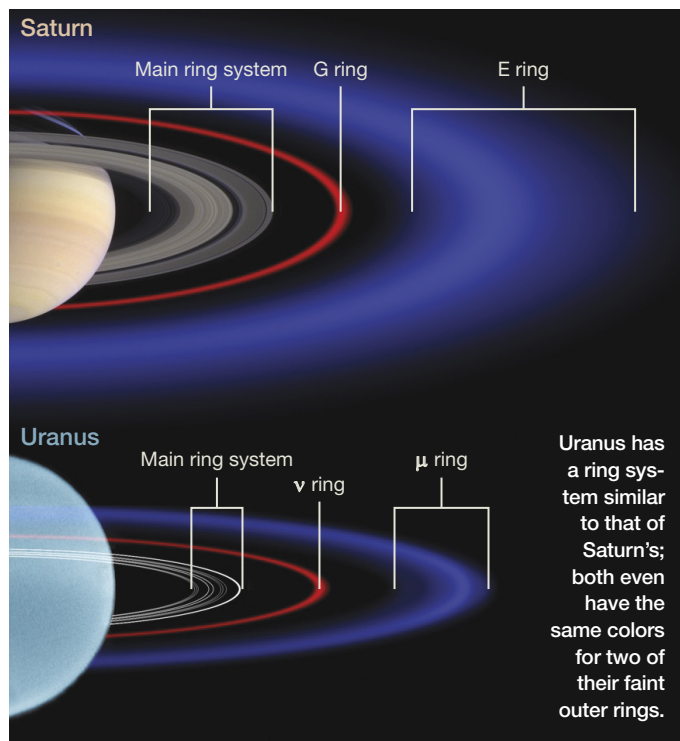
Read more at skyandtelescope.org/Proba3

Rubin's 11,000 Asteroids

The International Astronomical Union's Minor Planet Center (MPC) has confirmed the discovery of more than 11,000 new asteroids in 1½ months of Rubin's test-run observations. While most asteroids are in the main belt, new finds include 380 trans-Neptunian objects as well as 33 near-Earth objects. In all, the MPC submission included about 1 million individual observations tracking about 90,000 objects, of which some 80,000 were already known. "The significance of this is that Rubin is just starting," says Mario Jurić (University of Washington), leader of Rubin's solar system team. Currently, we know of 1.4 million asteroids in our solar system. Rubin is expected to bump that number by fivefold in less than a decade, well into the 6 million range. "So this is a 'It's here, it's working, it's coming' type of demonstration," Jurić adds.

■ JAVIER BARBUZANO

Read more at skyandtelescope.org/11000asteroids



Visualizing the Great Moon Hoax

Trace John Herschel's fantastic lunar "discoveries."

ON AUGUST 25, 1835, *The New York Sun* newspaper began publishing a series of articles on the fantastic lunar discoveries made by English astronomer John Herschel at the Cape of Good Hope. Andrew Grant, one of Herschel's assistants, transmitted these incredible sightings to the paper, which included all manner of geological wonders as well as lunar flora and fauna. The whole narrative was, of course, fictitious — Richard Adams Locke, a writer at the *Sun*, took advantage of public interest in life on other worlds at the time by creating an elaborate hoax to boost the paper's circulation. While Herschel was real, his assistants and the powerful telescope he was supposed to have used for these discoveries were fictitious. Let's explore a few highlights of the true lunar features in and around which these visual charades occurred.

According to Locke, on the night of January 10, 1835, while surveying the lunar highlands midway between Mare Fecunditatis and Mare Nectaris, Herschel and his assistants encountered an oval valley surrounded by "hills, red as the purest vermillion." At the foothills, the astronomers "beheld continuous herds of brown quadrupeds" — creatures similar to Earth's bison — as well as blue unicorn-like goats. Water birds resembling cranes and pelicans fished by a river running through the valley, while on one of these islands they glimpsed a "strange amphibious creature, of a spherical form, which rolled with great velocity across the pebbly beach."

Locke continued that, on the evening

▲ TRAIL OF DISCOVERY This shows the locations of the wondrous findings mentioned in the 1835 hoax: Lacus Mortis (A), Endymion (B), Cleomedes (C), Mare Crisium (D), Langrenus (E), Bullialdus (F), and Rupes Altai (G).

of January 13th, Herschel found the area between Lacus Mortis (labeled A above) and Endymion (B) "fertile to excess," with "not less than twelve luxuriant forests, divided by open plains . . . like those of North America." Endymion itself harbored roughly 38 species of forest trees, nine of mammals, and five of egg-laying animals.

Farther south, the "immense annular mountain" Cleomedes (C) contained three extinct volcanic craters. The whole valley around them was densely crowded with woods, though they detected "no living creature, except a large white bird, resembling the stork." On a verdant island in an eastern bay of an enormous lake (likely Mare Crisium, D), Herschel's group allegedly saw "battlemented and spired" shorelines glittering with unattainable sapphires. They also detected lunar palm trees with large crimson flowers, fruit-laden melon trees, herds of miniature zebra, long-tailed birds, and along the shore, multitudes of univalve shellfish.

Just south of the "lake" Langrenus (E), on a plain surrounded by lofty hills riddled with veins of gold, Herschel purportedly saw not only horned, giraffe-like quadrupeds and Earth-like sheep, but bat-winged creatures resembling human beings — as they could walk

"both erect and dignified."

Herschel (or rather, Locke) named

them *Vespertilio-homo*, or

man-bat, and the observers saw them engaged in conversation, appearing "innocent and happy."

On January 14th, Locke claimed that Herschel's group was examining a large, bright circle of hills close to the flaming marine volcano Bullialdus (F), when they spied snow-white crystalline hills bounding a green valley of "paradisical beauty and fertility." There, they saw more bat-like humanoids who spent "their happy hours in collecting various fruits in the woods, in eating, flying, bathing, and loitering about on the summits of precipices."

Around the new Moon of March, wrote Locke, Herschel trained his telescope onto a valley at the foot of the Altai Mountains (Rupes Altai, G), where they discovered a "very superior species" of the bat beings, who were "of infinitely greater personal beauty, and appeared in our eyes scarcely less lovely than the general representations of angels by the more imaginative schools of painters."

If you can, read Locke's 1859 work *The Moon Hoax; or A Discovery That the Moon has a Vast Population of Human Beings*. Several versions of it exist online.

■ Contributing Editor STEPHEN JAMES O'MEARA loves to share the visual wonders of the day and night skies.





SPAIN
Total Solar Eclipse - August 12, 2026

Wine, Wonder & Totality

- With Astronomer Bob Berman -

- 12th-Century Monastery & Vineyard
- 3 UNESCO World Heritage Cities
- Madrid - Toledo - Segovia - Avila
- Flamenco - Ham Carving - Star Party
- Spain's Clearest Eclipse Skies
- 5-Star JW Marriott & Abadia Retuerta



EGYPT
Longest Eclipse of the Century - Aug 2, 2027

The Nile & Totality

- With Astronomer Bob Berman -

- 6 Min 23 Sec of Totality
- Private Luxury Nile Dahabiya Cruise
- Pyramids - Sphinx - Egyptian Museum
- Temples of Kom Ombo - Edfu - Esna
- Cloudless Saharan Skies
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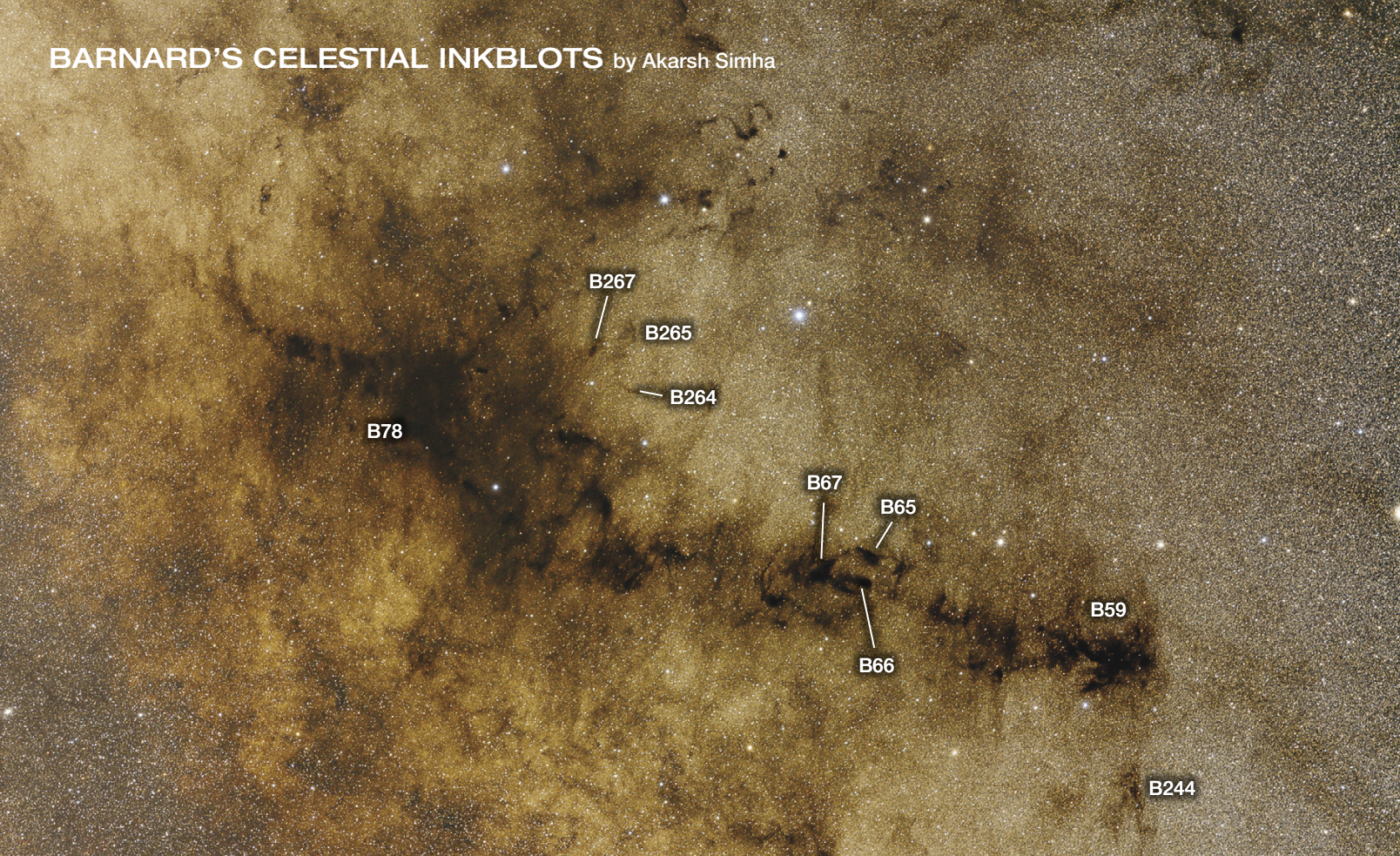


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Dark Clouds of the Summer Milky Way

Grab your binoculars and track down these elusive, velvety “voids” in the sky.

“**H**ere truly is a hole in the sky!” William Herschel exclaimed to his sister, Caroline, after he stumbled upon a dark nebula in Scorpius more than 240 years ago. Although we understand the nature of Herschel’s new discovery much better today, I can still relate to Herschel’s excitement when I encounter one of these “holes” while scanning the Milky Way with my 25×100 binoculars. Unlike most other deep-sky objects, I find dark nebulae are rendered better by binoculars than with my large-aperture telescopes. Binoculars offer wide fields of view, and the ease of toting them around to the dark, countryside skies essential for good views of dark nebulae make them ideal companions on hiking and camping trips.

It was perhaps the 19th-century Jesuit astronomer Angelo Secchi (*S&T*: Feb. 2025, p. 26) of the Roman College Observatory who first suggested that the dark voids observed by

Herschel were not true voids but clouds of opaque gas. Secchi had discovered one such region himself in Sagittarius in 1857. Now known as the Ink Spot, it’s located about 2½° north of 3.0-magnitude Gamma² (γ²) Sagittarii, or Alnasl. At the turn of the 20th century, a debate on the true nature of these objects ensued in the astronomical community. American astronomer Edward Emerson Barnard was the first to catalog these clouds of obscuring dust, and in 1919 he pub-

▲ **STARLESS PATCHES IN THE HEAVENS** This complex of Barnard dark nebulae, composed of opaque clouds designated B59, B65, B66, B67, and B78, is nicknamed the Pipe Nebula because of its distinctive shape. Unlike bright emission and reflection nebulae, dark nebulae are interstellar clouds of obscuring gas and dust. Their cosmic silhouettes are visible because they’re set against the rich star fields of the Milky Way. Many of these Barnard nebulae are likely sites of future star formation. The surrounding area is sprinkled with the smaller dark clouds B244, B264, B265, and B267. Unless noted, north is up in all images.

► **A PAIR OF GHOSTLY INKBLOTS** Located along the northern edge of M24, the Small Sagittarius Star Cloud, B92 (right) and B93 (left) both lie roughly 10,000 light-years away. The two objects, which have an angular separation of approximately 15', are also referred to as the Black Hole Nebula and the Black Spot Nebula, respectively. The American astronomer Edward Emerson Barnard first cataloged them in 1913.

lished a photographic survey of 182 dark nebulae bearing the B designation we know today (the Ink Spot is listed as B86). Barnard's work brought this class of objects to the attention of researchers. His catalog was posthumously expanded to include some 350 nebulae that he had observed. Barnard had left open the possibility that some of these objects were perhaps voids, but today we know that almost all of them are dark clouds of obscuring matter. Dark patches that may be a void are rare, and the only one that I happen to know is in NGC 1999 in Orion (see *S&T*: Feb. 2022, p. 57).

Interstellar dust is strewn throughout the Milky Way, and drawing boundaries to assign catalog numbers to portions of it seems like a challenging endeavor. This is mirrored in my observing. Because our eyes and the various camera sensors perceive shadings of darkness differently, I'm frequently unable to reconcile what I see in my binoculars with the outlines of dark regions plotted on my copy of the *interstellarum Deep Sky Atlas*. Sometimes, the nebulae appear visually smaller than the cataloged area; other times they lie amid a larger, uncharted region of dark nebulousity. They also frequently exhibit a mottled appearance with differing shades of darkness. They can be visually underwhelming at times, and other times instead they're striking. Having no prior guess of what I'll see adds to the fun of going after these dark clouds!

Their visibility is very sensitive to light pollution — a bright, suburban (Bortle 6) sky background can blend into a dark nebula, making it difficult or impossible to see. Even a small telescope in a rural, transparent (Bortle 3) sky will often outperform a large-aperture telescope in a suburban setting. A technique I use to help ferret out dark nebulae is to compare different parts of the field of view by scanning my eyes across it and trying to pick up subtle changes in the sky background brightness. Then, I move the instrument a bit to see if the location where I'd detected the subtle change moves within the field.

No matter what your instrument, there are plenty of Barnard clouds you can enjoy. Smaller binoculars like 10×50s offer wide views and are suitable for snagging large nebulae, whereas my 25×100s, with higher light-gathering power and magnification, are ideal for spotting smaller clouds. A more optimal setup would be binoculars with changeable eyepieces so you can obtain a range of exit pupils up to 7 millimeters, the typical diameter of a dilated human pupil. Smaller exit pupils will help reveal tiny nebulae, while maximum exit pupils emphasize the starkest difference in surface brightness. Optimize your setup for contrast, baffling your binocular or telescope if necessary, and throwing a towel or hood over your head to block out stray light.

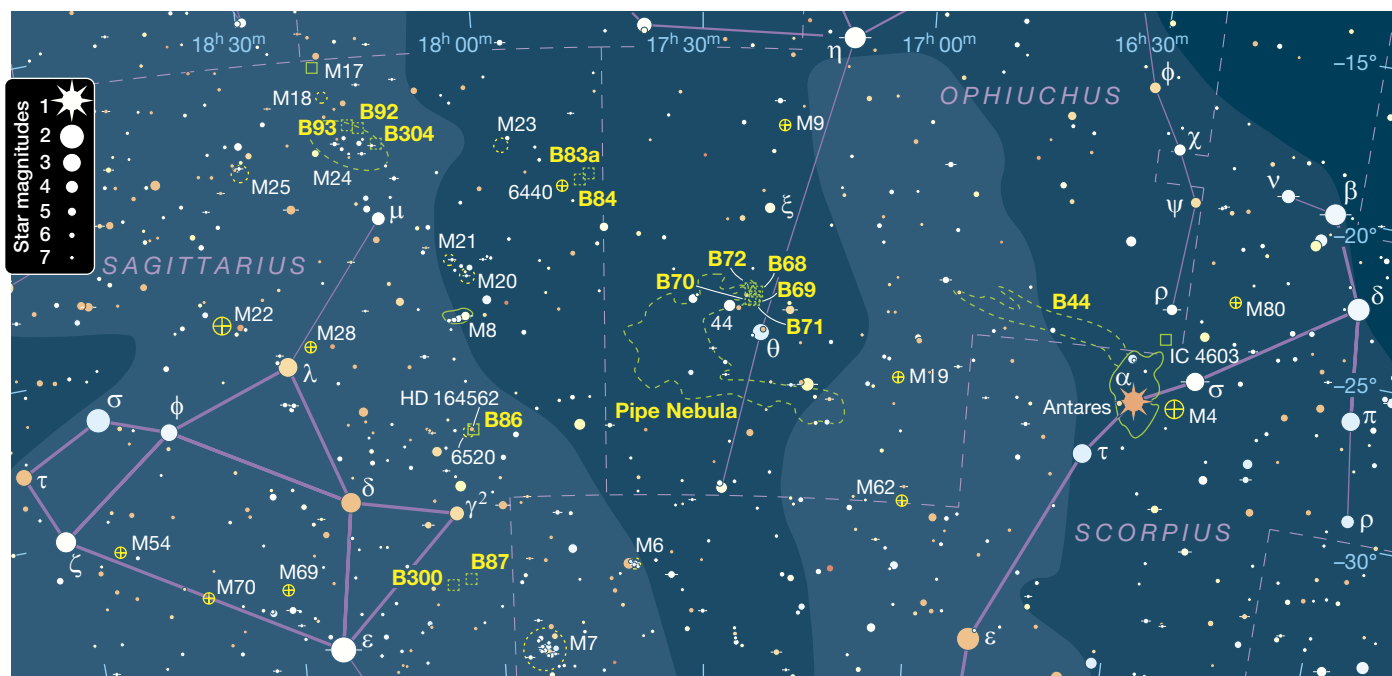


Into the Centaur's Dusky Mists

Let's begin our tour in the constellation Sagittarius, the Archer. The region around M24, the Small Sagittarius Star Cloud, offers an excellent binocular experience. From a moderately dark sky, M24 is visible as a naked-eye, hazy patch about 3° north-northeast of 3.8-magnitude Mu (μ) Sagittarii. Lying on its northwestern fringes are two inky nebulae: **B92** and **B93**. I've observed the pair even from a light-polluted suburban sky, but your success may depend on how attuned

What are Dark Nebulae Made of?

In addition to the immense clouds of molecular hydrogen that pervade the Milky Way, there are also vast swaths of dust grains made of heavier elements produced in previous generations of stars. They're believed to be made up of carbonaceous material or silicates coated with water, methane, and ammonia ices. These tiny motes, estimated to be a thousandth the width of a human hair, absorb and scatter light from background stars, resulting in the clouds appearing as opaque, dark patches. Infrared and radio waves can penetrate the dusty veil to reveal the hidden stars, thus confirming Angelo Secchi's suspicion. The dust clouds are colder spots in the interstellar medium, having temperatures around 10 to 20 kelvin. Their lower temperature makes them susceptible to the compressive action of gravity, causing pockets in these clouds to collapse and form stars. Dark nebulae are thus sites of present, or perhaps eventual, star formation.



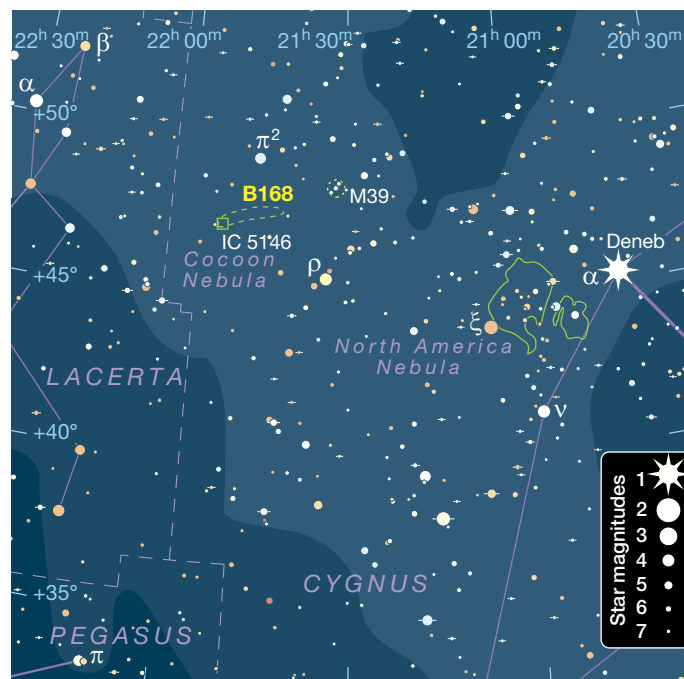
you are to looking for subtle changes of brightness in the field. B93, the easternmost of the pair, appeared in my 25×100 binoculars as an elongated patch of darkness. B92 was similar but stouter compared to B93. On some occasions, I've noted a long forked tail of darkness designated **B304** stretching farther west and also a curved extension to the south, giving it a sickle-shaped appearance. There are several other dark patches around M24, notably an elongated region southeast of it, but they're less intensely black than B92 and B93.

A more difficult but nevertheless rewarding nebula is **B84**, which lies about $\frac{1}{2}^\circ$ west-northwest of the globular cluster

▲ **NAVIGATING THE SAGITTARIUS-OPHIUCHUS STAR FIELDS** Use this finder chart as your celestial navigation tool. You can refer to the text for detailed star-hopping instructions. On all the charts, north is up and east is to the left. Stars are plotted down to magnitude 7.

NGC 6440. The cluster was easily visible in my 25×100s, and I've used it as a landmark to locate B84's subtle, elongated dark filament against a light-polluted suburban sky. Carefully studying it, I noted that a portion of B84 happens to have a higher contrast bowed toward the north. It took me different observing conditions to detect the nearly straight filament attached to the north and east of the bowed component. I picked up this segment while studying the region with my 12-inch telescope at a star party in southern India under a dark sky. In addition, **B83a**, 20' to the northwest, appeared with averted vision as a dark, condensed, somewhat elongated smudge. The entire nebula was rather subtle in my 12-inch, which showed the highest contrast in B83a and the segment of B84 northeast of the 8.8-magnitude star HD 161326.

Also in Sagittarius is **B87**, which Barnard nicknamed the Parrot's Head. You can find it below the Spout of the Teapot, about 2° south-southwest of Gamma² Sagittarii. At first, it appeared as a small dark region lying between a chain of three stars (HD 318954, HD 318955, HD 164773) and a single star (HD 164772), all 10th magnitude, but with more careful study, I was able to see the dark nebulosity circumscribe the lone star. This patch appeared as a dusky island in a star cloud, surrounded to the north, east, and west by a curved U-shaped wreath of dark nebulosity. **B300** appeared



▼ **SOARING WITH THE CELESTIAL SWAN** The constellation Cygnus is an easy-to-spot pattern anchored by 1.2-magnitude Alpha (α) Cygni, or Deneb. This region is home to bright emission nebulae and star clusters, including IC 5146, the Cocoon Nebula, and its associated dark cloud, B168, as well as the North America Nebula.



▲ **COMET-LIKE SMOKE TRAIL** When viewing IC 5146, the bright emission/reflection nebula and open cluster in Cygnus, the dark nebula B168 is an inseparable part of the scene, forming a dusky, sinuous tendril that surrounds IC 5146 and projects at least 2° west-northwestward. The Cocoon Nebula lies about 4,000 light-years away, and the 9.6-magnitude central star that illuminates it formed approximately 100,000 years ago.

as part of the eastern segment of this wreath. In images, the Parrot's Head shows two fine filaments extending southeast from it, which I didn't note visually — perhaps you will!

The Celestial Shield and Swan

About 15° north-northeast of the Teapot lies the constellation Scutum, the Shield. The Scutum Star Cloud is a wonderful sight through wide-field instruments. Anchored by the beautiful open star cluster M11 (also known as the Wild Duck Cluster) is a sprinkling of dark nebulae that appears like a smiley face! The smiling mouth lies north-northeast of M11, and the two eyes lie to the south and southeast. The southeastern eye corresponds to **B115** in Barnard's catalog, the southern eye to **B112**, and the mouth to **B320** and parts of **B111** combined. This is an example of how a visual impression can be rather different from the photographic catalog —

what we see in our binoculars doesn't necessarily correspond to how Barnard's objects are presented in the catalog, perhaps due to differing contrast perception and our brain's tendency to find familiar patterns.

Let's move next to Cygnus, the Swan. IC 5146, also known as the Cocoon Nebula, is a pretty challenging visual target even for large telescopes. However, it's surrounded by **B168** that extends west-northwest from the bright nebulosity as a long, dark lane. This 2° rift, nicknamed the Dark Cigar, is one of my favorite binocular targets, and I find it easier to see than the Cocoon Nebula. I first spotted it from a remote, dark site in California's White Mountains, and that fabulous view is what triggered my interest in pursuing dark nebulae. I spied a thick, black filament running roughly northwest-southeast that displayed substantial mottling. At the rift's northwestern terminus I saw a chain of stars running per-



pendicular to it. Two additional parallel rifts of dark nebulosity appeared flanking the chain on either side. I roughly estimated the length of the darkest portion to be about 2° and the full length at 3° . At the 2025 Golden State Star Party in Northern California, I had another excellent view of B168 through Analog Sky 80-mm binoculars with 5-mm exit pupils. Here, I could see a larger, Y-shaped dark structure, the cigar being the stem of the Y.

Dark Markings on the Raptor's Wings

During one of my drives back home to the San Francisco Bay Area from Death Valley in California, I set up my 25×100 binoculars near Mammoth Lakes for a couple of hours to study dark nebulae in Aquila, the Eagle. The sky had excellent transparency at the time. In one of the regions I looked at, I found **B138** particularly striking. Wow, what an amazing nebula! Barnard nicknamed this inky, crescent shape the Black Lizard. You can find it about midway between the 3.4-magnitude stars Lambda (λ) Aquilae and Delta (δ)

▲ **DUSKY COSMIC MONOGRAM** The prominent dark nebulae B142 and B143 together form the famous Barnard's E Nebula.

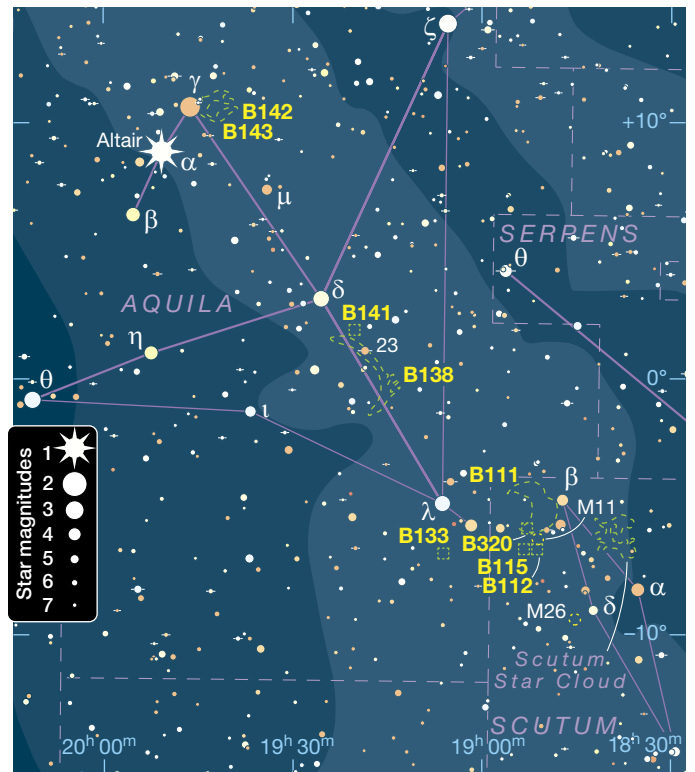
◀ **WHIMSICAL CARICATURE** The author imagines seeing a smiley face, formed by B112 and B115 (the eyes) as well as B320 and portions of B111 (the mouth). The open cluster M11 is left of center. South is up.



Aquila. I noted a curve starting around 5.3-magnitude 23 Aquilae, turning southwest at first and then turning south. To its west were a couple of bands of dark nebulosity of lower contrast, running north-south. At the southern terminus of the crescent, it appeared to flow into a “lake” of dark nebulosity. This crescent exhibited the highest contrast, so it’s hard to miss. That same night, I looked at several other nebulae in Aquila, but none made as strong an impression on me. For example, nearby **B141** appeared as a nondescript patch of more intense black nebulosity in a region of lighter nebulosity. It’s the contrasty, recognizable shapes, like B138, that get me really excited. The runner-up that night was **B133**, which appeared as a notably darker pencil of nebulosity within the western of two long filaments that head south and southeast

▲ **A SLITHERING SIGHT** Also known as Barnard 72 (B72), the Snake Nebula is a thin, $\frac{1}{2}^\circ$ -long sinuous dust lane that snakes out in front of the Milky Way star clouds near the northwestern edge of the Pipe Nebula’s bowl. Four adjacent small dark spots — B68, B69, B70, and B71 — are collectively called the Eggs. Situated 1.5° north-northeast of Theta (θ) Ophiuchi, the Snake Nebula lies about 650 light-years away and spans the angular width of the full Moon.

► **SKY DIVE WITH THE EAGLE** The +0.8-magnitude star Alpha (α) Aquilae, also called Altair, can serve as a jumping-off point for locating Barnard dark nebulae and star clusters discussed by the author. Its rich star fields are ideal for scanning with binoculars or small telescopes.



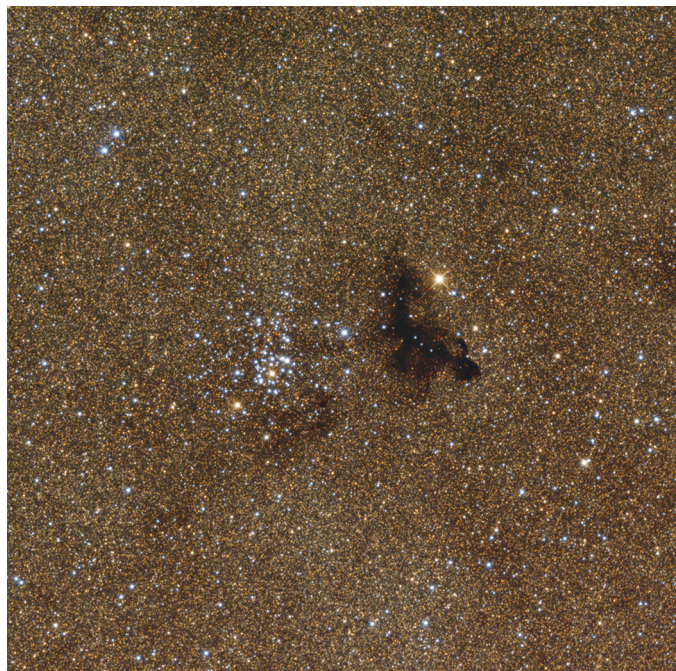
from Lambda Aquilae. I also spotted this patch, which lies about $1\frac{1}{2}^\circ$ south of the star, with my 25×100 binoculars from a brighter, suburban sky. Barnard described B133 as a “small, dark comet, with a tail curving to the north.”

Before leaving Aquila, I must mention the famous Barnard's E Nebula, comprising **B142** and **B143** (*S&T*: Oct. 2025, p. 58). Through my binoculars from a rural site, I noted its three-pronged pattern, with the northern and middle prongs (B143) being of high contrast, whereas the southern prong (B142) was less inky.

Venture Into the Serpent's Nest

The constellation Ophiuchus, the Serpent Bearer, harbors perhaps the best dark nebula known to observers in the Northern Hemisphere — the **Pipe Nebula**, a large silhouette against the rich Milky Way star field that's visible to the

► **RICH MILKY WAY TAPESTRY** B86, nicknamed the Ink Spot, spans about 6'. It's nestled between the 8th-magnitude open cluster NGC 6520 to the east and the 6.7-magnitude star HD 164562 to the northwest. They are ideal targets for binoculars or a small telescope under dark sky.



► **MOLECULAR CLOUD COMPLEX** This view shows the colorful region around 4.6-magnitude Rho (ρ) Ophiuchi (the bluish star lower left of center). B44 is visible as a thick, 5°-long dusky lane at left. The orange star and globular cluster at the bottom are +0.9-magnitude Alpha (α) Scorpii, or Antares, and M4, respectively. At a distance of about 460 light-years, the Rho Ophiuchi complex is one of the closest star-forming regions to our solar system.

naked eye and composed of B59, B65, B66, B67, and B78. Just north of it lies **B72**, which also bears the moniker the Snake Nebula (S&T: July 2014, p. 60). This dark cloud appears on deep-sky challenge lists, and it's certainly not easy to bag. You can find it about $\frac{3}{4}^\circ$ northwest of 4.1-magnitude 44 Ophiuchi. I first observed it with my 25×100s from the Anza-Borrego Desert in Southern California on a night when it was too windy to set up my telescope. A sizeable, low-contrast dark filament appeared to meander due north of the 6.7-magnitude star HD 157398. Its segment running east-southeast to west-northwest appeared to be thicker and more prominent.

B68 lies $\frac{1}{4}^\circ$ southwest of the Snake and showed higher contrast than B72. In fact, B68 (along with **B69**, **B70**, and **B71**) is part of a chain of four dark blotches (the Eggs) situated south and southwest of the Snake, three of which (B68, B69, and B70) I picked up with my binoculars on a later occasion. I also looked at the region with my 28-inch f/4.1 Dobsonian telescope at a 5.1-mm exit pupil. Perhaps you'd guess that the telescope made easy work of the Snake, but this was not the case. As I wrote in my notes, "B72 is very subtle. Only the ESE-WNW segment is distinct, but I can vaguely pick out the two north-south segments at its ends." When low contrast is the limiting factor, aperture seems to have little effect on detecting dark nebulae. However, it can help magnify detail — B68 showed raggedy, tapered edges in my 28-inch. The Eggs nickname is particularly apt since these dark nebulae are *Bok globules* — small, roundish regions of dense, dark nebulosity that are cosmic cocoons with young stars inside them ready to hatch. In fact, B68 is often used as an archetype of the class.

Completing the Tour

Circling back to Sagittarius, my favorite dark nebula in the sky might just be **B86**, the Ink Spot, or Secchi's "black hole." However, it's a difficult binocular object as it's tiny — I've glimpsed it as a subtle black smudge in my 25×100s, with the 7th-magnitude orange star HD 164562 touching its northwestern rim. The open cluster NGC 6520 is visible 6' to its southeast, and a larger dark region lies 20' to the north. Instead of binoculars, I would recommend a small telescope, which presents a beautiful composition along with the star cluster.

Finally, what about Herschel's hole in the sky? Research suggests that he was looking at the region immediately to the east of Rho (ρ) Ophiuchi and the reflection nebula IC 4603. In my 25×100s from a dark site, I noted some mottled dim nebulosity in that area while noting that it was devoid of stars. The dark nebula $2\frac{1}{2}^\circ$ southeast, **B44**, was visible in my binoculars, albeit with a low contrast. It, too, was heavily mottled throughout.

There are so many dark regions of the Milky Way to explore beyond the handful I've listed here. Their vast diversity in opacity and form is an enduring allure that's hard to resist. Good luck!

■ **AKARSH SIMHA** loses himself in the Milky Way through binoculars just as readily as he does in galaxy clusters through his telescope. He lives on the internet at <https://asimha.net>.

Barnard's Dark Clouds

Object	Constellation	Size	RA	Dec.
B92	Sagittarius	13' × 7'	18 ^h 15.6 ^m	−18° 14'
B93	Sagittarius	12' × 3'	18 ^h 16.9 ^m	−18° 04'
B304	Sagittarius	1° × 0.5°	18 ^h 13.3 ^m	−18° 43'
B84	Sagittarius	~30 × 20'	17 ^h 46.4 ^m	−20° 15'
B83a	Sagittarius	3' × 1.25'	17 ^h 45.3 ^m	−20° 00'
B87	Sagittarius	14' × 11'	18 ^h 04.2 ^m	−32° 30'
B300	Sagittarius	~38' × 20'	18 ^h 07.0 ^m	−32° 39'
B115	Scutum	3.5' × 2'	18 ^h 53.3 ^m	−06° 40'
B112	Scutum	10' × 6'	18 ^h 51.1 ^m	−06° 40'
B320	Scutum	15' × 15'	18 ^h 52.8 ^m	−05° 51'
B111	Scutum	~2° × 1.5°	18 ^h 50.6 ^m	−04° 57'
B168	Cygnus	~2° × 10'	21 ^h 53.3 ^m	+47° 16'
B138	Aquila	~3° × 1.3°	19 ^h 16.4 ^m	+00° 13'
B141	Aquila	~30'	19 ^h 20.2 ^m	+01° 54'
B133	Aquila	12' × 5'	19 ^h 06.2 ^m	−06° 54'
B142	Aquila	40' × 20'	19 ^h 39.7 ^m	+10° 31'
B143	Aquila	30' × 30'	19 ^h 41.4 ^m	+11° 00'
Pipe Nebula	Ophiuchus	~6.5° × 4.5°	17 ^h 24.4 ^m	−26° 47'
B72	Ophiuchus	35' × 15'	17 ^h 23.6 ^m	−23° 37'
B68	Ophiuchus	4'	17 ^h 22.6 ^m	−23° 47'
B69	Ophiuchus	3' × 2'	17 ^h 22.9 ^m	−23° 55'
B70	Ophiuchus	4' × 4'	17 ^h 23.5 ^m	−24° 02'
B71	Ophiuchus	1.5' × 1'	17 ^h 23.0 ^m	−24° 00'
B86	Sagittarius	6' × 4'	18 ^h 03.0 ^m	−27° 52'
B44	Ophiuchus	5° × 1°	16 ^h 40.6 ^m	−24° 05'

Angular sizes are from the author's visual estimates. 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. The objects' coordinates refer mainly to the central parts of the nebulae.

How One Year Changed Space Science in America

Skeletal budgets, grant cancellations, and workforce reductions dominated 2025. Will history repeat itself in 2026?

On Sunday, March 9, 2025, Allison (name changed to protect privacy) had a next-day meeting added to her calendar. As a program specialist at NASA, this wasn't too unusual; her days were busy shaping the agency's experiments and goals. But when she arrived to work the next day on the ninth floor of NASA Headquarters in Washington, DC, she found plainclothes guards gathered outside of a conference room. Her colleagues whispered among themselves, trying to guess what was happening.

The meeting was quick. Three NASA executives and a smattering of human resources staff informed Allison and a handful of other employees that they had 30 days left at the agency. Until the moment the words left their mouths, Allison, who had worked at NASA for decades, didn't believe it could happen.

"I was the kid whose dream was to make it to NASA," she says. "And I always imagined a different end to my time at the agency."

Allison was one of the first casualties of a large-scale "reduction in force" that would see more than 20% of NASA's civil workforce and an untold number of contractors leave in the first year under the second Trump administration. Combined with a tumultuous funding appropriations process that slashed then restored NASA's science budget, as well as widespread grant cancellations and delays for university scientists, 2025 was an unprecedented year for America's professional astronomy landscape. And as funding cycles began anew this spring, it appeared the process would repeat itself.

While 2025 brought bright spots — engineers finished

building NASA's Nancy Grace Roman Space Telescope early and within budget, and Firefly Aerospace carried 10 NASA science instruments to the Moon in the first fully successful commercial lunar landing (*S&T*: Jan. 2026, p. 34) — these achievements have largely been overshadowed by an environment of fear, frustration, and funding woes at the academic, federal, and international levels.

Some scientists, like Allison, have found themselves back at square one. As a child, "I had only dreamt of one place," she says: NASA. "I feel like I'm trying to decide what I'm going to be when I grow up again."

In Classrooms and Labs

Although NASA dominates our national space consciousness, the majority of the country's astronomers and planetary scientists aren't actually employed at the agency. That doesn't mean they escaped the turbulence of 2025.

Within the first 10 days of the second Trump administration, the Office of Management and Budget (OMB), which carries out the executive branch's priorities and releases federal funding, published a memorandum freezing all activities and spending related to federal grants until they could be reviewed for their alignment with the new administration's priorities. OMB quickly rescinded the memo, following an injunction by a federal judge and a lawsuit by more than 20 states. But it was an early signal that 2025 would not be a normal year for science, says Casey Dreier, chief of space policy at The Planetary Society, a nonprofit that promotes and advocates for space exploration.

Many non-federal researchers make their living through "soft money," or a combination of grants and contracts, rather than a salary. A federal grant freeze would have caused astronomers and planetary scientists to halt their research — and, in some cases, to start worrying about paying bills.

"This was a fundamentally different approach, where the immediate consequences to important research, institutional capability, [and] workforce just were not considered or cared for," says Dreier.

The first programs to truly face the axe were those related to what's called "diversity, equity, and inclusion," initiatives designed to nurture talented individuals from different backgrounds. On March 21st, the now-defunct Department of Government Efficiency, spearheaded by SpaceX founder Elon Musk, claimed that they had canceled \$420 million in NASA contracts, some of which appeared to fall under diversity initiatives. While the full itemized breakdown remained murky, one cut program fostered collaborations between undergraduate students from underrepresented backgrounds



▲ **2025 IN REVIEW** This timeline highlights some of the whiplash changes professional astronomers experienced in 2025. For more info, see aas.org/public-policy-updates.

**More than
20%**

**Reduction in
NASA's civil
workforce,
2025**

OMB announces
spending freeze

NSF freezes grant
reviews

OMB calls
for voluntary
resignations

Federal judge places
hold on OMB freeze,
groups sue Trump
administration

White House
rescinds OMB memo

January

February

March

April

May

June

July

August

September

October

November

December

2026

"Skinny budget"
released,
proposing 24% cut
to NASA's overall
budget and 47%
cut to science

UK pledges \$67M
to attract foreign
scientists

Royal Society
allots \$40M to
attract foreign
scientists

Trump withdraws
Isaacman's
nomination

Full PBR for NASA
and NSF released

ROSES call
for proposals
(5 months late)

Senate committee
rejects PBR in
initial budget bills
for NASA and NSF

House committee
suggests smaller cuts
to NASA and other
agencies

Current and former
NASA employees issue
Voyager Declaration,
protesting cuts

NASA solicits
voluntary
resignations and
retirements

Norway
pledges \$30M to
attract
foreign
scientists

Spain allots \$51M to
attract foreign scientists

Jared Isaacman sits for
Senate confirmation
hearing to be NASA
administrator

French university allots
\$17M to attract foreign
scientists

NSF begins terminating
grants that do not align
with the administration's
new priorities

Senate committee votes
to advance Isaacman's
nomination

Government shuts
down, sends most
civil servants and
contractors home

Senate
confirms
Isaacman
as NASA
adminis-
trator

Trump renominates
Isaacman for NASA
administrator

Government
reopened

Funding bills
passed for FY2026,
rejecting almost all
PBR cuts

DOGE social-media
post claims approx.
\$420M saved
by terminating
"unnecessary
contracts" at NASA

**"This was a
fundamentally
different approach,
where the immediate
consequences to
important research,
institutional capability,
[and] workforce just
were not considered
or cared for."**

—CASEY DREIER

and top NASA scientists, and another at the University of California, Santa Cruz, supported student research with the National Radio Astronomy Observatory.

“These programs are there to basically maximize all the talent that we have in our society,” says astrophysicist Enrico Ramirez-Ruiz (University of California, Santa Cruz). Eliminating them targeted those who were “most vulnerable” in astronomy, he says: students and early-career researchers.

Widespread grant cancellations and unspent funds across agencies like the National Institutes of Health and the National Oceanic and Atmospheric Administration (NOAA) on other topics also prompted NASA grant recipients to clamp down on hiring graduate students, postdoctoral researchers, and early-career scientists.

“Personally, it was bleak — like hiring at the level of the pandemic,” says early-career planetary scientist Michael Battalio (Yale University). Since the start of 2025, Battalio has applied to more than two dozen jobs and received zero offers. Ramirez-Ruiz says his own university received nearly 400 applications for astronomy and astrophysics graduate-student positions and was able to make only four offers (usually, funding would allow for 20).

In addition to the cancellation of existing grants, new ones stopped being as attainable. NASA’s Science Mission Directorate runs an annual solicitation for research proposals through a program known as Research Opportunities in Space and Earth Science (ROSES). “It’s not the only source of funding, but it’s by far the most important,” says planetary scientist Paul Byrne (Washington University in St. Louis). ROSES funds everything from instrument development and lab experiments to graduate students and soft-money scientists.

While the ROSES call historically goes out in February, the 2025 call didn’t occur until July. And the total funding pool was \$125 to \$150 million, covering 300 grants — a quarter of

the funding and a fifth of the grants of 2024. Even within that shrunken pool, the priorities were “whittled down” to lunar science, Martian science, and astrobiology, says Amanda Hendrix, CEO of the Planetary Science Institute. While these topics, which align with the Trump administration’s focus on the Moon to Mars program, are vital, they make it “extremely difficult” to conduct research on other topics, she says.

“There’s both less money and far more people trying to get some of that money,” explains planetary scientist Vicky Hamilton (Southwest Research Institute). “That just creates a tremendous amount of uncertainty in terms of our jobs, and it does cause people to contemplate whether or not they want to continue to work here.”

Indeed, as academic opportunities in America shrank, some blossomed abroad. European governments allocated hundreds of millions of dollars to attracting American talent, and Canada pledged more than \$1 billion. “I think it’s fairly embarrassing to have scientists in the U.S. leaving to go live in Europe and elsewhere, because the opportunities here are drying up,” says Hendrix.

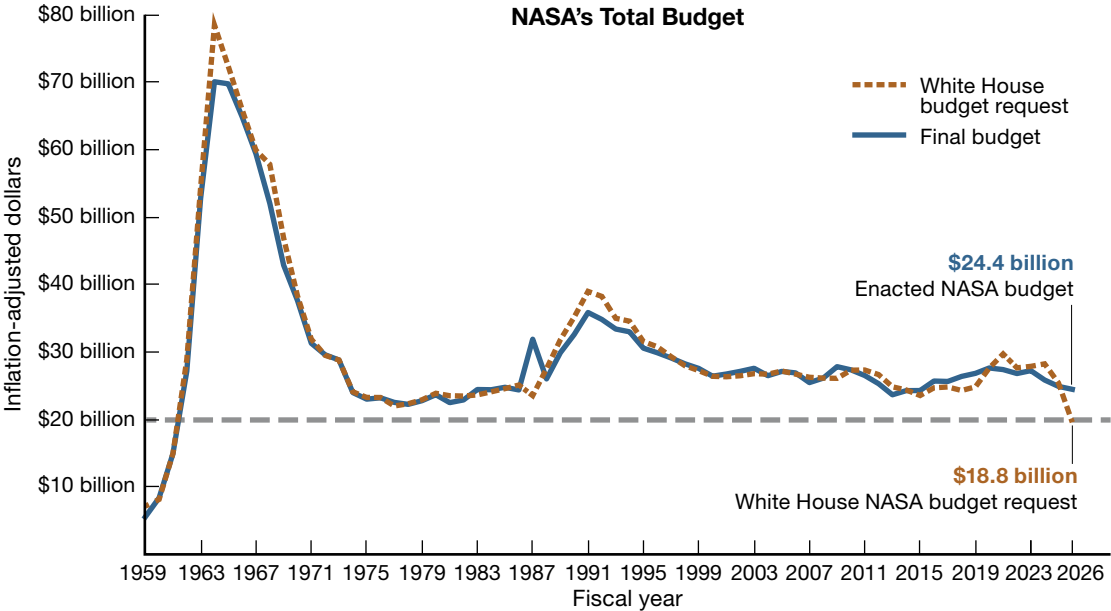
Multiple scientists interviewed for this story had colleagues who had made the leap. It’s “an exodus of the most talented individuals,” says Ramirez-Ruiz.

But with international positions still finite, many scientists have been contemplating leaving the field entirely — or, for students, not entering astronomy to begin with. “It’s hard to advise [students] on what to do,” says Hendrix. “It’s just a really rough time to be coming into this field.”

Shown the Door

For the first 50 weeks of 2025, the world’s largest space agency mirrored a boat without a rudder. The government did not confirm a NASA administrator until December, meaning

▶ A STEEP DROP The President’s requested budget (dashed line) has often diverged from the final budget passed by Congress (solid line). In the President’s proposed FY2026 budget, NASA faced its lowest funding level since 1961 — the start of human spaceflight. Note that the final 2026 budget level shown here doesn’t include an additional \$3 billion allocated by a separate bill in summer 2025 to support human space-flight efforts, bringing the total budget to \$27.5 billion.



BEATRIZ INGLESISS / S&T, SOURCE: THE PLANETARY SOCIETY, STATSBY SOURCE: THE PLANETARY SOCIETY / HTTPS://IS.GD/2026NASASUCCESS

the agency braved the waves of budget proposals and layoffs without an advocate in the executive branch.

On May 2nd, the White House released a “skinny budget” for NASA: the topline draft of the official President’s Budget Request (PBR) that outlined how the executive office envisioned the following year’s spending. The request proposed a 24% cut overall and a 47% cut to NASA’s science divisions — the lowest funding levels since 1961, adjusted for inflation.

Immediately, “everyone went into an absolute panic,” recalls Battalio. The proposed cuts were “extensive, random, and capricious.”

On May 30th, the full PBR for NASA became public. More than 40 missions were on the chopping block. That included projects in their “extended operations” phase — healthy spacecraft that have achieved their original science goals but are still producing results, such as the Chandra X-ray Observatory, the Fermi Gamma-ray Space Telescope, Juno at Jupiter, and New Horizons in the Kuiper Belt. Future missions like the Venus-bound DAVINCI and VERITAS were axed, and the near-built Nancy Grace Roman Space Telescope was funded at 42% of the previous PBR’s projection, jeopardizing an on-time launch. Major lunar projects like the Space Launch System, Orion, and the lunar Gateway space station were to be wound down.

The budget cuts “seemed to have had no input from anyone beyond the Office of Management and Budget. They certainly didn’t have input from NASA itself,” says Dreier. “It was a discordant and non-strategic approach.”

Furthermore, the PBR for the National Science Foundation proposed a 40% cut to the Nobel Prize-winning Laser Interferometer Gravitational-Wave Observatory (LIGO) and suggested that it shutter one of its two sites — an action that would cripple the project’s ability to detect sources and locate them on the sky. And the budget request for NOAA called for eliminating the Traffic Coordination System for Space

(TRACSS), a program that President Trump jump-started during his first term to prevent satellite collisions.

Work under such strangled budgets was “almost unplanable” for science directorate leaders, says Pamela Melroy, a former astronaut and deputy administrator of NASA. The budget would barely cover core infrastructure, she explains: salaries, facilities, computer systems, and electricity bills.

The shock quickly galvanized the scientific community, initiating one of the largest bouts of advocacy in NASA’s history. Thousands of scientists contacted their congresspeople, attended rallies, or spoke on the Hill about the value of the astronomical sciences.

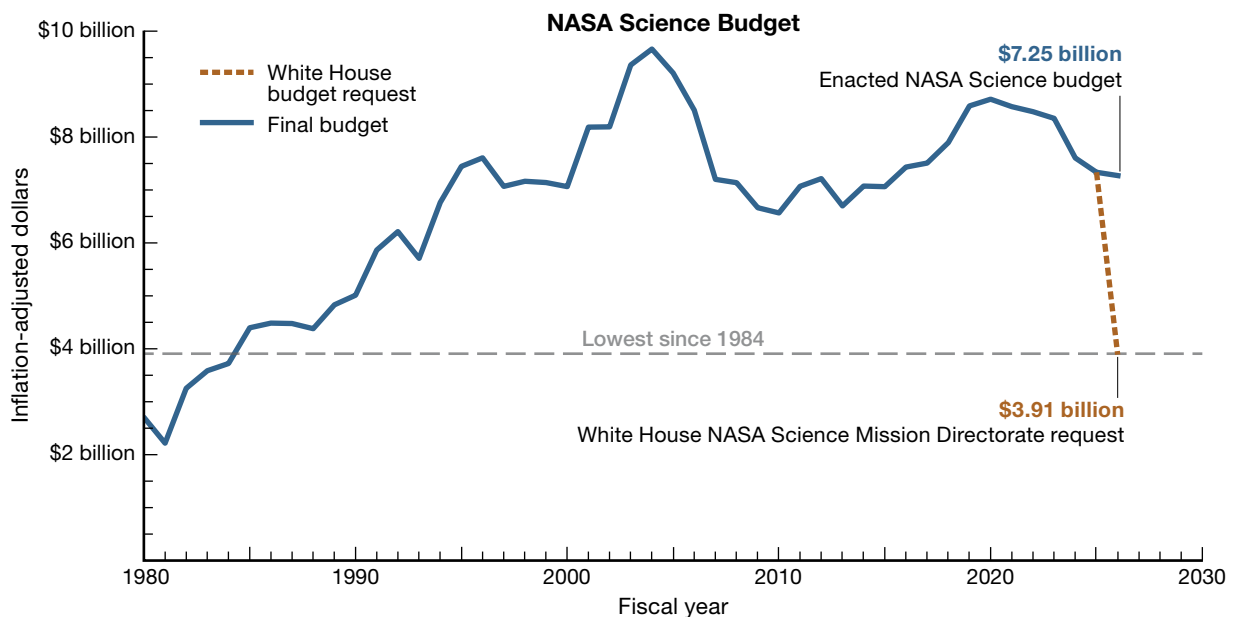
That pressure was definitely felt in the halls of Congress, says Representative George Whitesides, a member of the Science, Space, and Technology committee and a former NASA Chief of Staff. He pointed to the Planetary Society’s efforts in particular. “People do listen to their constituents,” he says, “and having that grassroots advocacy was really important.”

Indeed, after months of back-and-forth budget proposals from the House and Senate, Congress passed an appropriations bill for NASA in January 2026 that nearly completely rejected the White House’s cuts. The \$24.4 billion NASA allotment represented only a 1.8% topline budget cut, with a 1% cut to science — enough money to save nearly every endangered mission. Combined with additional funds for human space exploration set aside in the “One Big Beautiful Bill” Act passed in July, the 2026 year offered NASA some \$27.5 billion — its largest coffer since 1998, adjusted for inflation. The NSF and NOAA budgets funded LIGO and TRACSS, respectively.

“Congress made a pretty strong statement when they restored all of that funding,” says physicist David Reitze (California Institute of Technology), the executive director of the LIGO Laboratory. But in many ways, he says, the damage had already been done. Scientists like him had had to

► THE CLIFF

The White House’s proposed budget for fiscal year 2026 would have cut funding to NASA’s science divisions by 47%. Advocacy efforts almost entirely staved off the cuts, but as of press time the White House had suggested similar gutting for FY2027.



devote significant time in 2025 to ensuring the future of their missions, rather than conducting research. “Science is hard. Fundamentally, this just makes it much harder,” says Reitze.

Interim funding restrictions also had lingering effects. The OMB directed NASA to prematurely align its mission spending with the PBR — even though Congress’s final appropriations decision, not the White House’s initial request, determines the budget. In her decades at the agency, Allison had “never seen anything like that happen.” The concept is “fundamentally antithetical to the way it works,” adds Whitesides. Missions stalled their development accordingly.

While monetary cuts to the agency were eventually restored, other cuts weren’t so easy to reverse: those to NASA’s workforce.

In June 2025, concurrent with budget negotiations, NASA issued a call for civil servants to leave the agency voluntarily. Management launched initiatives such as a deferred resignation program and voluntary early retirement, which provided payments through January 2026. Nearly 4,000 employees took the offer — roughly 20% of the agency’s civil servant workforce. Meanwhile, an untracked number of contract workers, who traditionally constitute 75% to 80% of NASA’s overall workforce, had their contracts terminated or not renewed.

While the large majority of NASA departures were technically voluntary, employees were often made to feel like they had no choice, says astronomer Rose Ferreira, who was terminated from NASA while in a transitional role between contractor and civil servant.

“You can’t fight it, because there’s no point,” she says. “You count your losses, and you go.” *The Washington Post* reported that NASA employees were told they could be reassigned, transferred, or denied severance benefits if they did not resign or retire.

In July 2025, some 300 current and former NASA employees signed a document titled “The Voyager Declaration” protesting the funding and workforce cuts, which they claimed would “jeopardize NASA’s core mission.”

And casualties have happened. One is the Advanced X-ray

As American missions came under the knife, so too did American contributions to international missions.

Imaging Satellite, a proposed successor to Chandra that the project leader says “fell victim to the programmatic chaos of 2025” — not least when more than 20 project members retired or resigned. The prolonged period of upheavals forced the team to submit a concept report that didn’t meet known cost and schedule requirements in early 2026. NASA then disqualified the project from further consideration.

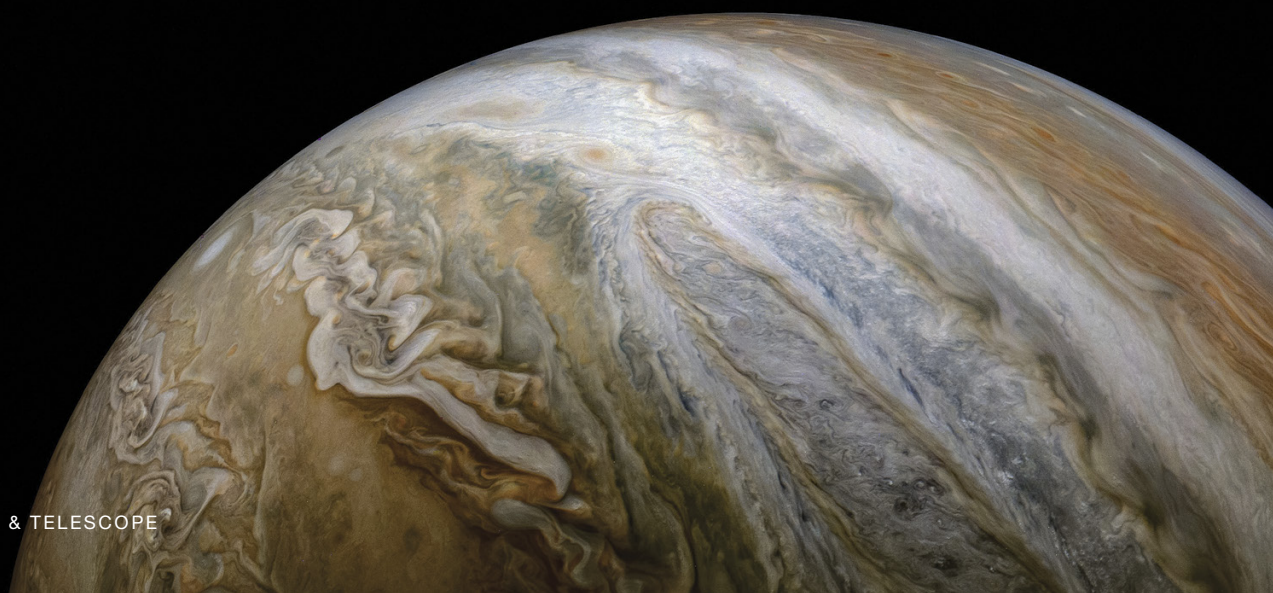
As of early 2026, the agency has shown signs of re-hiring: a new “NASA Force” aims to recruit top engineers to support NASA’s “exploration, research, and advanced technology priorities.” Billionaire and private astronaut Jared Isaacman, finally confirmed as administrator in December, has voiced support for research and the staff needed to conduct it.

Though the hirings are welcome, the sudden reversal has triggered reproach. “So let me get this straight: Everybody needs to leave, and now we need to rehire them?” says Melroy. She ties the havoc to the long stretch without an administrator at the agency’s helm, leaving leaders adrift. “Essentially, NASA was just swept up in the broader actions across the federal government, whether they made sense or not — and they clearly didn’t make sense.”

In that vein, some NASA employees and analysts say the most damaging losses aren’t to finances or personnel, but to trust. Daily life for remaining employees became strained with a 43-day government shutdown that furloughed 85% of the workforce. Ongoing travel restrictions have forced people to cancel their attendance at science conferences. Maryland’s Goddard Space Flight Center has closed access to its library, gym, a cafeteria, and vending machines. Even potted plants in NASA Headquarters have been removed because the government didn’t want to spend resources watering them.

Advisory groups, which provide input to NASA on scientists’ priorities, have been disbanded. Public webpages

JUPITER’S SPLENDOR This composite image combines data from the tenth flyby of NASA’s Juno mission to Jupiter, taken in 2017. Juno has given us unique insights into the giant planet’s interior, as well as stunning views of its cloudtops and moons. Juno was one of dozens of missions on the chopping block in the White House’s proposed NASA budget.



disappeared. And sources say employees have become scared to send any emails or messages that could be construed as critical of the government.

"It's subtle, and it's not reflected in the budget discussions," but there used to be "a really healthy and high level of trust between leadership and staff," says David Grinspoon, who in October was terminated from his role as NASA's senior scientist for astrobiology strategy. The year's events have broken trust in a way that "I don't see being easily fixed, just if we have a better budget year."

The World Stage

Changes to the U.S. astronomy landscape extended beyond the country's borders.

As American missions came under the knife, so too did American contributions to international missions, such as the gravitational-wave-hunting Laser Interferometer Space Antenna and the ExoMars Rosalind Franklin rover. While the final congressional budget restored financing for both, the long-beleaguered Mars Sample Return mission was not so lucky. The decision to scrap the \$7 billion mission and allocate only \$110 million to "Mars Future Missions" has stranded the European Space Agency (ESA) with the orbiter it designed to ferry back the Martian samples that the NASA robot was supposed to pick up from the surface. The orbiter alone has cost the Europeans hundreds of millions of dollars.

"It certainly casts the United States, to our allies in space, as profoundly unreliable," says Dreier. As a consequence, ESA has chosen to reassign the construction of a radar instrument on its upcoming Envision mission to Venus from NASA's JPL to European sources — a loss of at least \$300 million to the American space industry. "I don't blame them — I wouldn't trust us either, at this point," says Dreier.

Federal travel restrictions have also affected science diplomacy. While still at the agency, Grinspoon says he had to cancel multiple international trips at the last minute to events where he was supposed to represent the agency. It "embarrass[ed] myself and NASA and the United States." Conversely, international scientists have been hesitant to travel to the U.S. for conferences and collaborations due to fears about crossing the border, Byrne says.

Still, one of the largest changes to America's role in astronomy and space exploration has been how the nation acquires or shuns talent. The U.S. used to be "tapping into the entire world when it comes to the most talented individuals," says Ramirez-Ruiz. Changes to immigration and border policies, Visa restrictions, and a ban on Chinese nationals working as contractors or students on NASA projects have narrowed the country's pool of scientists and engineers.

Researchers "appreciate that what is happening is political in nature, and not us as individual scientists telling our [international] colleagues to go jump in a lake," says Hamilton. But that "doesn't make it any easier for them when they have their own priorities that depend on us living up to our commitments, and then we don't."



▲ **ADVOCACY** Leaders from 20 national science, education, and space organizations joined with people from across the country on October 6, 2025, for the Save NASA Science Day of Action, urging Congress to protect NASA and NSF science budgets.

What Comes Next

Will hardship continue in 2026?

Scientists have been "preparing themselves that this is going to be how it is as long as this administration is in power," says Byrne. But many are cautiously optimistic that "whatever combination [of activism and politics] succeeded last time will succeed again," says Battalio.

The top worries are largely financial: that the 2027 PBR (released in April) looks much like the 2026 one, that the OMB will refuse to spend congressionally allocated funds, and that belt-tightening has stalled the development of new, ambitious missions beyond Roman — all while China ramps up its space funding.

At least for 2026, the systems of pushback among scientists, advocacy groups, the public, and Congress are in place. And researchers are more aware than ever of how the government and science intertwine.

"I think a lot of scientists were born and grew up in a world where public support for their activities was taken for granted," says Dreier. Now, they face a "critical moment," he says: defending their own profession.

For the individuals already lost, the future remains unclear. With NASA hiring again, would scientists like Allison, Ferreira, and Grinspoon return?

Not yet, they say. As he left the agency, Grinspoon came to realize that "I'm really sad to be leaving such an exciting place to work," he says. And yet, "I'm really excited to be leaving such a sad place to work."

■ **HANNAH RICHTER** is a freelance Earth, space, and science policy journalist based in Washington, DC. Her work has appeared in *Science*, *Nature*, *Scientific American*, *Popular Mechanics*, and *WIRED*, among others.

Narrowband Imaging with Color Cameras

Dual-bandpass filters open up new opportunities
for astrophotographers with color detectors.

TWO FILTERS, FOUR WAVELENGTHS Tricolor narrowband images like this colorful shot of NGC 7000, the North America Nebula, and IC 5067, the Pelican Nebula, used to be beyond the scope of astrophotographers using color detectors. But the growing popularity of dual-passband filters extends the capability of photographing these bright emission nebulae with color sensors. Ron Brecher explains how to combine images from these filters using the Hubble Palette (used above) and other narrowband color combinations. This image was captured through a Sky-Watcher Esprit 70 EDX refractor and QHY367C Pro camera equipped with Optolong L-Synergy and L-eXtreme filters.

Color cameras have come a long way in the last decade, particularly for use in deep-sky astrophotography. Until quite recently, they were seen as inferior to shooting with a monochrome camera and individual filters due to the color detector being subdivided into a grid of 25% red, 50% green, and 25% blue pixels that require interpolation to convert the signal into a color image. Additionally, color-camera users faced limitations as compared to pairing a monochrome sensor with filters, particularly if they are interested in targeting nebulae at specific wavelengths. The reality today is that with some creative choices of currently available filters paired with modern image-processing tools, color-camera users can capture gorgeous images of the night sky in both natural light and narrowband wavelengths.

Dual-Bandpass Filters

Narrowband imaging refers to photographing specific wavelengths in the visible spectrum where ionized gases emit light. These include doubly ionized oxygen (O III) at 495.9 and 500.7 nanometers in the blue and green regions of the spectrum, and hydrogen-alpha (H α) at 656.3 nm and ionized sulfur (S II) at 672.4 nm, both of which reside in the red end of the visible spectrum. These filters reveal nebulae in our own Milky Way as well as in other galaxies while suppressing other wavelengths. Shooting these specific spectral regions requires special filters that pass only a small slice of the visible spectrum where each of these wavelengths reside, typically with passbands of between 3 and 7 nm wide. In addition to highlighting nebulosity, these filters also block many sources of artificial light pollution and even most moonlight, permitting urban imagers to record gorgeous pictures of supernova remnants, planetary nebulae, and emission nebulae.

The filter matrix covering the sensors in most color cameras — including one-shot-color astronomy cameras,

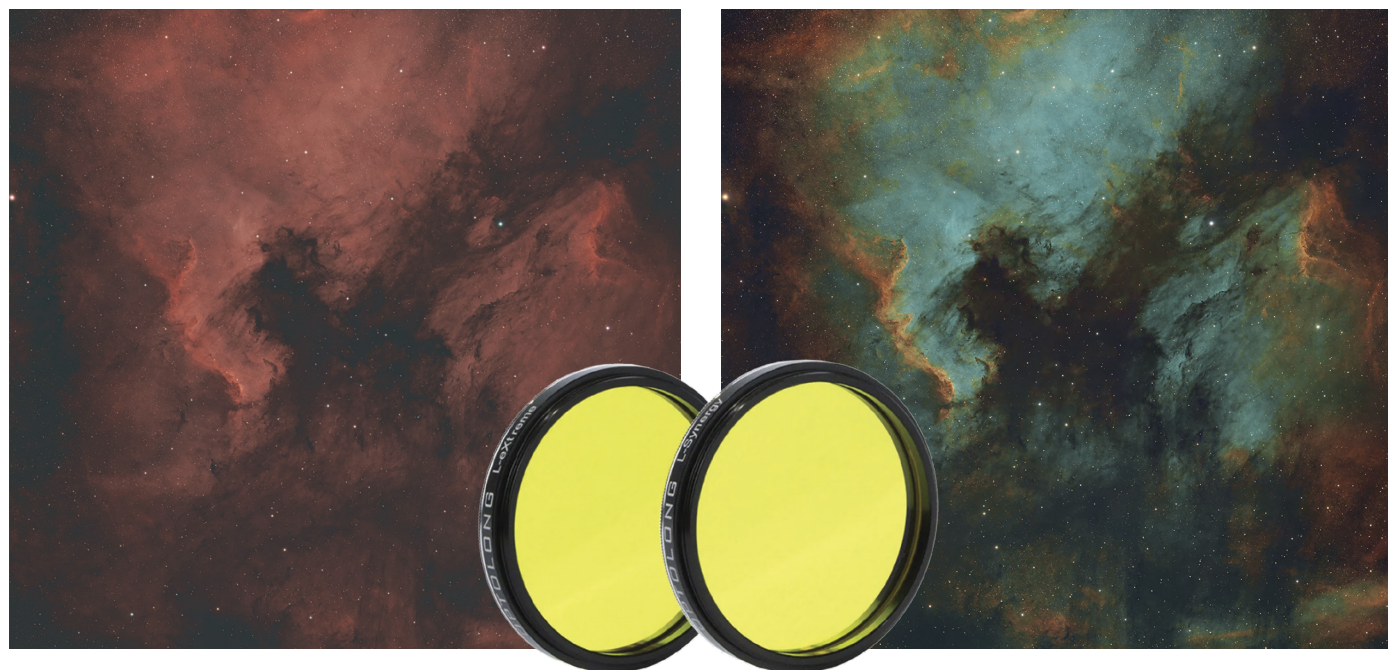
DSLRs, and mirrorless cameras — lets through a broad range of wavelengths spanning the visible spectrum from roughly 400 to 700 nm. In the past, narrowband imaging with color cameras was very inefficient. For each filter used, only one or two of the resulting color channels recorded useful data. For example, placing an H α filter in front of a color sensor would produce an image with information recorded in the red channel, while the blue and green were essentially blank. Several years ago, a few manufacturers began producing dual-band narrowband filters that are growing in popularity with urban color-camera imagers, offering a gateway into the realm of narrowband imaging that didn't waste signal.

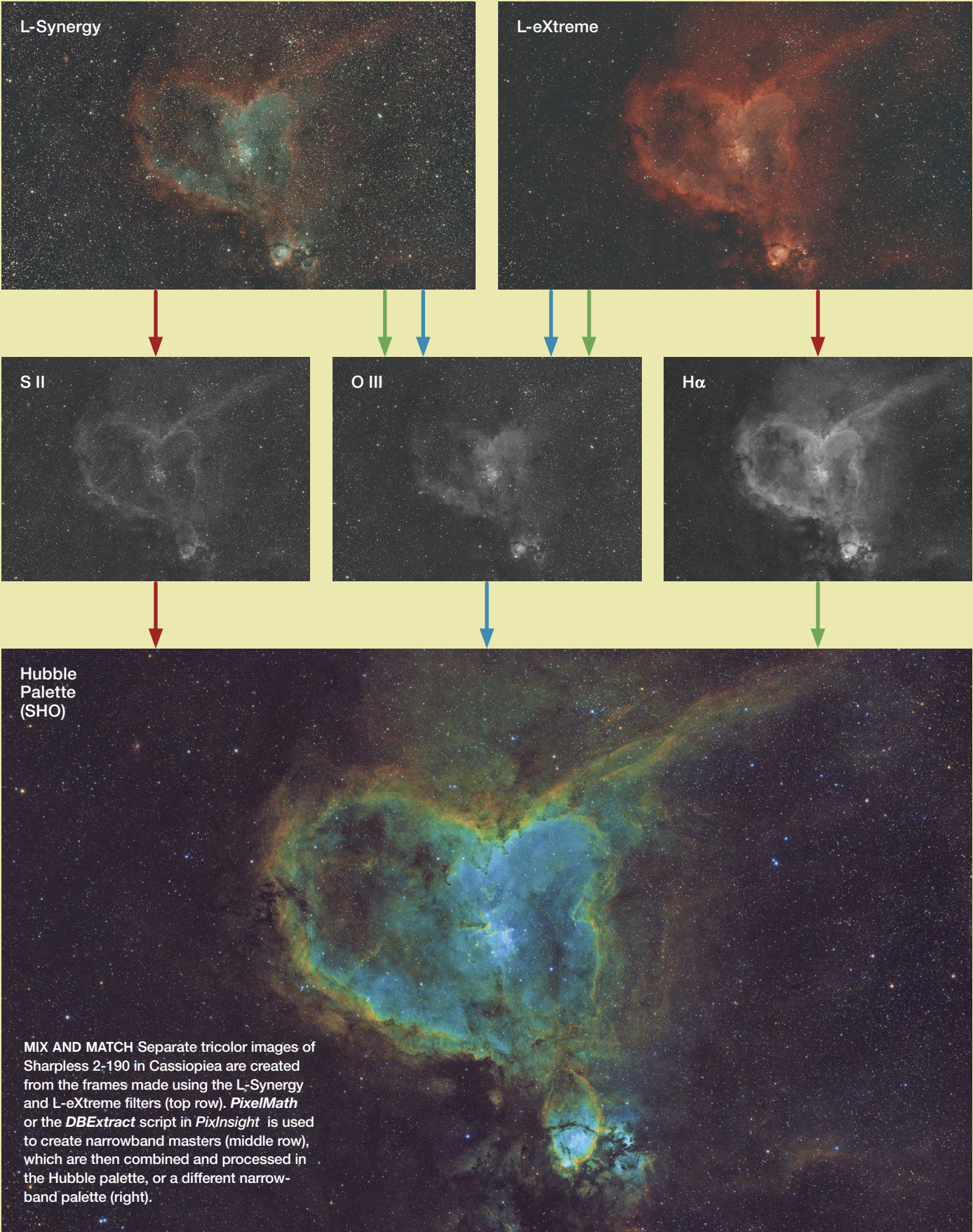
The first of these dual-bandpass filters transmit both O III and H α emissions, producing images that record O III in both the blue and green channels and H α mainly in the red. These images could then be used to enhance natural-color (or unfiltered) data made separately, and this technique quickly became popular among color-camera users. More recently, another dual-band filter became available that transmits both O III and S II (*S&T*: Feb. 2026, p. 70). By imaging through each of these filters, it's possible to combine the data to produce true tricolor narrowband images that rival those produced with monochrome cameras. Currently, Askar (www.sharpstar-optics.com) and Optolong (optolong.com) are the main vendors of these filters. I use Optolong's L-eXtreme filter, which passes O III and H α wavelengths, and its L-Synergy filter, which passes O III and S II.

Narrowband Palettes

Because narrowband filters pass such a small portion of the visible spectrum, any color image made with them alone is

▼ **DUAL PASSBAND** The L-eXtreme filter at left passes the light of doubly ionized oxygen (O III) and hydrogen-alpha (H α), while the L-Synergy shown at right transmits O III and ionized sulfur (S II).





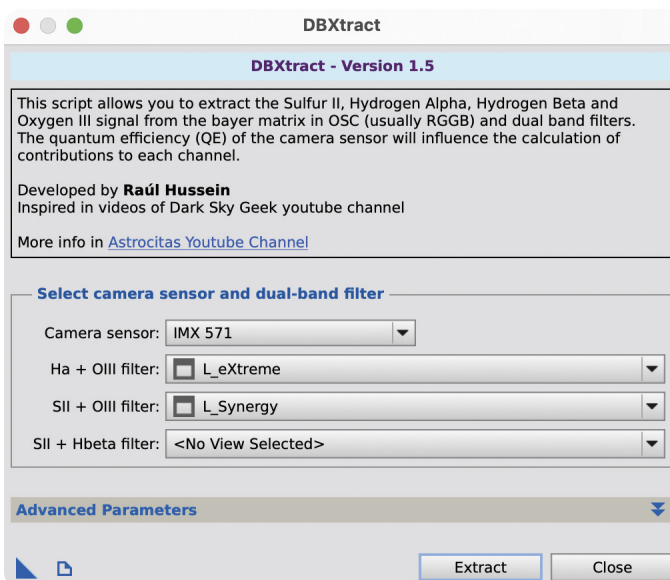
a false-color rendition. There's nothing wrong with this, as I've written previously (*S&T*: June 2022, p. 64). While the colors may not appear natural (approximating what the eye would see if a deep-sky object were bright enough), false-color pictures are aesthetically beautiful and scientifically useful, highlighting the different chemical elements present in a nebula.

To make a tricolor narrowband image, emissions from O III, H α , and S II are assigned to individual blue, green, and red color channels. The most commonly used combination is called the *Hubble Palette*, which designates the sulfur emission to red, H α to green, and O III to blue. Data specialists working with images recorded by the Hubble Space Telescope were the first to use this color scheme, which is also referred to as the SHO palette. Another popular narrowband palette combination based on images produced with the 3.6-meter Canada-France-Hawaii Telescope on Mauna Kea assigns H α as red, O III as green, and S II as blue, also referred to as the HOS palette. There are other more complex palette options, but these will get you started with the process.

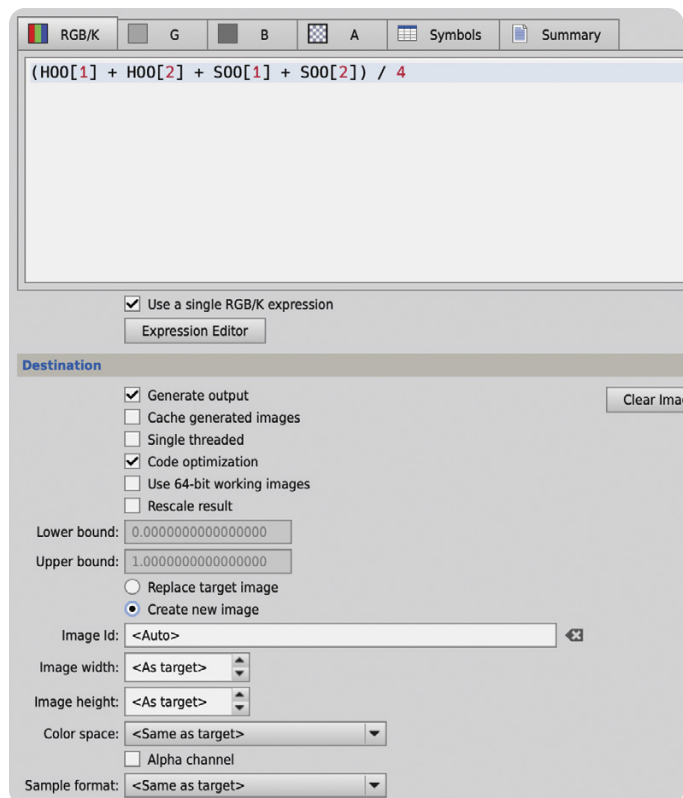
Acquisition Strategy

You'd think that producing a tricolor narrowband image with a color camera would be easier than with a monochrome camera. After all, the color camera requires only two dual-bandpass filters while the latter needs three individual narrowband ones. It turns out that the process is similar to monochrome in terms of complexity. Imaging through two filters requires taking new flat-field calibration frames for every filter change. Filter drawers make these swaps easier than removing your imaging equipment to change filters, but the most convenient approach is to use a filter wheel. These typically come with at least five filter slots, and users with cameras lacking a physical shutter should fill one of the slots with an opaque, filter-sized disk to aid taking dark frames. A fourth slot might be used for a UV/IR-blocking filter for capturing broadband images to make enhanced-color images, which we'll discuss later.

It's good practice to acquire about the same total exposure time with each dual-band filter. Modern CMOS sensors are generally more efficient than CCD sensors, which require long exposures to reach greater signal depth. With CMOS cameras, the total exposure time matters much more than the length of individual subframes. This means you can choose an exposure length that's suitable for your mount's tracking and guiding capabilities. Very short exposures produce a large number of individual subexposures, requiring more storage space and more time to reduce into master frames per filter. Overly long exposures can result in not having enough frames for statistical rejection of outlier pixels (think unwanted aircraft or satellite trails). When imaging through a wide range of focal ratios, I find that 5-minute exposures provide the best compromise. I can record about 45 frames in a 4-hour session — enough to get a decent finished image on most bright targets. Remember to dither after every exposure (move the



▲ **QUICK WORK WITH SCRIPTS** The third-party **DBExtract** script uses information about the recording camera's sensor to create three narrowband files — O III, H α , and S II — from the L-Synergy and L-eXtreme master images. The resulting grayscale pictures are then recombined using the **ChannelCombination** process to create a tricolor narrowband image in the Hubble palette or any other color combination desired.



▲ **MATHEMATICAL APPROACH** To combine the O III channels into a master image, use the **PixelMath** process and input the formula above. Note that the file names are based on master images titled SOO and HOO, so if you've titled your master files differently, you'll need to reflect that in the formula.

telescope/camera randomly by a few pixels) to smooth out the image and ensure the best results.

Some Assembly Required

I use *PixInsight* (pixinsight.com) for all of my image processing. I begin by calibrating, aligning, and stacking all my subexposures for each filter into master color images (S&T: Nov. 2019, p. 36). To keep track of which filtered image is which, I title the L-eXtreme image HOO (for one channel of H α and two containing O III) and the L-Synergy image is titled SOO (one S II and two O III channels). I use the *WeightedBatchPreprocessing* script for this task (found under **SCRIPT > Batch Processing > WeightedBatchPreprocessing**). If separate script runs are used for each filter, the two master results have to be aligned to each other. The *StarAlignment* tool (**PROCESS > ImageRegistration > StarAlignment**) makes this easy. When the process window opens, select either master image as the *Reference image*, then in the *Target images* section, click the *Add Views* button and select the other master. Then click the blue circle at lower left of the tool window to generate an aligned copy of the target image.

Next, the two master images should be cropped identically using **PROCESS > Geometry > DynamicCrop**. Make sure that all non-overlapping edges are cropped out. At this point, I'll neutralize the background and remove gradients with *DynamicBackgroundExtraction* or *AutomaticBackgroundExtractor* (both found under **PROCESS > BackgroundModelization**).

With this preparatory work done, it's time to make our three narrowband master files from the two dual-band masters. First, I split the color channels of the SOO and HOO masters into individual red, green, and blue images

using *ChannelExtraction* (**PROCESS > ChannelManagement > ChannelExtraction**) with its default settings. The result is six monochrome images, two of which need to be renamed. I first retile the red channel of the SOO master S, then rename the red channel of the HOO master H.

The remaining green and blue channels are handled differently. All four of these images contain O III signal, so I combine them together using **PROCESS > PixelMath > PixelMath**. In the process window **RGB/K** tab, type the expression $(SOO_G + SOO_B + HOO_G + HOO_B) / 4$, and in the *Destination* section, select *Create new image*. Drag the New Instance Triangle (at lower left of the process window) onto any of the four O III images, and in a moment the action is complete. Rename the resulting image as O.

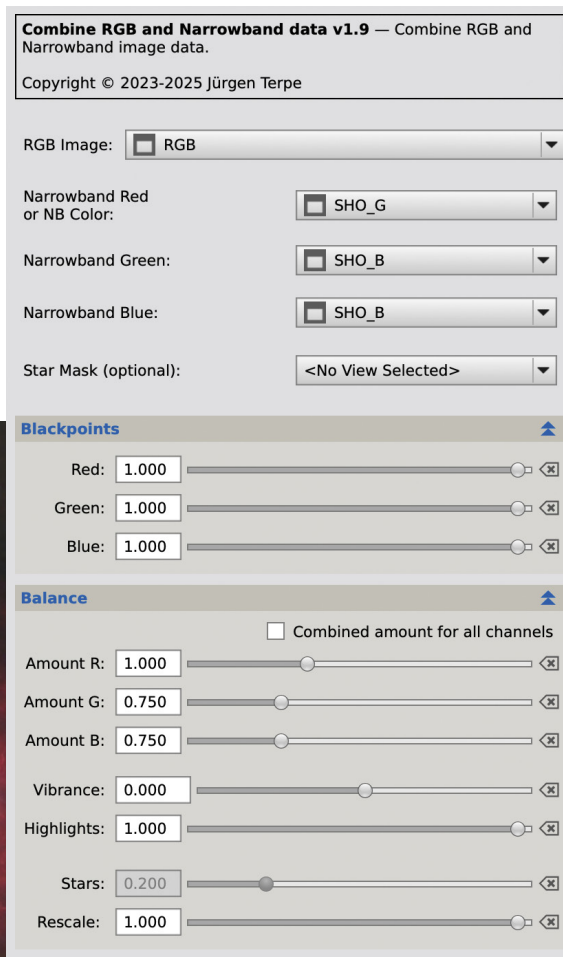
There's also Raúl Hussein's script called *DBExtract* that automates the manual steps described above. It uses more sophisticated image blending and considers the sensor model to produce output images. This script is installed using a repository. To do so, open **RESOURCES > Updates > Manage Repositories** and click the *Add* button. Enter the repository address <https://dbxtract.astrocitas.com/> into the text box exactly as it appears here (this is not a URL that you can open in a browser), then click *Add*. You then open **RESOURCES > Updates > Check for Updates**. Now close *PixInsight*, which

applies the new updates. When you next launch the program, look for the script under **SCRIPT > Utility > DBExtract**.

Using *DBExtract* is easier than installing it. Just choose your camera sensor from the drop-down list and select your master images. The script also handles images from filters that pass S II and hydrogen-beta (H β) emissions, such as the Antlia ALP-T dual-band, 3.5-nm S II and H β filter available at www.antliafilter.com.

Once the individual narrowband channels are ready, you can combine them in any desired palette just like an imager who shot the data with a monochrome sensor and three individual filters. I always start with the Hubble palette (SHO) combination, assembled using **PROCESS > ChannelManagement > ChannelCombination**. The resulting tricolor image is then processed up to the point of completing stretching (for

◀ **EMISSION-LINE BOOST** Using the *CombineRGBandNarrowband* script makes it easy to blend narrowband accents into a broadband image.





▲ **VERSATILITY TO THE MAX** In this enhanced-color image recorded in broadband RGB as well as narrowband wavelengths, M27, the Dumbbell Nebula, glows with a teal hue due to emissions from ionized oxygen. The red features are from hydrogen and sulfur emissions.

basic processing tips, see the June 2023 issue, page 60). After I stretch, I split out the color channels again using **Channel-Extraction**. Now I can explore options for recombining those channels in many different ways.

To generate several different palette combinations simultaneously, I prefer a script by Frank Marek to explore the different options. This third-party script called the Perfect Palette Picker is also installed using **RESOURCES > Updates > Manage Repositories**. Type the repository address <https://raw.githubusercontent.com/setiastro/pixinsight-updates/main/> into the text box exactly as it appears here, then click **Add**. When you next launch the program, look for the script under **SCRIPT > SetiAstro > Perfect Palette Picker**.

Launch the script and follow the instructions provided. Simply assign the three grayscale images (S II as red, H α as green, and O III as blue). Uncheck the **Linear Input Data** box as these files were sourced from a stretched color master. Click **Create Palettes** and use the zoom controls at the top of the script interface to inspect the output thumbnails. Click on any thumbnail that you're interested in pursuing, and a full-size image will be generated in that palette. Once you've generated the narrowband images you want to work with, exit the script. Finish all your different images with some hue, brightness, and saturation adjustments.

Enhanced Color Pictures

Some imaging targets lend themselves well to a natural-looking broadband approach, supplemented with H α - or O III-filtered image data. Examples are supernova remnants in rich star fields as well as nearby galaxies. These methods work

well with color cameras. The color broadband image and each narrowband channel should be processed up to the point of nonlinear stretching. You can then combine all the data using PixInsight's standard **NBRGBCombination (SCRIPT > Utilities > NBRGBCombination)**, though there are more versatile options available. If you install the Toolbox repository <https://www.iddeviceapps.de/PixInsight/Utilities/> as described previously, you'll gain access to a set of scripts by Jürgen Terpe (both will appear under **SCRIPT > Toolbox**). Since H α and S II emit mainly at red wavelengths, I suggest first combining H α with the broadband image using the **CombineHaWithRGB** script. The **CombineRGBandNarrowband** script is used to blend S II into the red channel and O III into the green and blue channels. This approach should help you preserve their natural-looking hues. Both scripts include full documentation accessible from a button within the script.

Until recently, a monochrome camera setup was the only practical option for imagers wanting to create tricolor narrowband pictures. New filter manufacturing technology has once again changed the game. Modern color cameras fitted with the latest dual-band filters can deliver stunning Hubble palette results rivaling those made with monochrome detectors. Think of it this way: If you already have a color camera, it now has access to cool new imaging opportunities. And if you're still sitting on the fence between choosing a monochrome or color camera, the choice just got harder.

■ Contributing Editor **RON BRECHER** photographs the sky from his home observatory, the Doghouse, in Guelph, Ontario, Canada. Visit his website at astrodoc.ca.

The Wonder Years

Snapshots of young planetary systems are filling in our picture of what happens as these systems develop.

Since the time of Kant and Laplace in the 18th century, humans have dreamed of the nebulous birthplaces of planetary systems. Only recently, however, have we been able to see planet formation in action. Thanks to the Atacama Large Millimeter/submillimeter Array (ALMA; *S&T*: Sept. 2025, p. 34), we can now directly observe the innermost regions of the flattened disks of gas and dust around stars where planets are born. As we have built optical systems that are ever better at filtering out starlight and revealing faint gas and dust, press releases about “baby pictures” of planetary systems have become *de rigueur*.

We now also know of more than 6,000 “adult” planets orbiting stars in the Milky Way Galaxy. Our current planet-hunting technology is biased toward worlds that are large and/or close to their host star, so we’re still missing many kinds of planets, including worlds akin to most of those found right here in our own solar system. Yet even with these limitations, we now know that when we look up at the night sky, there is, on average, a minimum of one planet per star out there. Wow!

But how do the conditions within the disks of gas and dust lead to the diverse range of full-fledged planetary systems? Our planetary photo album is incomplete: We have baby pictures and a smattering of adult portraits, but there are blank pages in between. As any parent knows, getting your teenager to pose for the camera can be a much bigger challenge.

As planetary systems evolve into adolescence, that primordial disk skirting the star (known as a *protoplanetary disk*)

gets dispersed — some is incorporated into planets, some accreted onto the star, and some blown away. By the time planetary systems are about 10 million years old, most of that natal dust and gas are gone, even though the planetary system is not yet done forming. The tenuous, dusty disk within which the adolescent planetary system now orbits is called a *debris disk*. You can think of the debris disk as a bulkier version of our solar system’s asteroid and Kuiper belts, in which the leftover crumbs of planet formation (some as large as Pluto or Vesta) collide and grind themselves down into smaller and smaller pieces, until they are tiny enough to be blown away by starlight. Thus the debris disk is not just the leftovers of the earlier disk but rather a new phase in which destructive collisions dominate instead of growth.

These debris disks can stick around for quite a while; we observe them around stars with ages up to billions of years. For context, our Sun will shine for about 10 billion years all told, while a star that is two or three times more massive might live for only 1 billion years. So while I’m going to refer to debris disks as an adolescent phenomenon, occasionally adolescence bleeds into adulthood.

Yet although they stick around, these disks are difficult to spot: A debris disk can be hundreds or thousands of times fainter than its protoplanetary predecessor.

The Holy Grail of planet-formation research is to assemble a *predictive model* of how the initial conditions in protoplanetary disks lead to the full range of planetary system outcomes — in other words, to discover the series of developmental



stages that explains which types of planets end up where. To do this, we need to assemble our set of snapshots into a life cycle, one that includes those adolescent ages between 10 million to 1 billion years or so.

Only once we have the ability to make predictions that are consistent with all the data will we be able to answer the big questions: How “normal” is our solar system? How common are different types of planets? And, therefore, how common are those types of planets that are conducive to the formation of life as we know it? Debris disks provide the missing pages of the photo album that show us what’s happening to planetary system architectures on those adolescent time scales that we know so little about.

Dusty Doings

A lot was happening during our solar system’s first 100 million years. The giant planets had already formed and were jostling into their final orbital configurations. Meanwhile, the leftover fragments strewn throughout the solar system — known as *planetesimals* — were in a tizzy. During this era, a Mars-size object that we now call Theia smashed into Earth, forming the Earth-Moon system — part of the final assembly stages of the terrestrial planets. Flying fragments in the inner solar system caused the dramatic cratering record that is still visible on dry and airless worlds like Mercury and the Moon.

This chaos produced a significant amount of dust which, counterintuitively, is easier to see than the planets themselves. That’s because a thin layer of dust covers a much

▲ **ABUNDANT DUST** As planetary systems wrap up formation, the ubiquitous rocky fragments collide and grind themselves down, creating vast debris disks.

greater area than if you take those same particles and crunch them together into a ball.

Our solar system today hosts not one, but two, ghostly debris-disk remnants. The one that is visible to the naked eye from a dark-sky location is the *zodiacal light*: a diffuse pillar of light that follows the plane of the solar system, easiest to see at dawn and dusk. In the inner solar system, we are effectively bathed in this dust, which comes mostly from a mix of asteroids and short-period comets.

From outside our solar system, though, the zodiacal light is outshone by dust in the Kuiper Belt beyond the orbit of Neptune. This belt is a massive reservoir of remnant planetesimals, kept in cold storage from our system’s planet-formation days. (Pluto is its most famous, though not its most massive, denizen.)

Despite the Kuiper Belt’s relative prominence, though, if we were alien astronomers looking back at our own solar system, what we would actually see is nothing: Our current technology is not yet sensitive enough to detect twins of our own debris disks around another star.

Nevertheless, there are many disks larger and brighter than ours; we can already observe debris disks around about one-quarter of nearby main-sequence stars. All the exo-Kuiper Belts we have ever seen are therefore scaled-up versions of our own solar system’s Kuiper Belt, with at least

10 times the amount of dust that lingers in our planetary system. Even though we can only see the metaphorical tip of the iceberg at this point, the ubiquity of observable debris belts tells us that, like planets, debris disks are everywhere.

Rings and Gaps and Halos, Oh My!

In 2014, astronomers using ALMA discovered that the large, seemingly unremarkable planet-forming disk around the young star HL Tau actually contained concentric glowing rings separated by dark gaps. After the iconic image hit the presses, follow-up studies quickly demonstrated that rings and gaps are ubiquitous in bright, young protoplanetary disks.

Astronomers became obsessed with characterizing the structures within disks. While early on the temptation was to equate each gap with the presence of a planet, inevitably a range of theoretical investigations has shown that the situation may be more complicated. There's actually a bit of a chicken-and-egg problem: Which come first, the gaps or the planets?

We're still not sure. We do, though, have evidence that there are planets growing inside at least some highly structured protoplanetary disks. Some we've found by studying direct images, which show gas accreting onto planets embedded in disks. Others we've detected by spotting local variations in the velocity of the disk material as it orbits the star.

With evidence that rings and gaps are intimately entwined with the formation of planets, astronomers naturally have wondered what happens to these structures — and the underlying planetary system architecture they reflect — as disks evolve from the protoplanetary to the debris-disk phase.

By last year, millimeter-wavelength telescopes such as ALMA had observed more than 70 debris disks, but largely only in a very blurry mode. From these blurry images, it seemed as though many debris disks showed ring structures

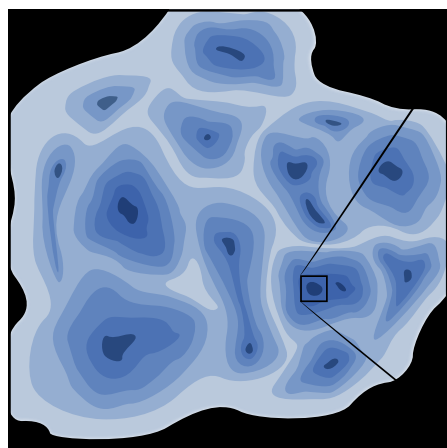
that were a lot wider than those in protoplanetary disks. But we couldn't yet see with enough detail to tell whether the rings were actually wide, or whether the blurry images were causing us to miss unresolved gaps.

This problem motivated our team to propose the largest ALMA program to study debris disks yet, observing a sample of two dozen in higher detail: the ALMA Survey to Resolve Exo-Kuiper Belt Substructures (ARKS).

What we found was that the answer is not simply “yes, the rings are wide” or “no, there are gaps,” but a little bit of both. We did in fact find that many systems exhibited sharper features when we made sharper images — no surprise there! But we also found that there is a smaller subset of debris disks with wide dust belts and broad, gradually sloping ring edges, unlike the sharp, narrow rings that we see in protoplanetary disks. And interestingly, all of the stars in our sample for which astronomers can directly see massive planets on very distant orbits belong to this second category.

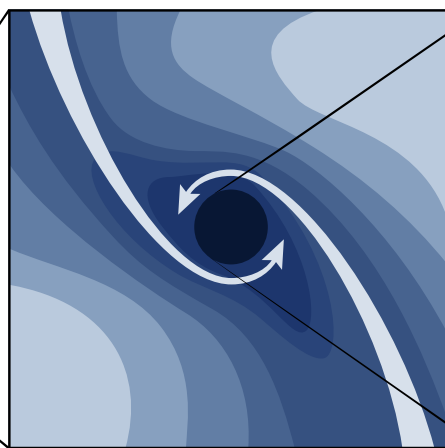
I had always assumed that massive planets would carve very sharp edges in the disk with their gravity, like a hoe digging a trench in moist soil. But it turns out that the opposite is true: Massive planets subtly smooth out the rings' edges. The planet's gravity tugs and pushes on little planetesimals, especially the ones in *resonant orbits*, whose orbital periods form whole-number ratios with the planet's period (just as Pluto orbits twice for every three Neptune orbits). Those gravitational nudges push smaller bodies into more elongated orbits, in the same way that a parent pushing at just the right moment helps their child go higher on the swing set. The overlap of these myriad less-than-perfectly-circular orbits smooths out the edges of the debris ring (see page 38).

Smaller planets, by contrast, can't shove as hard. Even if there are loads of planetesimals in resonant orbits, the



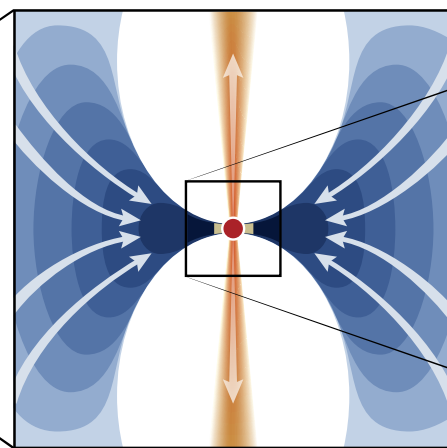
MOLECULAR CLOUD

Stars are born in clouds of dust and molecular gas.



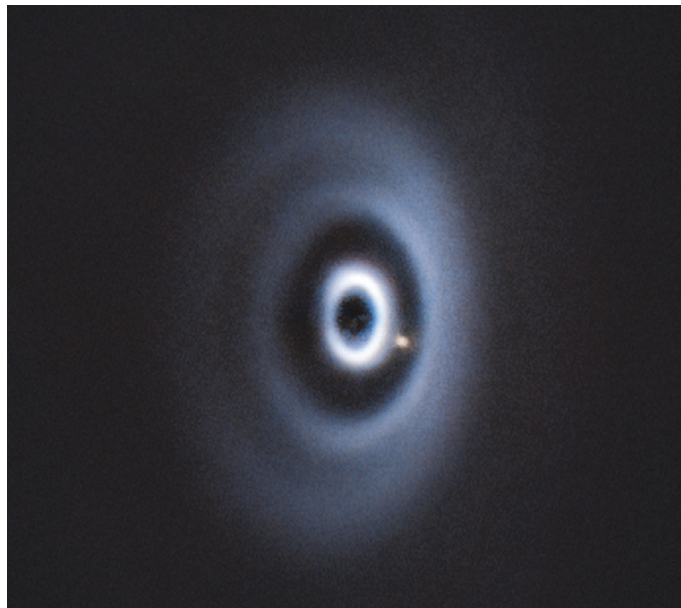
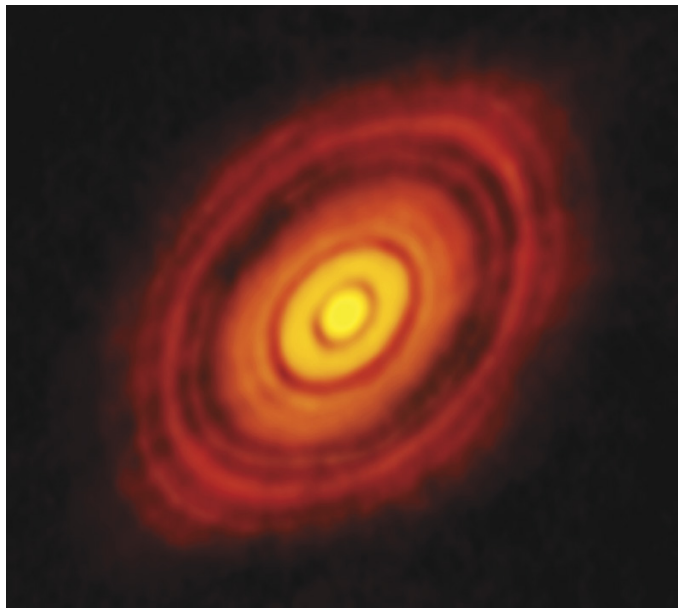
DENSE CORE

Dense regions of the cloud collapse under the weight of their own gravity, rotating as they do so.



PROTOSTAR: 0–1 MILLION YEARS

Inside the core, a star forms surrounded by a disk, fed by material from the core as collapse continues. To conserve angular momentum, the protostar ejects material as outflows from its poles.



▲ **PUT A RING ON IT** *Left:* This now-iconic ALMA image shows rings in the protoplanetary disk around the young star HL Tauri. *Right:* This image from the Very Large Telescope reveals a baby planet in a disk with multiple rings around the star WISPI 2. The planet is about five times Jupiter's mass and lies nearly 60 astronomical units from its host star (masked in the rings' center). Subsequent observations have found a second giant planet closer to the star (interior to the bright ring in this image).

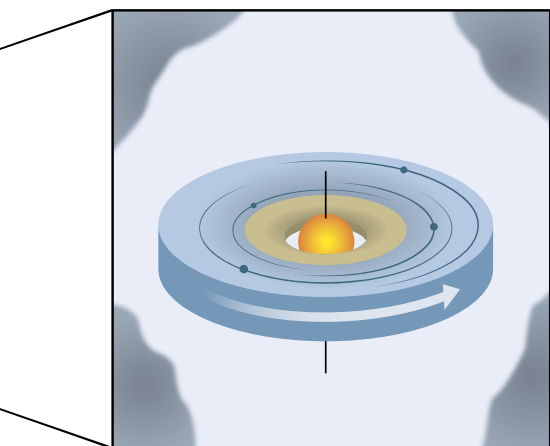
smaller planet won't move them around as effectively, so small planets carve sharper edges in the disk instead. Studying the sharpness of the debris disk's edges at radio wavelengths therefore gives us insight into the masses and orbits of planets that are otherwise hard to detect.

Shaking Things Up: The Vertical Dimension

With all this focus on what's going on in the disk plane, you could be forgiven for forgetting that planetary systems have

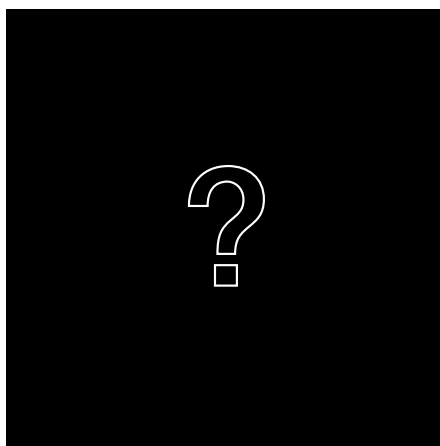
another dimension: height. Whether a disk appears flat like a pancake or puffy like a donut when we observe it at millimeter wavelengths depends on how much total mass lurks in the disk — including those unseen but all-important planets.

When a dust grain swings near a massive body like a planet, it receives a little kick from the planet's gravity that makes the orbit a little wonkier. A disk that hides several Uranus and Neptune analogs will therefore be much puffier than a disk that contains only a few Pluto-like planetesimals. When



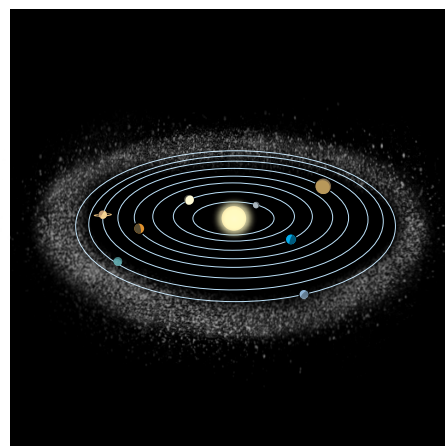
PROTOPLANETARY DISK: 1–10 MILLION YEARS

Radiation and outflowing material remove the planetary system's natal envelope and cut the link with the cloud. Planetary building blocks form, and giant planets quickly coalesce.



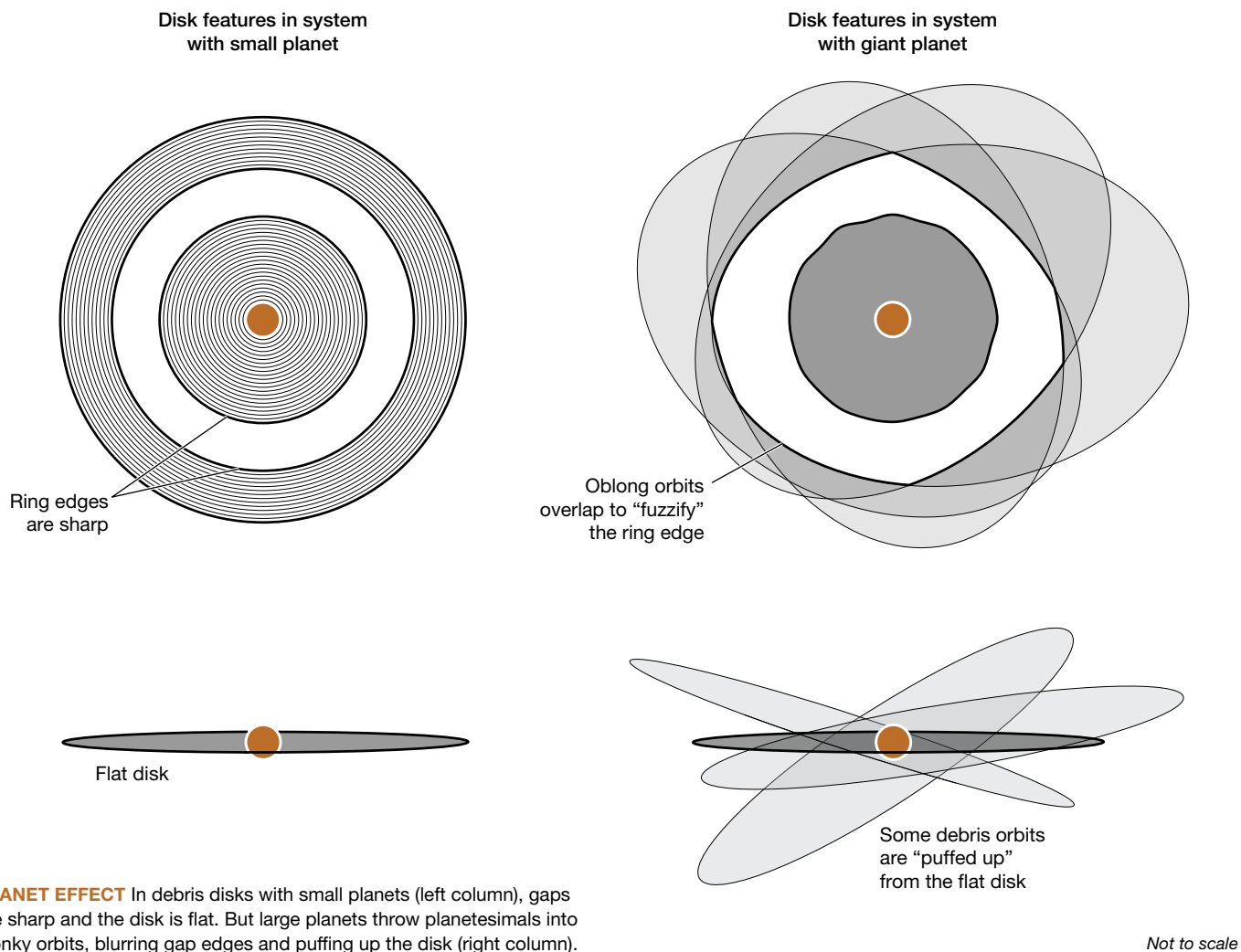
FINAL ASSEMBLY OF TERRESTRIAL WORLDS: 10–100 MILLION YEARS

The teenage years. The gas disk dissipates. Terrestrial planets build up from countless collisions. Debris fills the system.



FULLY FORMED PLANETARY SYSTEM

Planet formation has finished, but some debris remains.



PLANET EFFECT In debris disks with small planets (left column), gaps are sharp and the disk is flat. But large planets throw planetesimals into wonky orbits, blurring gap edges and puffing up the disk (right column).

we analyze the vertical structure of nearly edge-on disks in the ARKS sample, about half of them seem to require an embedded mass greater than that of Neptune to puff them up.

We were even able to probe the distribution of material above and below the disk plane. For context, in our solar system, there are two different vertical scales present in the Kuiper Belt. One is known as the “classical belt,” which is a relatively flat component of leftover planetesimals that managed to survive all the jostling of planetary orbits during the Sun’s adolescence. The other is the much puffier “scattered belt.” The scattering was most likely caused by Neptune, plowing outward through this region billions of years ago, tossing planetesimals hither and thither in its wake (S&T: June 2025, p. 22).

When we looked at the nearly edge-on ARKS targets in detail, we found that more than half of them were not well matched by a single vertical scale, but rather required a two-scale structure similar to the Kuiper Belt. This consistency suggests that Neptune’s past ramble likely isn’t unique: Giants may often migrate and sculpt the outer reaches of exoplanetary systems during their formative years.

Planet Formation: It’s a Gas!

Here’s a fun bit of trivia: We knew about gas in debris disks before we knew about debris disks! In 1975 an astronomer named Arne Slettebak wrote a two-page article in *The Astrophysical Journal* about some weird stars, containing a single table of data with a column labeled simply, “Peculiarity.” Next to the star Beta (β) Pictoris, he notes a pair of unexpected spectral lines, and in the text he states that “They are evidently of interstellar or circumstellar origin.”

We now know that Beta Pic — along with at least a couple dozen other debris-hosting stars — is orbited by a reservoir of both atomic and molecular gas. Despite these early hints, more than 30 years passed between when Slettebak first noticed the peculiar spectral lines in Beta Pic and when ALMA demonstrated unequivocally that molecular gas is common in debris disks, especially around stars just a bit heavier than the Sun.

This gas is not necessarily the last wisps of the protoplanetary disk, which was composed mostly of molecular hydrogen (H₂). Instead, it might be liberated from the surfaces of icy dust grains or planetesimals in the debris disk. If so,

then it should be made of the same carbon- and oxygen-rich compounds as comets.

Far from being a mere peculiarity, this difference could be significant in the life of a planet. We now know that if you care about planetary atmospheres — which arguably you should, if you like to breathe — you should care about the composition of the gas in debris disks.

A series of studies by Quentin Kral (Paris Observatory) and others provides the headlines about the importance of this relatively small quantity of late-stage gas: After the planet's formation, the lingering gas raining down onto the world from the debris disk can alter (in the case of a gas giant) or even completely overwrite (in the case of a rocky planet) the molecular composition of the planet's atmosphere. Accretion of gas lingering in the solar system's debris disk can explain the surprising overabundance of heavy elements in the atmospheres of Uranus and Neptune, for example. Some of the air you breathe as you read this article probably came to Earth from gas in the Sun's debris disk. It is therefore critical that we understand its composition.

But there's a major hitch: Due to a quirk of quantum

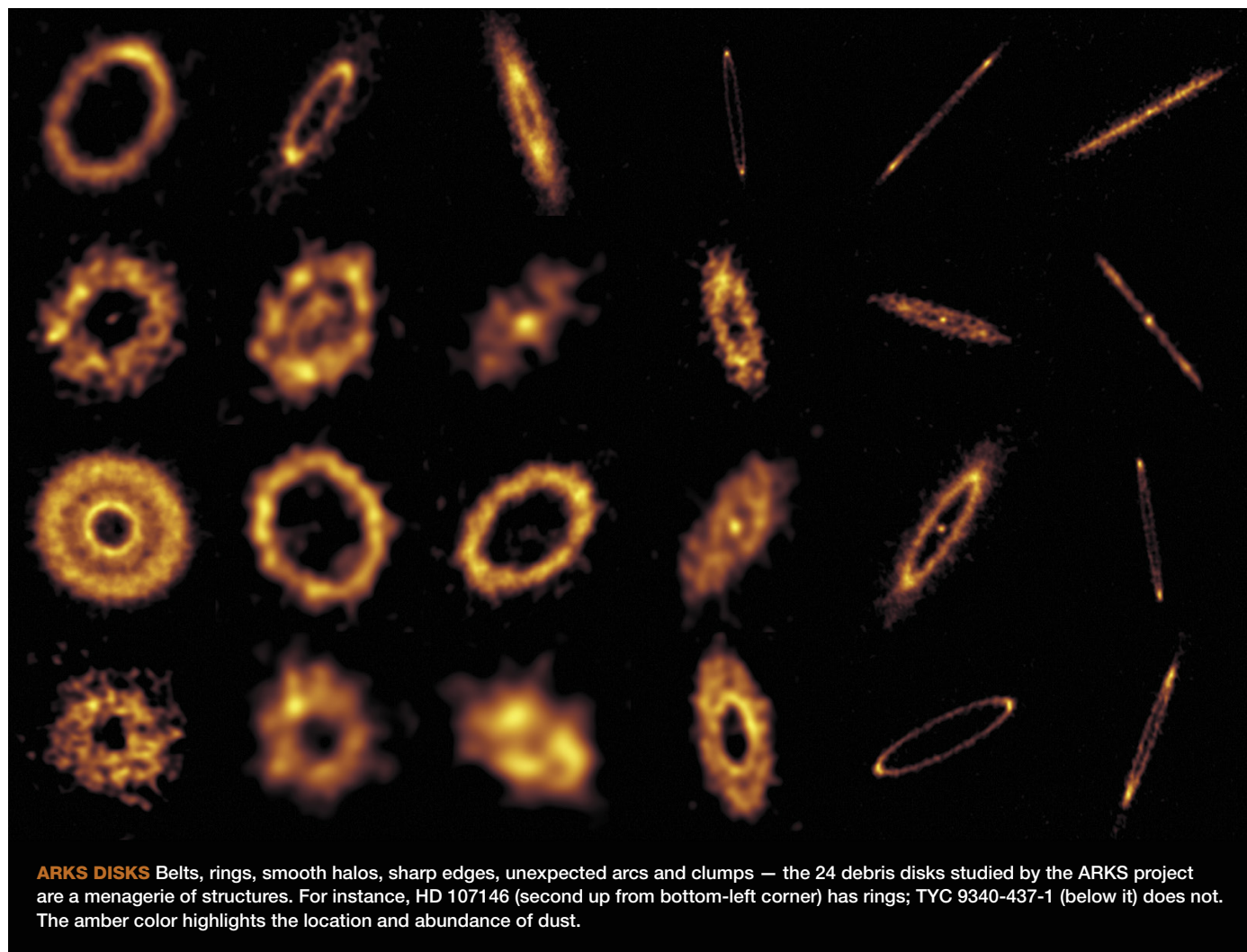
mechanics, the most abundant molecule in the universe, H_2 , is essentially invisible at the temperatures of debris-disk gas. If we want to determine whether the gas in debris disks is hydrogen, then we have to be clever.

We can search for other trace species that are common in comets, like cyanide or methanol. Or we can look at how much the gas disk puffs up: At a given temperature, we expect a lighter mix of gases (like hydrogen) to be fluffier, and heavier gases (like carbon and oxygen) to be flatter.

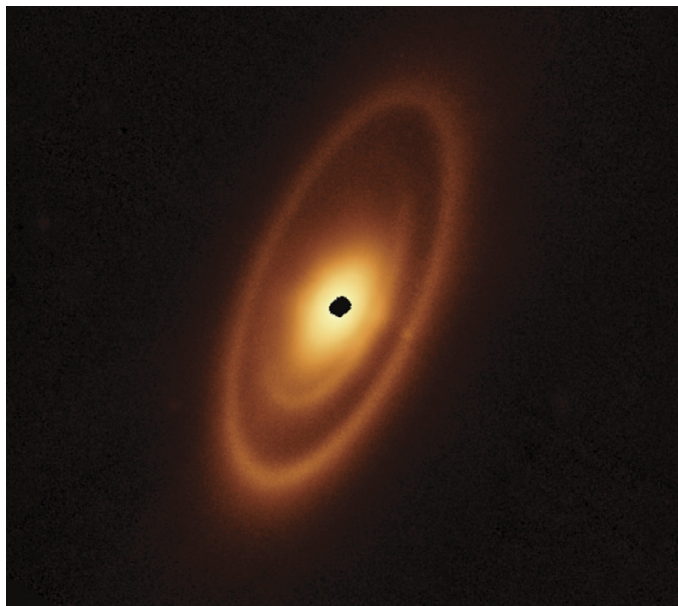
We've also started to make some progress by looking at how vigorously the gas molecules jiggle, which is reflected in how wide the features in their spectrum are. At the same temperature, heavy molecules jiggle less than lighter molecules.

Unfortunately, there's a lot of other physics that can affect how wide your spectral features appear or how fluffy your gas disk becomes.

We do have some pretty strong hints that the older and fainter debris disks consist of second-generation exocometary material, released in collisions. We've seen clumps of gas emission that most likely mark the location of a recent crash. We've also seen such small amounts of gas around such old



ARKS DISKS Belts, rings, smooth halos, sharp edges, unexpected arcs and clumps — the 24 debris disks studied by the ARKS project are a menagerie of structures. For instance, HD 107146 (second up from bottom-left corner) has rings; TYC 9340-437-1 (below it) does not. The amber color highlights the location and abundance of dust.



▲ **SURPRISE RINGS** Astronomers knew the star Fomalhaut had a debris disk, but when they looked at it with the James Webb Space Telescope, they discovered there are actually three nested belts of warm dust, the inner two having gone unseen. The disk extends some 150 astronomical units from the star — three times farther out than our own solar system's classical Kuiper Belt.

stars that there's no way those little blips of gas could have survived since the protoplanetary disk phase.

But the origin of the gas reservoirs inside younger and more massive debris disks remains mysterious. We continue to search for clues within this population that will help us solve the enigma.

Teenage Dreams

We have crossed several major thresholds in understanding planetary system formation thanks to ALMA. First came sub-

structure in the brighter and younger protoplanetary disks. Now, we're seeing its fainter echoes as planetary systems continue to mature through the adolescent debris-disk stage.

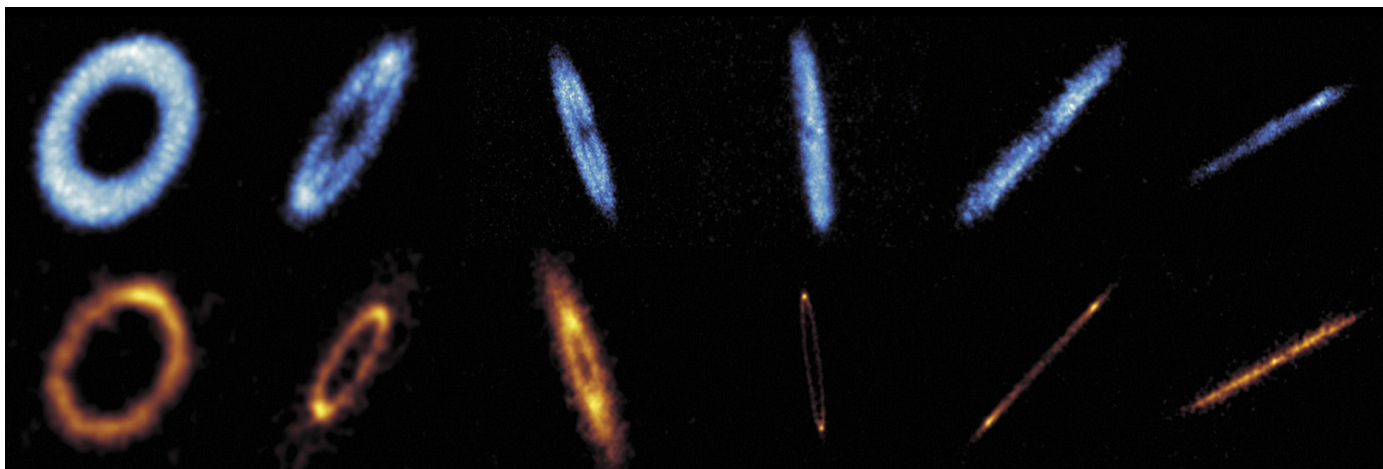
In the structure of debris disks, we're seeing signs that giant planet migration is common, and that heavier elements are available to rain down on planets' atmospheres as they finish forming, changing their chemical makeups. For planetary systems, then, adolescence is proving to be just as formative as the baby years.

These debris-disk images are snapshots; blank pages remain in our photo album. But we occupy a special moment in which high-resolution radio telescopes like ALMA can show us the details of circumstellar disk evolution, just as high-contrast imaging systems are also revealing younger and fainter planets. That Holy Grail vision of connecting our understanding of mature planetary systems with their natal environments finally seems within reach.

My students are the first generation to grow up knowing, unequivocally, that planets exist around other stars. Perhaps their generation will be the first to take these snapshots of individual planets and disks in their various life stages and piece them together to infer a comprehensive census of planetary systems and their evolution.

We may never be able to detect every planet in the galaxy, but we don't necessarily have to. With enough snapshots we'll learn what's out there — the frequency of worlds made of dust, ice, and gas, and how their orbits evolve with time — and this knowledge will give us both a mirror in which to view our own home and a bedrock for understanding potential environments for life in the universe.

■ **MEREDITH HUGHES** is an astronomer at Wesleyan University and co-principal investigator of the ALMA large program ARKS, alongside colleagues Sebastian Marino (PI, University of Exeter) and Luca Matrà (co-PI, Trinity College Dublin).



AND NOW WITH GAS Six of the ARKS disks are rich in gas. The top row shows the distribution of carbon-monoxide gas (blue); the bottom row shows the dust in the same six disks and is the same as the top row of the image on page 39. The gas surrounding Beta Pictoris (top-right corner) is fairly clumpy, perhaps from a recent collision. Its dust also shows signs of being puffed up vertically, which could be due to the influence of one or more giant planets. Beta Pic has two known giant planets.



7 MORNING: The waning crescent Moon climbs in tandem with the Pleiades. You can enjoy this sight in the east-northeast until the rising Sun washes it away. Turn to page 46 for this and other events listed here.

9 MORNING: The lunar crescent and Mars are side by side as they come into view above the east-northeastern horizon. Around 4° separates the pair, a gap that grows as the morning hours wear on.

10 DAWN: The Moon, two days shy of new, forms an isosceles triangle of sides around 7° long with Gemini's bright lights, Castor and Pollux. Face east-northeast to take in this scene.

11 DAWN: Seek out an unobstructed view toward the east-northeastern horizon and see if you can spot the razor-thin lunar crescent with Mercury less than 2° lower right. Binoculars will help.

12 NEW MOON (1:37 P.M. EDT): A total solar eclipse is visible along a narrow path that stretches from the Arctic over Greenland, Iceland, and Spain and ends in the Mediterranean. Much of western Europe and northern North America will see a partial eclipse. Turn to page 48 for more.

12-13 ALL NIGHT: The Perseid meteor shower is expected to peak (see page 48). Viewing conditions are optimal this year with the Moon at new phase. The Perseids are a long event, and you can expect to see meteors any time after mid-July and well into the second half of August.

15 DUSK: Face west-southwest to see the waxing crescent Moon leading Venus by a bit more than 4° as they sink toward the horizon.

16 DUSK: The waxing lunar crescent hangs some 6° lower right of Virgo's lucida Spica. This sight graces the west-southwestern horizon.

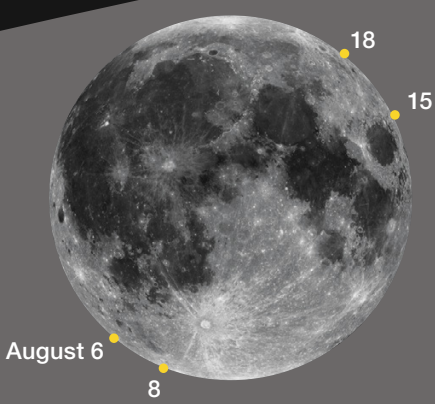
20 EVENING: The waxing gibbous Moon and the Scorpion's smoldering heart, Antares, pair up picturesquely in the south-southwest. You'll see the Moon around $1\frac{1}{2}^\circ$ below the star.

28 FULL MOON (12:19 A.M. EDT): A deep partial lunar eclipse is visible to viewers across the Americas, with all of South America and the eastern half of North America seeing all the phases. Page 50 has details.

—DIANA HANNIKAINEN

▲ If skies are clear, viewers in the Americas will get to enjoy a partial lunar eclipse. The photo shown here is from September 2015. SEAN WALKER

AUGUST 2026 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	31					

LAST QUARTER NEW MOON

August 6 August 12
02:21 UT 17:37 UT

FIRST QUARTER FULL MOON

August 20 August 28
02:46 UT 04:19 UT

DISTANCES

Perigee August 10, 11h UT
363,286 km Diameter 32' 53"

Apogee August 22, 08h UT
404,640 km Diameter 29' 32"

FAVORABLE LIBRATIONS

- Yakovkin Crater August 6
- Hausen Crater August 8
- Hubble Crater August 15
- Compton Crater August 18

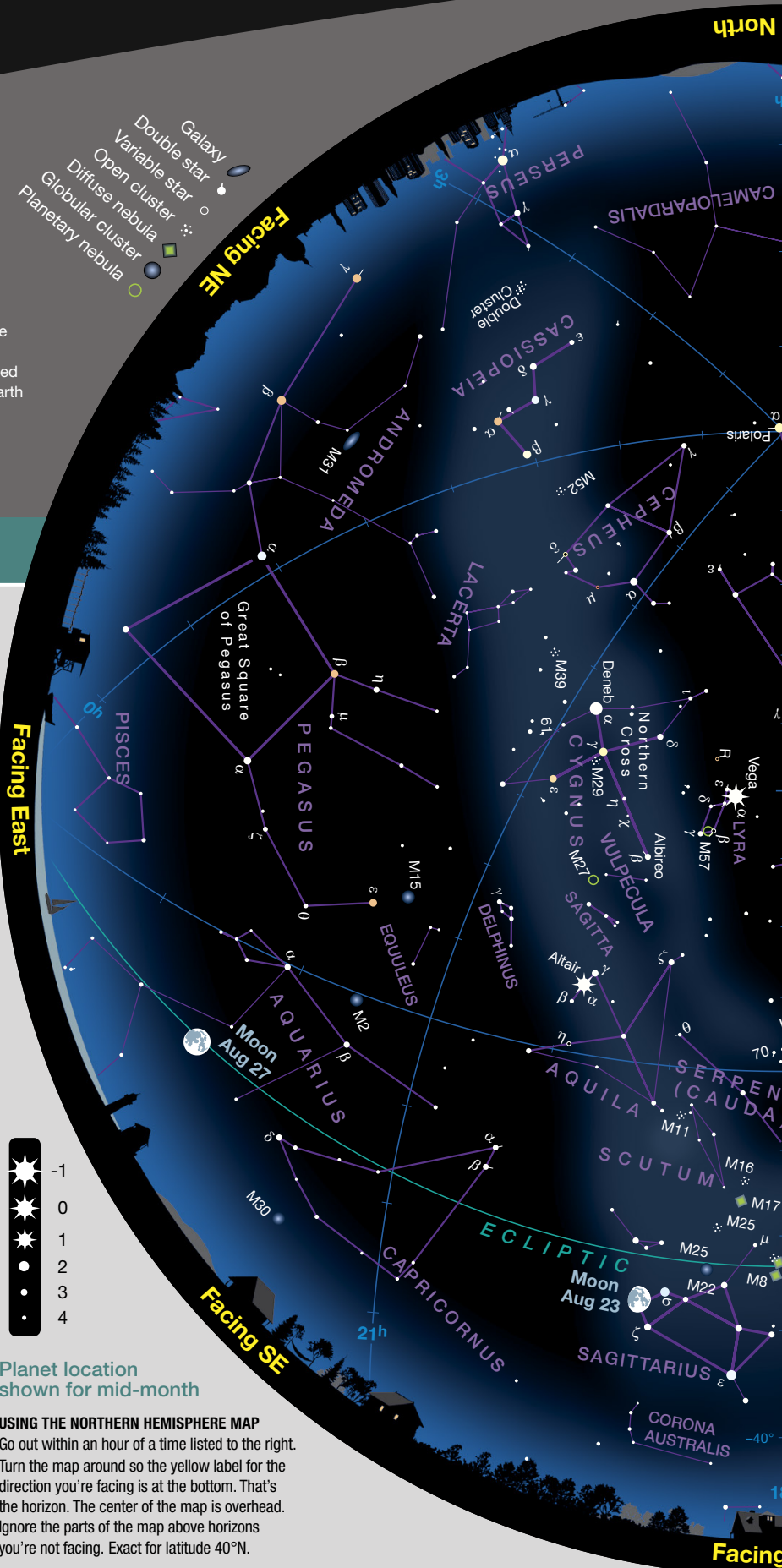
- Galaxy
- Double star
- Variable star
- Open cluster
- Diffuse nebula
- Globular cluster
- Planetary nebula

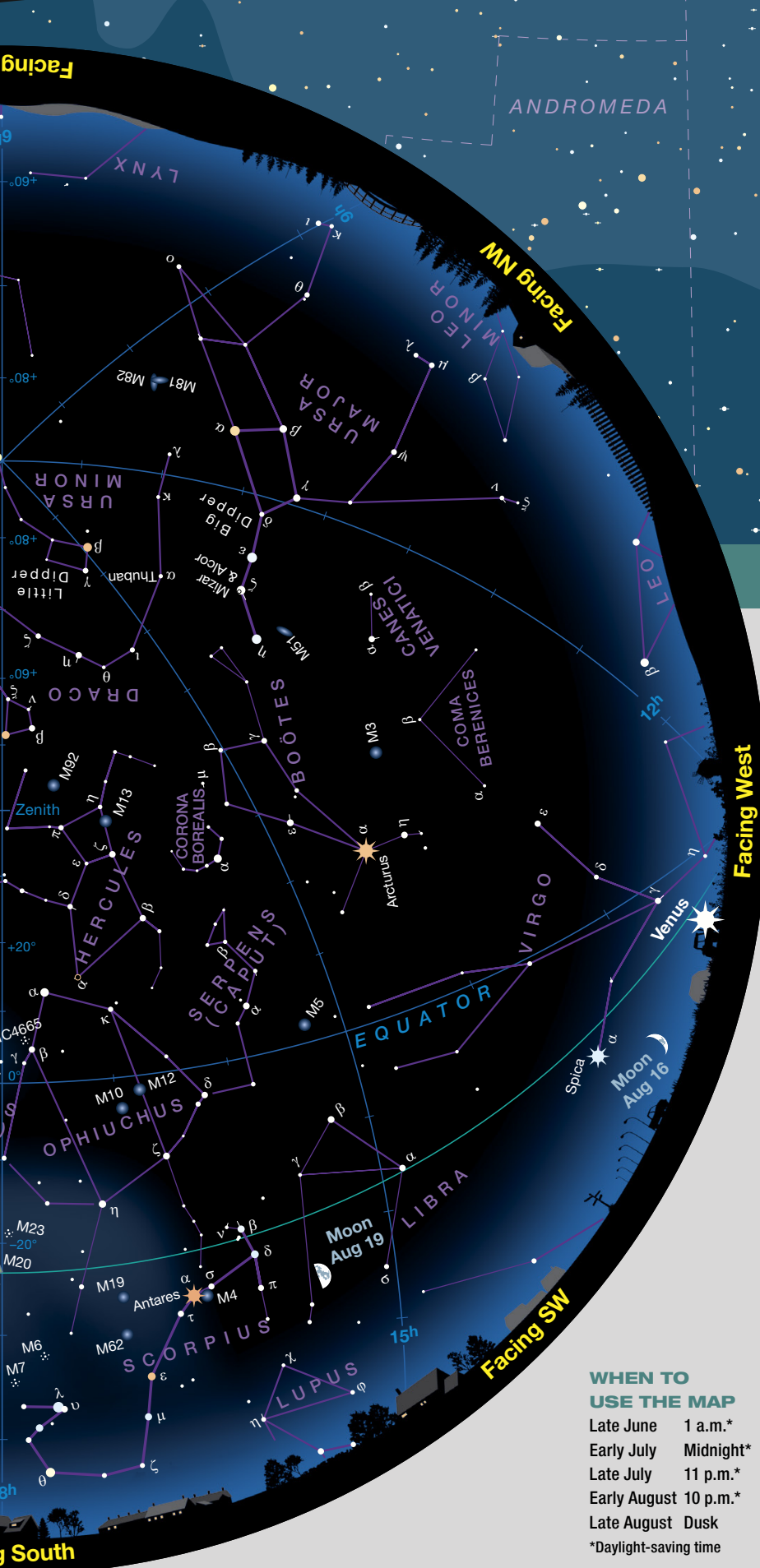
Facing East



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

A Long Look at the Lizard

Lacerta, the Lizard, is one of my favorite under-dog constellations — and even I have a hard time picking it out by memory. But what the Lizard lacks in celestial real estate, bright stars, or fame, it makes up in subtle beauty. Within its borders, rich fields of the Milky Way are spangled with double and multiple stars, asterisms, and open clusters.

One of my favorites in this part of the sky is the open cluster **NGC 7209**. My preferred way to get there is to first identify the flattened W-shape, almost like a mini-Cassiopeia, formed from north to south by Beta (β), Alpha (α), 4, 5, and 2 Lacertae. NGC 7209 is a little less than 3° due west of 2 Lacertae, and 1.5° north of a charming arc of three close stars anchored by 5th-magnitude HD 209945. At magnitude 6.7 and with an apparent diameter of $25'$, the cluster is just a pretty, mottled haze in my 10x50 binoculars. In my 15x70s, NGC 7209 takes on a bit more definition, with three distinct clumps forming an arc, and with averted vision the stars within resolve into grainy patches. Resolution is fleeting because of the cluster's distance. At 3,800 light-years, it's pretty far out there for an open cluster one might study with binoculars.

If either your skies or your eyes make resolving the cluster a challenge, take in the local scenery. At 10x magnification, NGC 7209 sits in the center of a pentagon of 6th- to 10th-magnitude stars. And an S-shaped chain of similarly dim stars winds back toward 2 Lacertae. Take some time to look around the rest of Lacerta — you may develop a sneaking fondness for it yourself.

■ Now **MATT WEDEL** is wondering what other constellations he'll appreciate more in 10 years than he does right now. Should be fun finding out!

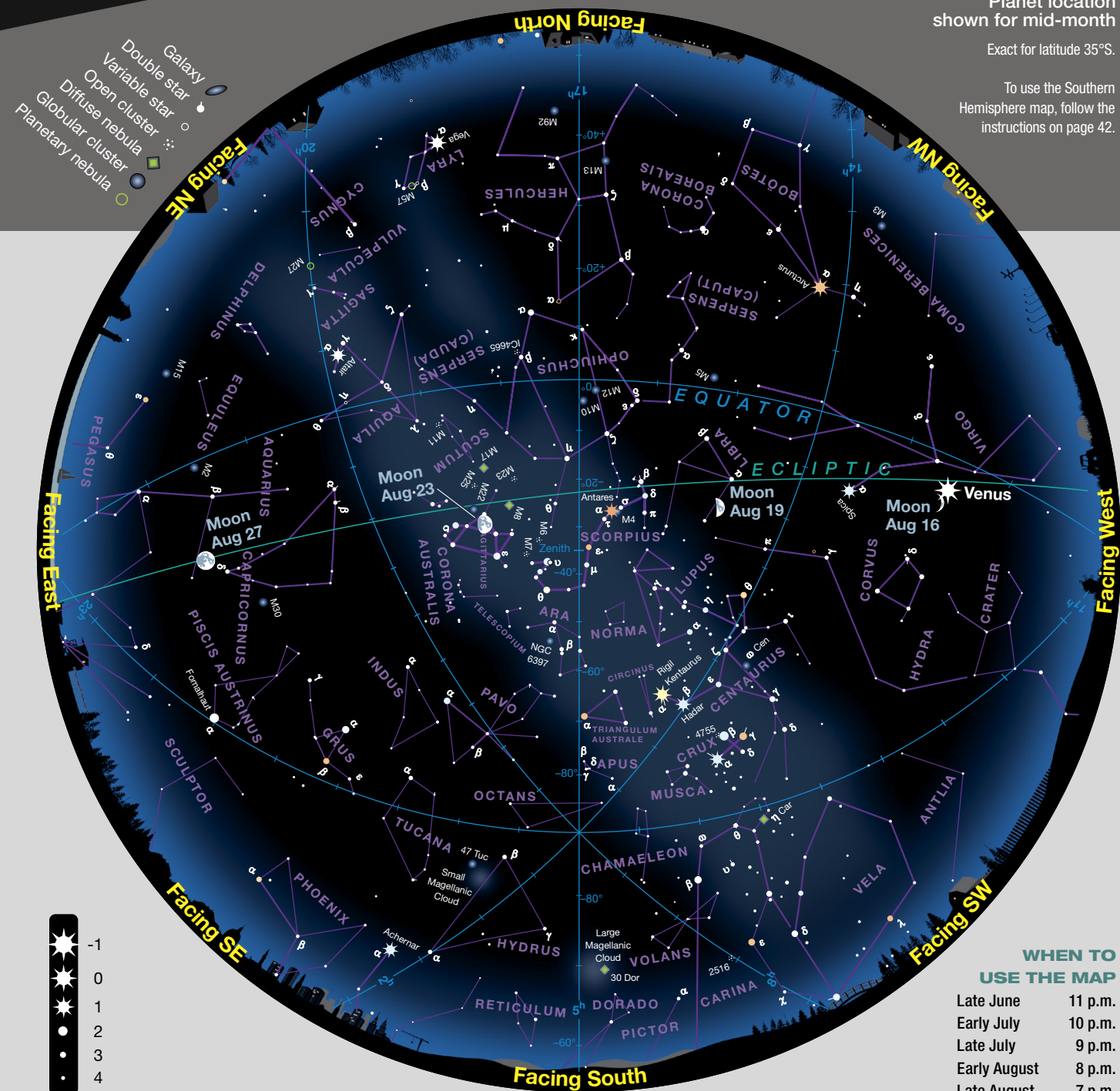
WHEN TO USE THE MAP

Late June	1 a.m.*
Early July	Midnight*
Late July	11 p.m.*
Early August	10 p.m.*
Late August	Dusk
*Daylight-saving time	

AUGUST 2026 OBSERVING

Southern Hemisphere Sky Chart

by Jonathan Nally



NORMA, named after the kind of set square or right angle that would be used by an architect or builder, is one of the smallest constellations, covering less than half a percent of the sky. It has eight stars of magnitude 5.0 or brighter; the brightest, Gamma² (γ²) Normae, is magnitude 4.0.

Not marked on the chart above but about halfway between the outline of Norma and the star Mu (μ) Scorpii, is

Mu Normae, a seemingly insignificant star at magnitude 4.9, but actually one of the most stupendous stars in our galaxy — an enormous blue supergiant. Astronomers aren't fully sure of its mass, but it's probably somewhere between 30 and 60 times that of the Sun. Likewise, its luminosity is uncertain — somewhere between 300,000 and a million times the Sun's brightness. A true superstar for sure! ■

Cerberus Metamorphosis

This celestial beast was the product of radical transformations.

As darkness descends this month, look to the high heavens for Cerberus, the hideous hound that guards the entrance to Hades, the abode of the spirits of the deceased. Although you won't find that now-obsolete constellation labeled on this month's Northern Hemisphere Star Chart on pages 42–43, it's there, in part, daring you to imagine its full, dim, and daunting form.

Cerberus first appears as an independent constellation in Johannes Hevelius's 1690 *Firmamentum Sobiescianum* star atlas, which shows Hercules holding a triple-headed serpent. It's composed of just four stars, only two of which are plotted on this month's star chart. Look between the northern wingtip of Aquila, the Eagle, and the row of five stars marking the outstretched eastern arm of Hercules for two pairs of unconnected stars. The pair to the right belongs to Cerberus. Today we know them as 95 and 109 Herculis. They shine at 5th and 4th magnitudes, respectively, so you'll need clear, dark skies to see them.

Note that Hevelius did not depict Cerberus as a hound. Nor has any other celestial cartographer, for that matter. The dozen or so dim naked-eye stars in that roughly 10°-wide region of sky were a playground for the imagination. Before we sum up the changes that occurred there over time, let's see what mythology has to say about Cerberus.

The Greek poet Hesiod (circa 700 BC) first named Cerberus in his poem *Theogony* and described him as a savage dog with 50 heads. Later Greek poets enhanced the terror by giving him a mane of snakes and the claws of a lion. In his 1905 book *Cerberus: The Dog*

of Hades, Maurice Bloomfield writes, "Not until [Greek mythographer] Apollodorus, . . . in the second century BC, comes the familiar description: [Cerberus] now has three dog heads, a dragon tail, and his back is covered with the heads of serpents."

In myth, Cerberus was believed to be impossible to conquer. That's why King Eurystheus of Mycenae — whom Hercules was condemned to serve until he completed 12 great labors — assigned the capture of the Hades hound to Hercules as his twelfth task. But when Hercules returned and presented the live beast to the king, the terrified ruler made him carry the hound back.

Prior to Hevelius's serpentine depiction of Cerberus, Hyginus in his 1482 *Poeticon Astronomicum* depicts Hercules reaching for the trunk of an apple tree with a snake coiled around it — a representation of the eleventh labor of Hercules, in which the hero retrieved the golden apples of the Hesperides (S&T: Aug. 2025, p. 45). This motif may have inspired Hevelius and other celestial car-

tographers to imagine Hercules holding something in his outstretched hand.

Among the first to do that was German astronomer Petrus Apianus. On the star chart in his 1540 *Astronomicum Caesareum*, Hercules lifts the Nemean Lion by the ruff in a representation of his first labor. German celestial cartographer Johann Bayer returned to the theme of Hercules' eleventh labor in his 1603 *Uranometria* star atlas; he portrays the hero's outstretched hand holding an apple-bearing branch. Ninety years later, Hevelius transformed that branch into the three-headed serpent. But even this version would not last long.

The 1721 *Stellarum Fixarum* star map engraved by John Senex — the most widely used contemporary star chart, and the product of an unwilling collaboration between English astronomers John Flamsteed and Edmond Halley — depicts Hercules holding an apple branch entwined by a three-headed snake. In his 1729 *Atlas Coelestis*, Flamsteed reverted back to the hero simply making a fist.

The time has come for you to unleash the hounds of your imagination, and see if you can envision this region as the terrifying three-headed dog from Hades.

■ Cosmic Mythographer **STEPHEN JAMES O'MEARA** has been studying the constellations and their lore for more than 50 years.



► Cerberus, the intimidating three-headed hound who guards the gates of Hades, once appeared among the stars. This 1608 etching by Italian artist Antonio Tempesta shows Hercules grasping the collar of the flesh-eating hound.

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

Mercury and Jupiter Meet at Dawn

The solar system's innermost planet has a busy month with several interesting conjunctions.

WEDNESDAY, AUGUST 5

Each year **Mercury** emerges from the Sun's glare on a half dozen occasions — three times at dusk and three at dawn. This morning marks the planet's greatest elevation for its current apparition for observers at mid-northern latitudes. Mercury rises roughly 90 minutes before the Sun and shines at -0.4 magnitude, making it a reasonably easy target if you have an unobstructed east-northeastern horizon.

Of the five naked-eye planets, little Mercury is often the last one fledgling skywatchers manage to spot. This is partly because of the planet's proximity to the Sun, but also because its apparitions tend to pass quickly — you really need to stay on top of what's going on

in the sky (by reading this magazine, of course), or Mercury's brief window of visibility might open and close before you know it. But if you don't catch the planet this morning, don't worry — you'll get another chance in November. That's when it puts on its best dawn showing for 2026.

FRIDAY, AUGUST 7

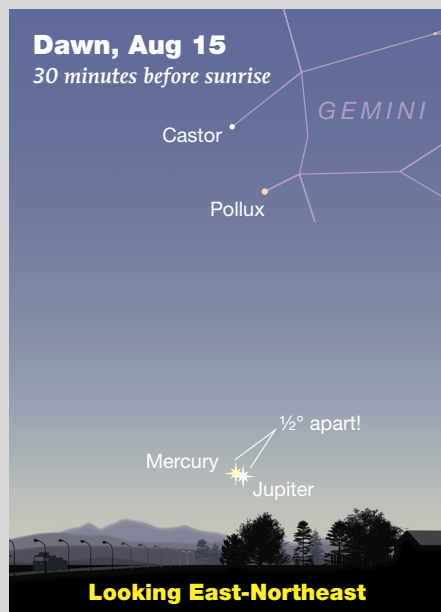
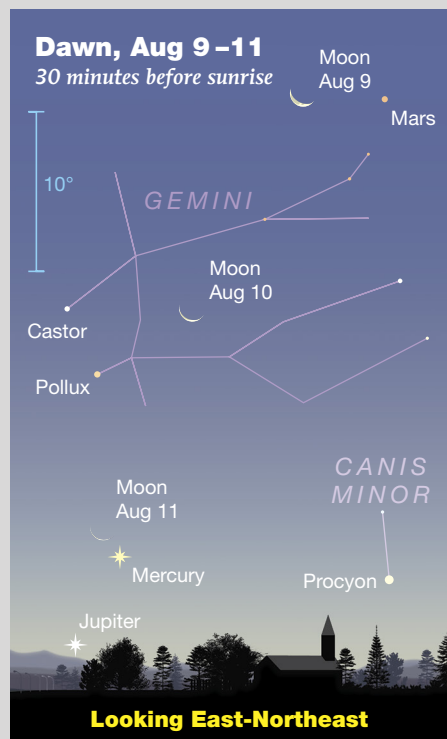
As the night of the 6th transitions into the morning of the 7th, the rising **Moon** glides directly through the **Pleiades** in Taurus — at least for skywatchers in the U.S. Northeast and in the eastern half of Canada. (See page 50 for occultation details.) The rest of us have to content ourselves with the slightly less-inspiring sight of a 37%-illuminated waning lunar crescent positioned just northeast of the cluster. With each passing hour, the Moon drifts farther and farther from the Pleiades, so plan

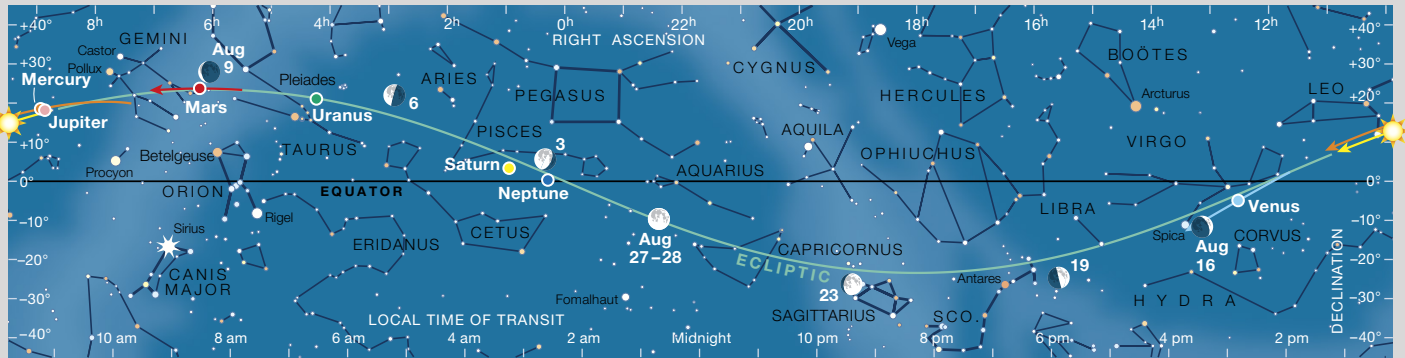
to look as soon after moonrise as possible.

SUNDAY, AUGUST 9

This morning the **Moon** visits **Mars** and, once again, the sight is best appreciated soon after moonrise, when the gap between the two objects is smallest. Although they rise together shortly after midnight, it's worth waiting until around 1 a.m. local daylight time for them to climb a little higher above the east-northeastern horizon. The 15%-lit lunar crescent sits roughly 4° left of the Red Planet, which glows at a peachy magnitude 1.3. Mars is just beginning its slow rise to prominence and won't reach opposition until next February.

The morning sky offers a second attractive alignment, this one featuring **Mercury** along with Gemini's two brightest lights, **Castor** and **Pollux**. The innermost planet has lost a little altitude since the 5th but is still reasonably well placed. One hour before





▲ The Sun and planets are positioned for mid-August; 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.

sunrise Mercury is clear of the east-northeastern horizon and climbing higher as dawn brightens the sky. The planet glows at magnitude -0.7 , easily outshining both Castor (magnitude 1.6) and Pollux (1.1). The two stars are separated by $4\frac{1}{2}^\circ$ and Mercury is double that distance from Pollux, the Gemini luminary it's closest to. With each passing morning, the alignment becomes more obviously out of whack.

TUESDAY, AUGUST 11

Today's dawn conjunction is going to be a challenging one. To see the whole thing, you'll need a clear view toward the east-northeast. If you're so favored, you'll get what is likely your first look at **Jupiter** since it vacated the dusk sky last month. Not only that, but nearby a wafer-thin crescent **Moon** hangs a bit more than $1\frac{1}{2}^\circ$ upper left of our old

friend **Mercury**. All together, the trio is arranged in a narrow triangle with a $6\frac{1}{2}^\circ$ -long base connecting the two planets. Over the next few mornings, the space between Jupiter and Mercury continues to shrink as the latter plunges sunward.

SATURDAY, AUGUST 15

At dawn today **Jupiter** and **Mercury** are at their very closest, separated by a bit more than $\frac{1}{2}^\circ$. That's close enough that you can easily view both planets together with binoculars or in the eyepiece of a telescope at modest magnification. The planetary duo is found low in the twilight sky, with Jupiter rising only one hour ahead of the Sun. Fortunately, Mercury has brightened to magnitude -1.3 , while Jupiter is a touch brighter at magnitude -1.8 . Both throw off enough light to pierce a bright background sky.

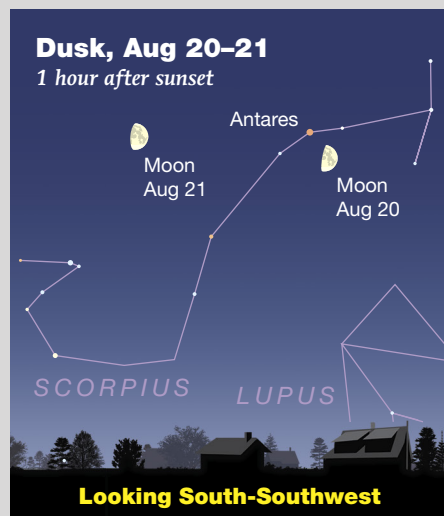
Later today, you can enjoy a second remarkable pairing as the crescent **Moon** greets **Venus** above the west-southwestern horizon at dusk. The 13%-illuminated lunar crescent sits about 4° lower right of the brilliant Evening Star. Coincidentally, today is also the date of Venus's greatest elongation from the Sun. And though it's 46° east

of the solar disk, the planet was actually higher in evening twilight at the end of May. This two-week disconnect between dates is the result of the shallow angle the ecliptic makes to the dusk horizon at this time of year for observers at mid-northern latitudes. When the ecliptic is more perpendicular to the horizon, the dates of "greatest elongation" and "greatest altitude" more closely match.

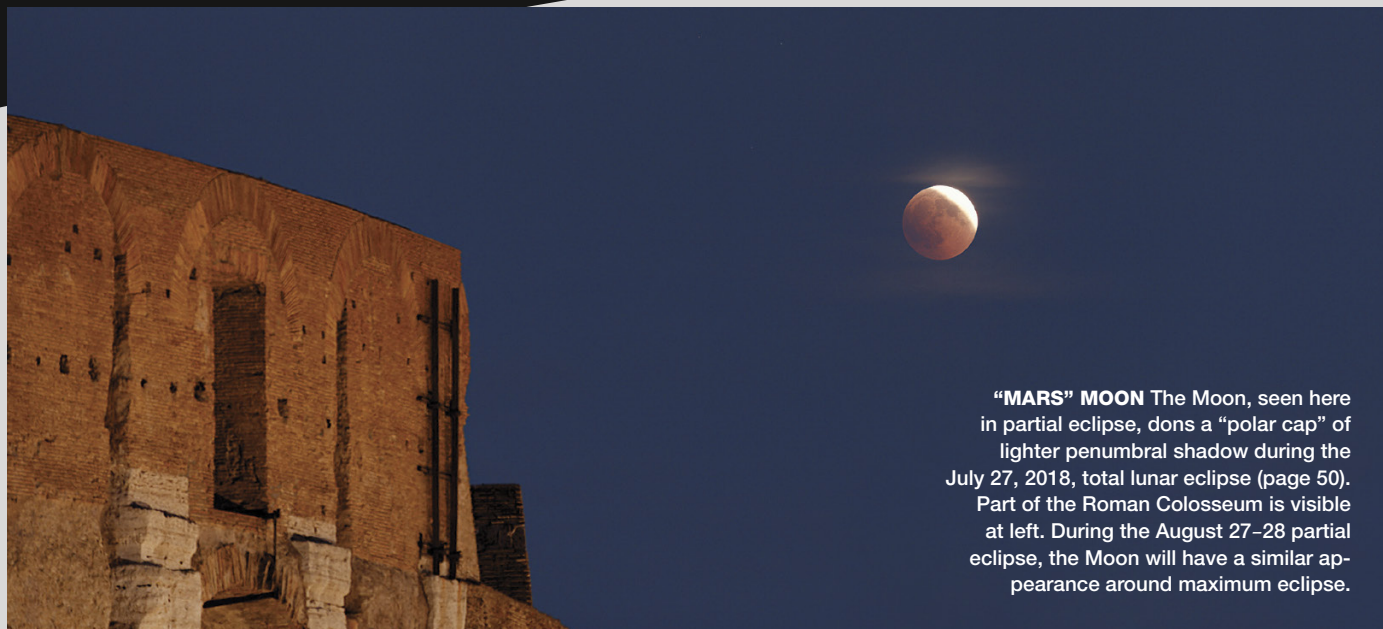
THURSDAY, AUGUST 19

As darkness falls this evening, cast your gaze toward the south-southwestern horizon to see the waxing gibbous **Moon** sitting lower right of **Antares**, the Alpha star of Scorpius, the Scorpion. The Moon is 60% illuminated and one day past first-quarter phase. As a result, it throws off a lot of light. Thankfully, Antares (magnitude $+0.9$) is bright enough to stand up to the lunar glare. Indeed, of all the stars strung out along the ecliptic, only Aldebaran in Taurus is brighter, though only by 0.05 magnitude. Keep watching the conjunction as the evening wears on to see the gap between the two objects gradually narrow. Observers on the West Coast have the best view and get to see the Moon pass within $1\frac{1}{4}^\circ$ of the star at about 11:30 p.m. Pacific Daylight Time. By then, however, the pair is sinking toward the southwestern horizon.

■ Senior Contributing Editor **GARY SERONIK** keeps tabs on the night sky from his home in British Columbia's Okanagan Valley.



◀ 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 seen at arm's length.



“MARS” MOON The Moon, seen here in partial eclipse, dons a “polar cap” of lighter penumbral shadow during the July 27, 2018, total lunar eclipse (page 50). Part of the Roman Colosseum is visible at left. During the August 27–28 partial eclipse, the Moon will have a similar appearance around maximum eclipse.

Our Cosmic Cup Runneth Over

Observers have a full slate of celestial excitement this month.

The year’s lone total solar eclipse takes place on August 12th, the eve of the Perseid meteor shower maximum. Three planets are in view during totality. **Venus** (magnitude -4.4) will be obvious 45° to the left of the Sun, with **Jupiter** (-1.8) and **Mercury** (-1.0) paired up 10° and 15° to the right, respectively. Right before their eyes, observers can see a real-time visualiza-

tion of our heliocentric solar system. The Moon’s shadow touches down on Earth at sunrise on the 12th in Russia’s Taymyr Peninsula, then speeds over the Arctic Sea, missing the North Pole by just 100 km (60 miles) and turning towards Greenland.

Maximum eclipse of 2 minutes 18 seconds occurs just off the coast of Iceland at 17:46 UT. At that point, the

umbral shadow spans about 300 km as it hurries south at some 3,400 km/h (2,100 mph). Reykjavík, the capital of Iceland, lies just within its eastern edge. There, residents will enjoy 59 seconds of totality, starting at 5:48 p.m. local time.

From Iceland, the shadow arcs southeast over the Atlantic, passing about 250 km southwest of Ireland. In the

Perseids Pump Up the Volume

IT’S HARD TO TOP a total solar eclipse, but its fortuitous pairing with the **Perseid** meteor shower presents a rare opportunity to witness two grand cosmic events back-to-back. The shower also serves as a consolation prize for those unable to see the eclipse.

The same celestial chess play required for a total solar eclipse — a new Moon — is responsible for the dark sky that will make this year’s shower exceptional. The Perseids are

active from mid-July to late August, but the peak occurs the night of August 12–13, when Earth passes through the densest part of the swarm. Under ideal conditions, viewers can catch up to 100 meteors per hour. Since most skywatchers have to contend with some degree of light pollution, 50 per hour is a more realistic expectation.

Perseids are the remains of Comet 109P/Swift-Tuttle, which orbits the Sun roughly every 133 years. Each time the comet passes through the inner solar system, the Sun’s heat vaporizes a portion of its dust-rich ice. The crumbs spread along the comet’s orbit, which the Earth intersects annually. As

our planet cuts across the debris trail, sand- to pea-size comet castoffs slam into the atmosphere at 210,000 km/h (130,000 mph) and incinerate in brief flashes of light. The meteors originate from a point called the *radiant* located in the constellation Perseus, the reason they’re called Perseids.

The shower is active as soon as it gets dark. But the later you stay up the more meteors you’ll see. As Earth rotates, the radiant climbs higher during the night. I like to “sample” the shower early from 10 to 11 p.m. local time, then get a few hours of sleep before waking up around 2 a.m. and watching till 4 a.m.

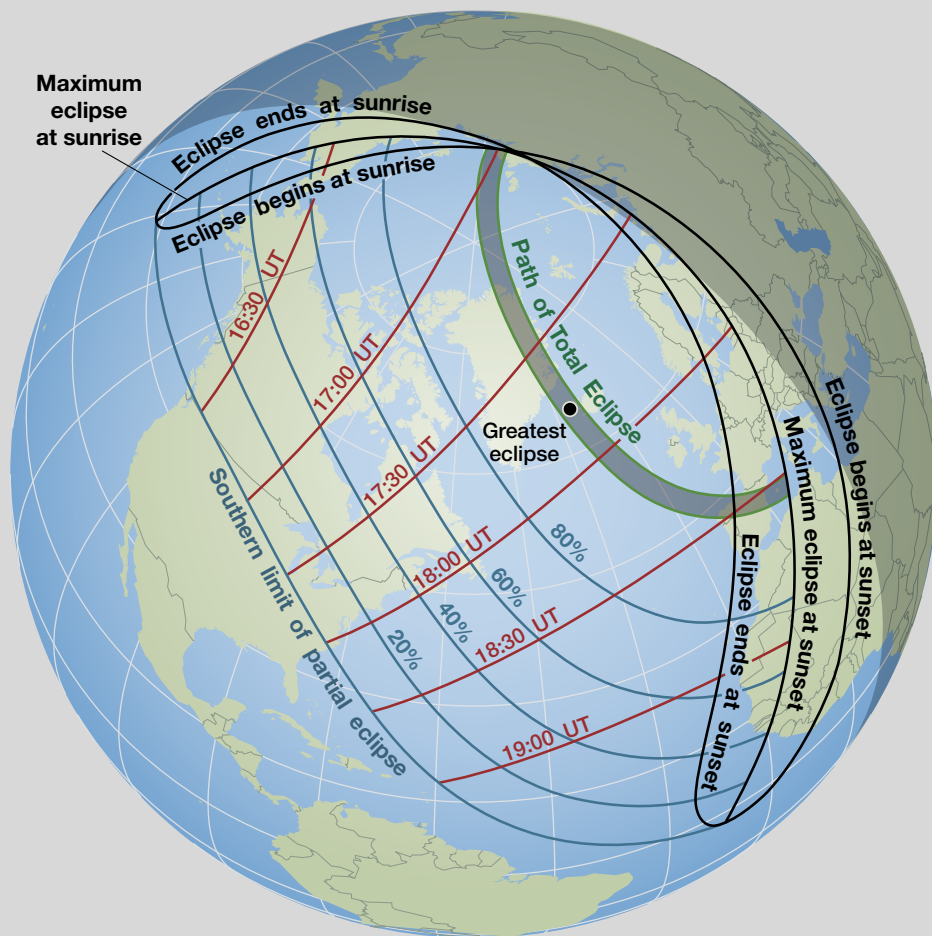
All you need to watch the shower are

► **SOLAR ECLIPSE PATH** The arc shows the ground path of the Moon's shadow during the August 12th total solar eclipse. Greatest eclipse occurs off the west coast of Iceland, where the Moon covers the Sun for 2 minutes 18 seconds. A partial eclipse is visible from parts of the northern and eastern U.S. as well as much of Canada.

city of Cork, 96.4% of the Sun will be obscured at maximum eclipse. Minutes later, the eclipse track crosses the northern half of the Iberian Peninsula, where it is now evening. Many larger Spanish cities lie near or within the shadow path. The northeastern fringe of Portugal also gets a taste of totality.

The near-sunset eclipse will not only present wonderful opportunities for including a terrestrial foreground in photos, but rare sights, too. Atmospheric scattering reddens the Sun's corona, while refraction flattens and elongates the silhouetted Moon and the emerging solar crescent when totality ends.

After the shadow departs the Spanish island of Menorca, it races across the Mediterranean Sea at some 14,600 km/h, before lifting off the planet southwest of Sardinia at sunset. For in-depth weather analysis along the entire eclipse path, I highly recommend Jay Anderson's site at eclipsophile.com. You'll also want to explore Xavier Jubier's interactive eclipse map at xjubier.free.fr/en.



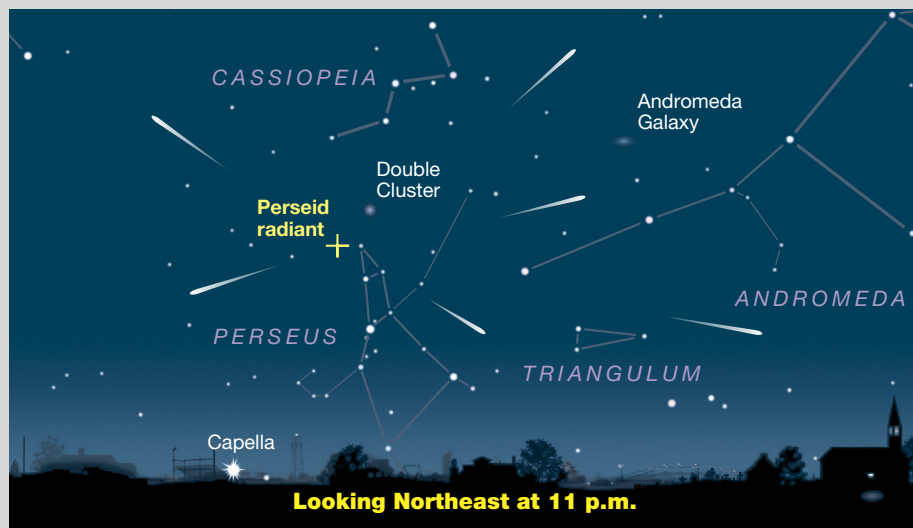
Outside the path of totality, millions of people will be treated to a partial solar eclipse. The region includes Europe, western Africa, Canada, and the northeastern third of the U.S. In northernmost Maine the Moon covers 29% of the Sun around 1:50 p.m., cre-

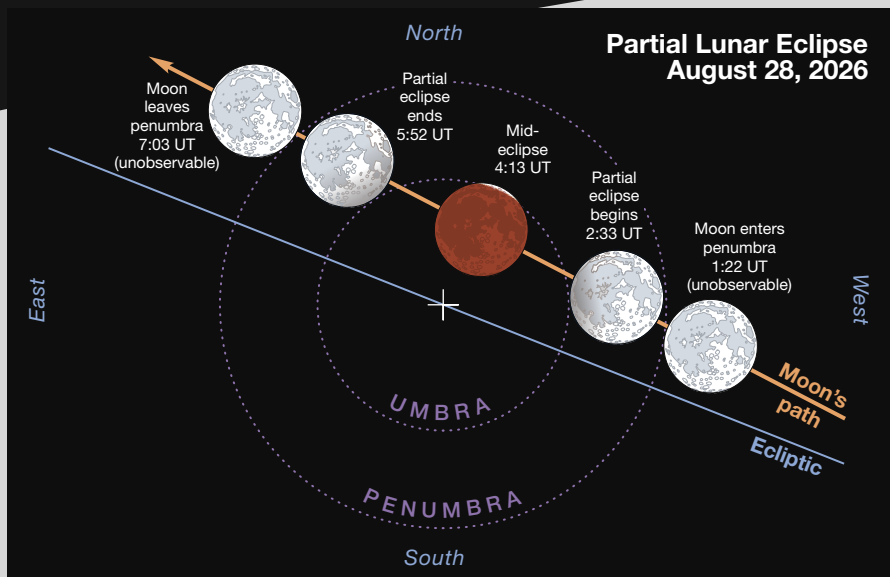
ating a fat solar crescent. Chicago, just inside the southern limit, barely gets a peck on the cheek with the Sun 0.15% covered at 12:28 p.m.

There's so much to see and feel when the Sun, Moon, Earth, and human hearts align.

your eyes and a reasonably dark location. If light pollution is overwhelming, consider a drive to the country. You won't regret it. Remember that comfort and staying warm are paramount when it comes to meteor-watching. Dress for fall, kick back on a lounge chair under a warm blanket, and be wowed.

► **METEOR SHOWER MAP** The Perseids will be extra special this year because moonlight won't be a factor. Similar to railroad tracks that appear to converge in the distance at a vanishing point, meteors stream from a point in the sky called the radiant. You can trace all shower members back to the radiant, which aids in distinguishing them from random meteors called *sporadics*.





Good Things Come in Pairs

JUST TWO WEEKS after the solar eclipse, the Moon takes its turn in the shadow. Eclipses always come in pairs, with a lunar eclipse occurring two weeks before or after a solar eclipse. This happens because the Moon is still close enough to the Sun-Earth orbital plane to cross into Earth's shadow.

On the night of August 27–28, the full Sturgeon Moon undergoes a deep partial eclipse. There's more than one shadow at play during a lunar eclipse. The semi-dark outer shadow, the *penumbra*, becomes obvious some 30 minutes before the partial phase begins and disappears after it ends. Look for a smudgy gray cast on the Moon's limb.

At mid-eclipse, Earth's dark inner shadow, the *umbra*, will cover 96.2% of the Moon. Only the north polar region escapes umbral darkness. Like a turtle's head it pokes out beyond the shadow's edge into the gray outer penumbra. The reddened Moon fringed in white eerily resembles the planet Mars with its north polar cap.

The eclipse is widely visible across the Americas, Europe, Africa, and the eastern Pacific. Greatest eclipse, when the Moon nestles deepest within the umbra, occurs at 12:13 a.m. (August 28th)

▲ PHASES OF THE LUNAR ECLIPSE On August 27–28 the Sturgeon Moon dives deeply enough into Earth's shadow to undergo a near-total eclipse. The partial phase lasts more than 3 hours, with a maximum obscuration of 96.2% – dark enough to conduct a search for meteorite impact flashes through a telescope with a low-light video camera. The eclipse is visible across more than half the Earth. Penumbral shading will be obvious up to half an hour before and after partial eclipse.

Eastern Time. For many U.S. observers the lunar pageant gets underway during convenient evening viewing hours. That, and pleasant August temperatures, should encourage lots of people to step outside and watch the show.

Sunlight streaming around Earth's circumference is first reddened and then refracted into the umbra by the atmosphere, painting the shadowed Moon in shades of burnt orange, red, and copper. The hue varies from eclipse to eclipse depending on the state of the atmosphere. Clouds, dust, volcanic ash, and water droplets all affect the particular shade of red. In binoculars and small telescopes, you may notice that the umbra's fuzzy border has a turquoise color. Ozone in the upper stratosphere absorbs red light, allowing only the bluer colors to pass.

Seeing the Moon transform from a glaring white disk into a ruddy ball suspended in a star-studded sky never gets old, no matter how many lunar eclipses you've experienced.

Moon Occults the Pleiades at Midnight

WE'RE STILL IN the thick of **Pleiades** occultation season, with another cluster cover-up on tap for August 7th. Early that morning, the 36%-illuminated lunar crescent blots out several of the brighter Pleiads in the cluster's western half from about midnight to 1:30 a.m. local time. The events are only visible in the eastern half of North America, with the **Moon** low in the northeastern sky. Farther west, observers see a lovely Moon-cluster conjunction, but no occultations.

Observers in the northeastern U.S. have the best view. From Boston, the cosmic hide-and-seek begins at 12:27 a.m. when the Moon's bright limb covers the stars one by one. They start flashing back into view at 1:15 a.m. In the Central Time Zone, occultations are already underway at moonrise and may be difficult to see. Instead, watch for the stars as they reappear at the dark limb. To determine your own local times for these events, simulate them with an app like *Stellarium Mobile* (free) or *Sky Safari*. Or use an online planetarium like Stellarium on the Web at **stellarium-web.org**. Set the time for when the Pleiades rise; then zoom in on the cluster and step forward in time, noting when each star disappears and reappears.

Action at Jupiter

THE BIG PLANET was missed last month, but after its conjunction with the Sun on July 29th, it's back for a dawn apparition. Around the middle of the month, you can catch the -1.8-magnitude planet low in the twilight morning sky through a telescope. Jupiter is still quite close to the Sun, so in the interest of eye safety, stop before sunrise. You've got about half an hour of observing if your eastern horizon is clear, so make the most of it.

Starting on August 11th, Jupiter is a mere 2½° above the east-northeastern horizon just before dawn. It rises earlier each morning until the end of the month, when it reaches 15° at sunrise. Jupiter's only encounter with another planet happens when Mercury zips by from the 14th to the 16th.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The diagram on this page shows their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated below. 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.)

August 11: 4:05, 14:01, 23:56;
12: 9:52, 19:48; **13:** 5:44, 15:40;
14: 1:36, 11:32, 21:27; **15:** 7:23, 17:19;
16: 3:15, 13:11, 23:06; **17:** 9:02, 18:58;
18: 4:54, 14:50; **19:** 0:46, 10:42,

20:37; **20:** 6:33, 16:29; **21:** 2:25, 12:21, 22:16; **22:** 8:12, 18:08; **23:** 4:04, 13:59, 23:55; **24:** 9:52, 19:47; **25:** 5:43, 15:39; **26:** 1:35, 11:31, 21:26; **27:** 7:22, 17:18; **28:** 3:14, 13:10, 23:05; **29:** 9:01, 18:57; **30:** 4:53, 14:49; **31:** 0:45, 10:40, 20:36.

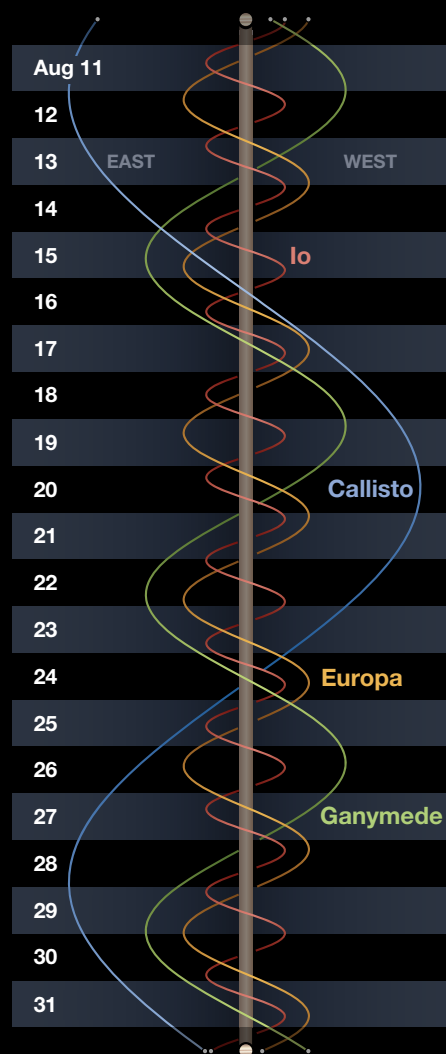
These times assume that the spot will be centered at System II longitude 88.5° on August 1st. If the Red Spot has moved elsewhere, it will transit 1⅓ minutes earlier for each degree less than 88.5° and 1⅓ minutes later for each degree more than 88.5°.

Phenomena of Jupiter's Moons, August 2026

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

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

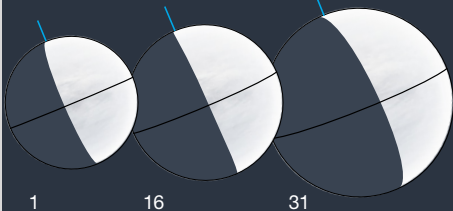


The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites'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

Mercury



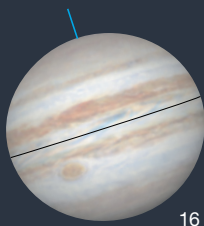
Venus



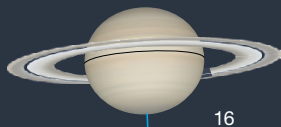
Mars



Jupiter



Saturn



Uranus



Neptune



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

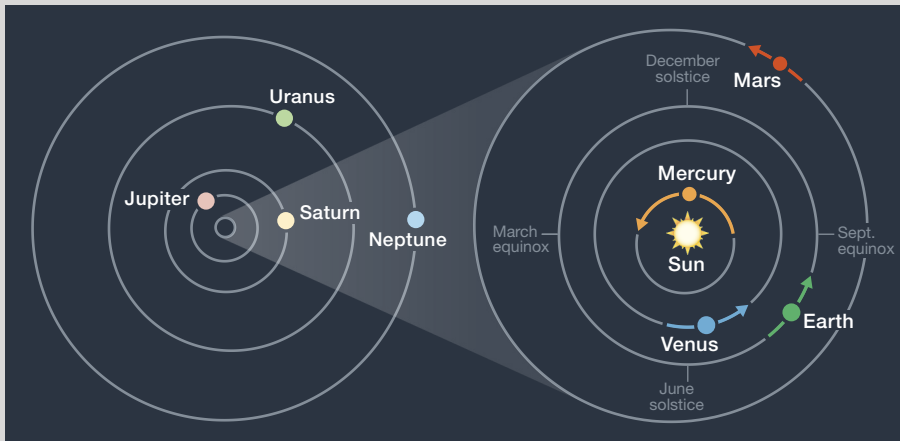
► **ORBITS OF THE PLANETS**
The curved arrows show each planet's movement during August. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn until the 18th • **Venus** visible at dusk • **Mars** visible at dawn • **Jupiter** visible at dawn low in the east-northeast starting on the 10th • **Saturn** rises in the evening and is visible till dawn.

August Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	8 ^h 43.4 ^m	+18° 09'	—	−26.8	31' 31"	—	1.015
	31	10 ^h 35.8 ^m	+8° 51'	—	−26.8	31' 41"	—	1.010
Mercury	1	7 ^h 21.6 ^m	+19° 56'	19° Mo	+0.3	7.9"	35%	0.848
	11	8 ^h 16.3 ^m	+20° 02'	16° Mo	−0.9	6.1"	71%	1.101
	21	9 ^h 34.4 ^m	+16° 08'	7° Mo	−1.6	5.2"	96%	1.299
	31	10 ^h 50.3 ^m	+9° 10'	4° Ev	−1.6	4.9"	99%	1.375
Venus	1	11 ^h 36.8 ^m	+2° 29'	45° Ev	−4.3	20.8"	56%	0.800
	11	12 ^h 12.5 ^m	−2° 24'	46° Ev	−4.4	23.2"	51%	0.720
	21	12 ^h 45.9 ^m	−7° 09'	46° Ev	−4.5	26.0"	46%	0.640
	31	13 ^h 16.4 ^m	−11° 35'	45° Ev	−4.6	29.7"	39%	0.562
Mars	1	5 ^h 28.2 ^m	+23° 20'	46° Mo	+1.3	4.7"	94%	1.998
	16	6 ^h 11.8 ^m	+23° 43'	50° Mo	+1.3	4.8"	93%	1.932
	31	6 ^h 54.1 ^m	+23° 23'	55° Mo	+1.3	5.0"	92%	1.856
Jupiter	1	8 ^h 36.4 ^m	+19° 05'	2° Mo	−1.8	31.3"	100%	6.301
	31	9 ^h 03.0 ^m	+17° 23'	24° Mo	−1.8	31.8"	100%	6.202
Saturn	1	0 ^h 56.8 ^m	+3° 20'	114° Mo	+0.6	18.5"	100%	8.994
	31	0 ^h 53.3 ^m	+2° 50'	144° Mo	+0.5	19.3"	100%	8.610
Uranus	16	4 ^h 12.5 ^m	+20° 59'	78° Mo	+5.7	3.6"	100%	19.639
Neptune	16	0 ^h 15.6 ^m	+0° 09'	139° Mo	+7.8	2.3"	100%	29.106

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 au equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit skyandtelescope.org.



Catch a Shooting Star

This year offers ideal conditions for photographing the Perseid meteor shower.

With the peak of the Perseid meteor shower on the night of August 12–13 coinciding with new Moon, the entire night will be dark, moonless, and meteor-filled! But nights before and after the peak date can be good as well (see page 48).

Conditions couldn't be better for capturing a meteor, or many. You can get a camera or two going, then lie back and enjoy the show. Here are my suggestions for gear and techniques.

Lenses and Exposures

From a city site, you might be lucky to catch an occasional bright meteor. For your best chances on peak night, plan to be at a site dark enough to see the Milky Way. The faintest meteors will then show up to your eye and to your DSLR or mirrorless camera.

Meteors are fleeting, lasting only a second or two. And faint meteors are the most numerous. So to maximize your meteor catch, use a photographically “fast” lens, one with a wide maximum aperture (low f/number), to let in as much light as possible during the brief time a meteor is visible. I recommend at least an f/2.8 lens, if not faster at f/2 or even f/1.4. Picking up more meteors may be a fair trade-off for any optical aberrations the lens might exhibit at the corners of the camera frame when used wide open (see *S&T*: August 2022, p. 54).

I generally shoot with fast and wide 14-mm to 16-mm rectilinear lenses (they yield straight horizons), though 10-mm



A NIGHT OF RADIATING STARS This composite shows the 2021 Perseid meteor shower's radiant from Dinosaur Provincial Park in Alberta, Canada. The author used a Canon EOS 6D DSLR camera at ISO 6400 and a 14-mm lens at f/2.8 on a Sky-Watcher Star Adventurer 2i tracking mount. He layered 27 one-minute meteor frames onto a blend of three frames for the sky, and a stack of four untracked images for the foreground taken at the start of the night.

to 12-mm fisheye lenses with their curved horizons can also work well, too.

Despite the brevity of meteor flashes, I keep the shutter open for the maximum length of time the sky will allow before it overexposes. At f/2.8, that might be 20 to 30 seconds at ISO 1600 to 3200. At faster apertures, try to keep the exposure time long but lower the ISO.

The key to success is to take lots of exposures. Use an intervalometer, either built into most cameras (called an Interval Timer), or a separate device plugged into the camera's remote port, to fire the camera shutter with no more than one second between exposures. A simple, inexpensive shutter release cable paired with the camera's burst mode, or continuous-shooting mode, will also work.

You want the shutter to be open as much as possible, as the night's best meteors have a habit of appearing

when the shutter is closed. If you shoot short exposures, say only five seconds, an interval of one second means the shutter is closed for 16% of the shooting cycle. You might miss a sixth of the meteors. With 30-second exposures at the same interval, the camera “down time” is only 3%. And a tip: If a bright meteor appears, don't immediately close the shutter; otherwise, you'll end up with a nice meteor but set against a dark, underexposed sky. Plus, bright meteors often leave yellow ionization vapor trails that can linger for several minutes. So, keep shooting!

► **BASIC CAMERA GEAR** The author's setup for shooting untracked frames (*left*) consists of a wide-angle, full-frame camera on a 3-way geared head and sturdy tripod. His tracked setup (*right*) uses a ball-head mount and a polar-aligned Sky-Watcher Star Adventurer 2i tracker to compensate for Earth's rotation.





◀ **PERSEID TRIO** This tracked composite captures three meteors streaking along the Milky Way in 2023. Also visible are the three 1st-magnitude luminaries of the Summer Triangle — Alpha (α) Lyrae, or Vega (top), Alpha Aquilae, or Altair (far right), and Alpha Cygni, or Deneb (to the left of center). The author used a Canon EOS R mirrorless camera and an RF 15-35 mm lens set at 35 mm for the individual shots.

◀ **METEORS GALORE** Perseids rain down and the northern lights glow during the 2018 Saskatchewan Summer Star Party.

image, it's best to use a star tracker (motorized mount) to follow the sky. Doing so makes it far easier in later processing to align and stack the individual images, assuming your initial polar alignment of the tracker was accurate.

For a tracked set framing the radiant, I start the sequence with the camera aimed to compose the horizon scene well. I take several images first with the tracker motor off to obtain the static foreground images to be used in the final blend.

However, you can also shoot composites using a camera on a stationary tripod head. If so, frame the scene at the start of the night as you think would be best for the foreground. But you won't be able to simply stack all the images later, as the motion of the sky and the rising radiant point will make the stacked meteors appear to shoot from a wide band in the sky. The radiant effect will be lost.

When shooting for an untracked composite, I suggest using a lens wide enough to include Polaris due north. Just as the sky turns about Polaris (or close to it), you'll need to manually rotate each meteor frame during post-processing around that point.

Stacking a Tracked Composite

Stacking meteor shower images taken either untracked or tracked involves complex work at the computer. I use *Adobe Photoshop* ([photoshop.adobe.com](https://www.adobe.com)), but you can use other image-editing programs such as *Canva Affinity* (www.affinity.studio). I first use *Photoshop's* companion program *Adobe Bridge* (https://is.gd/adobe_bridge) to bring

Aiming and Framing

Aiming toward Perseus will capture meteors streaking in all directions away from the radiant, the effect of perspective that I show in the accompanying examples, all taken from Canada. But Perseids, as in any meteor shower, can appear anywhere in the sky. Meteor trails are longer the farther they are from the radiant. An option is to shoot to the south or southwest to get parallel meteors raining down to the horizon in front of the Milky Way.

However, I can guarantee that no matter which way you aim your camera, meteors will appear elsewhere! But it's

foolish to chase them. Keep the camera, or better yet two or three cameras, aimed with a consistent framing to cover as much sky as possible. The more sky coverage you have, the less likely you are to miss the best ones.

To Track or Not to Track

A single shot taken on a fixed tripod that shows one brilliant meteor over a scenic landscape can be a prize winner. But the images that might inspire you are often composite photos showing several hours' worth of meteors all in one frame, revealing the shower's radiant. If you want to create such an

► **FISHEYE VIEW** The author captured this sweeping sky view of the 2021 Perseids with a Canon EOS Ra and 7.5-mm lens from Dinosaur Provincial Park. The planet Jupiter can be seen at lower right.

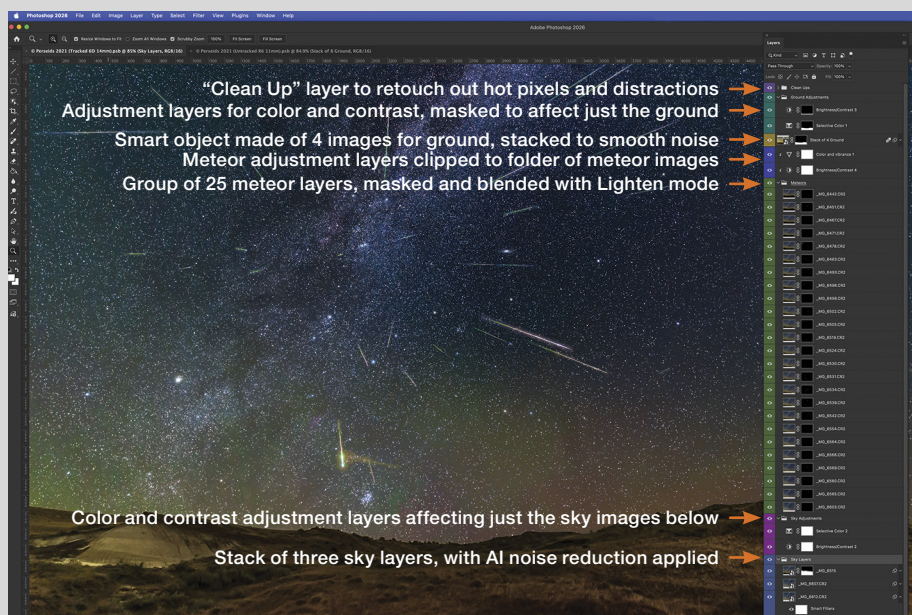
► **STACKING TRACKED METEORS** This *Adobe Photoshop* screenshot shows the many layers that went into the tracked meteor composite — with the masked ground layers on top and a group of 25 meteor frames below (each masked to reveal just the meteor). They are blended onto a stack of sky exposures at the bottom, with each element having its own adjustment layers for color and contrast.

all the developed RAW files into *Photoshop* with its Tools > Photoshop > Load Files into Photoshop Layers... command found in the pulldown menu along the top of the screen. Alternatively, from *Adobe Lightroom Classic* (https://is.gd/lightroom_classic), use its equivalent command Photo > Edit In > Open as Layers in Photoshop...

Whatever the workflow, every meteor composite involves three basic elements: a foreground image (taken at the start of the night), a base sky image (which in a tracked set can be any of the tracked images), and all the other images with meteors. Go through your night's haul and flag those with meteors, likely just 10% of the hundreds you took . . . if you're lucky!

With those select few layered onto the base sky image, add a mask to each meteor image layer. Click on the image layer in the Layers Panel to select it and then click on the layer mask icon (the white box with a dark circle) at the bottom of the Layers Panel. Edit the mask by using the Brush Tool to paint on the mask. Use a black brush to first paint out (hide) the meteor. Then Invert the mask (Command/Control + I) so just the meteor is revealed. It's easier to first paint out the meteor you can see, then invert the mask to bring it back in. Change the layer's Blend mode to Lighten. Rinse and repeat through the stack!

Assuming you're aimed northeast, as the camera tracks through the night more sky appears at the bottom of the frame as the foreground, which you framed at the start, moves off the frame. Adding the foreground back in



requires expanding the canvas down to make room for the foreground image below the bottom of the sky content.

Stacking an Untracked Composite

A more tedious process is working with an untracked set. To have all the meteors placed accurately so they radiate as they should from northern Perseus, you'll have to rotate each frame around Polaris, so that the frame is at least close to aligning with the base sky image.

To help with that, change the Blend mode of the meteor layer to Difference. Then rotate the layer until the stars

seem to cancel each other out. They'll never do so exactly; just get it close. Add the mask, paint out the meteor, invert the mask, and change the Blend mode to Lighten, and so on through the stack. Expect to spend as much, if not more time processing the final image as you took to shoot them! But the reward is a unique image from a memorable night under the "shooting stars" of summer.

■ Contributing Editor ALAN DYER is coauthor with Terence Dickinson of *The Backyard Astronomer's Guide*. He can be reached through his website at amazingsky.com.

Globular Cluster Challenge

See if you can snag these elusive stellar cities.

Globular clusters are favorite targets for most backyard astronomers. They're among the most magnificent deep-sky objects for observers — dozens of these spherical star cities are bright enough to be obvious in a 60-mm scope. Several are even detectable to the unaided eye. And yet, among the Milky Way's globulars there are some

that present quite a challenge to the visual observer and require a large aperture, decent skies, and diligent effort to detect. On this tour, we'll visit a few tough ones that lie in the direction of the galactic center, which is where we find the largest concentration of globular clusters.

It's not too difficult to understand

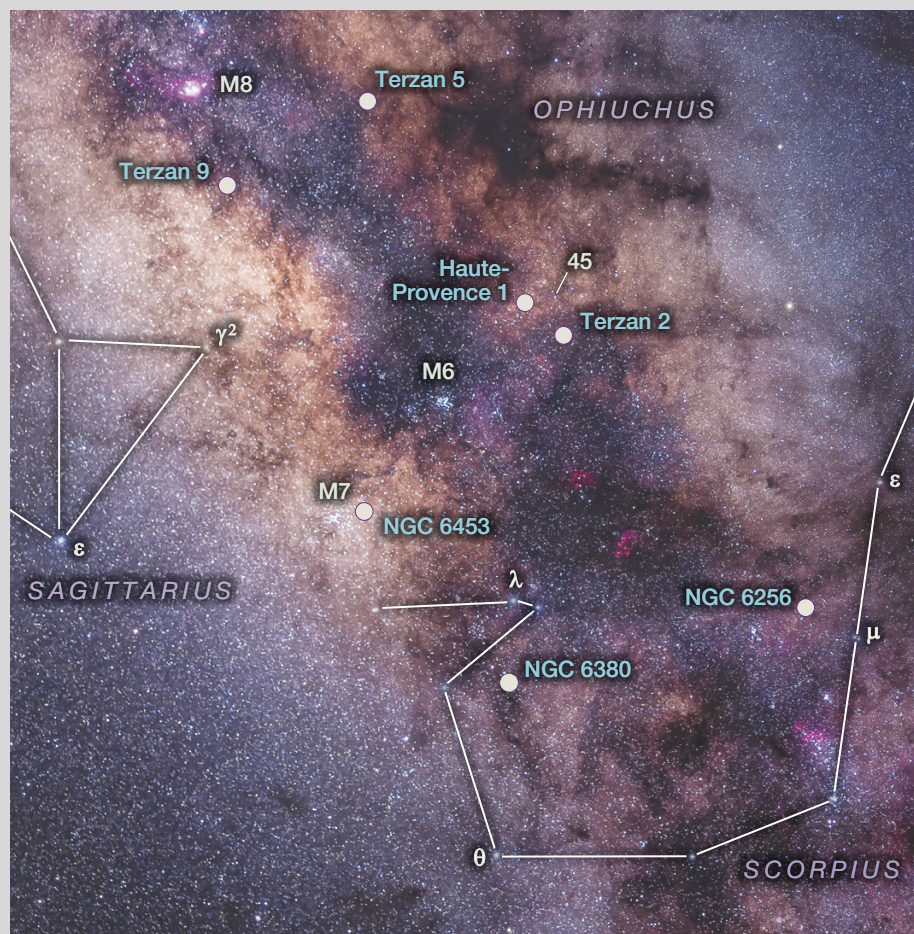
why we see more globulars toward the core of the Milky Way than we do when our view is directed away from it. As these clusters exist in a roughly spherical arrangement around our galaxy, from our offset vantage point in a spiral arm, we naturally encounter more of them when we look toward the galactic center. It was in studying this distribution that in the early decades of the 20th century American astronomer Harlow Shapley deduced the Sun's location in the Milky Way.

There are at least 50 cataloged globular clusters within 15° degrees of the galactic center. I've enjoyed seeking out some of them with my larger-aperture Dobsonians. Let me introduce you to a selection of my favorites.

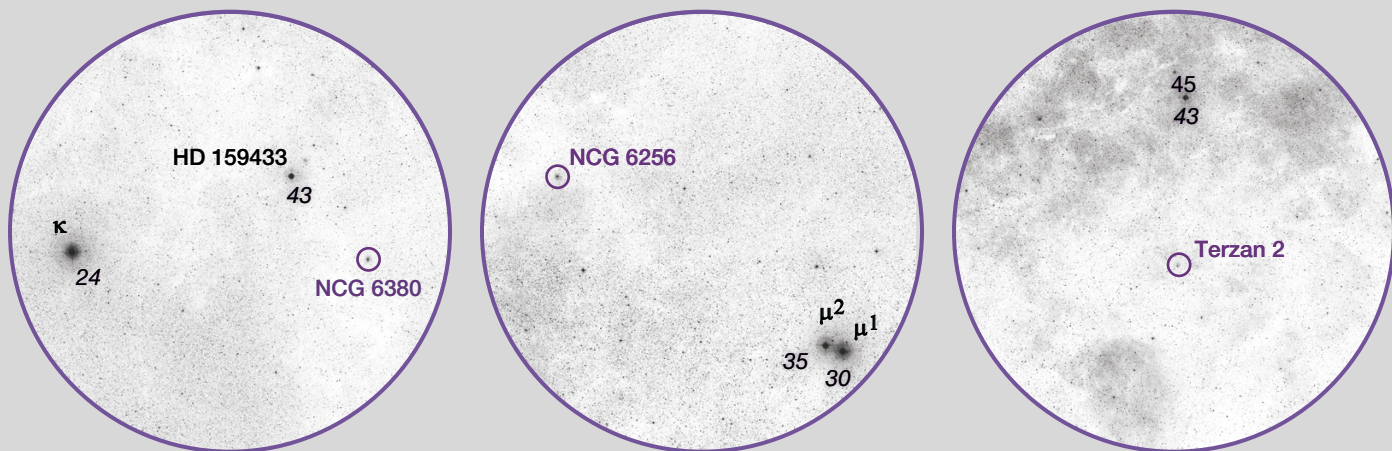
Tricky Targets in a Sea of Stars

NGC 6380 is considered one of the more difficult globulars to snag in the *New General Catalogue of Nebulae and Clusters of Stars* published in 1888. The 11.3-magnitude cluster sits about 1.5° west of 2.4-magnitude Kappa (κ) Scorpii and almost 2° south of Lambda (λ) Scorpii, also known as Shaula. It's about 34,300 light-years from us and lies within 10,000 light-years of the galactic center.

Scottish astronomer James Dunlop may have observed the globular in 1826, but his inaccurate position and description cast doubt on that observation. In addition, Contributing Editor Steve Gottlieb speculates that Dunlop could not have seen the object in his 9-inch speculum-metal reflector. Credit for its discovery should rather go to



▲ **FAROUT GLOBULAR CLUSTERS** The clusters discussed here are all toward the galactic center — you'll find them in Sagittarius, Scorpius, and Ophiuchus. Their distances range from almost 18,000 to more than 35,000 light-years. Get your big scopes out and see if you can spot them.



▲ **GO DEEP** Not only are these globular clusters challenging due to their location in the very busy galactic center region, but some are also far from convenient star-hopping points. Use these finders as aides to get to the targets. NGC 6453 is not shown as all you need to do is find the open cluster M7 and search for it along the northwestern edge. Each image is about 2° across and star magnitudes are labeled without the period.

John Herschel who recorded it on June 29, 1834. More than a century later in 1959, Turkish-Mexican astronomer Paris Marie Pişmiş using the Schmidt camera at the Tonantzintla Observatory at San Andrés Cholula in the Mexican state of Puebla, reported it as a new discovery. Consequently, the object is also known as Ton 1 and Pismis 25.

NGC 6380 was originally classified as an open cluster, perhaps due to the obscuring proximity of the 10th-magnitude star HD 159073 as well as the thick interstellar dust that enshrouds the cluster. Based on its appearance in photographic plates, British-born astronomer Andrew David Thackeray confirmed its identity as a globular cluster in the 1950s.

In my 30-inch f/4.45 Dobsonian at 185×, NGC 6380 first appeared as a faint, fan-shaped, nebulous cloud extending north-northeast of HD 159073. Averted vision and longer study slowly revealed a hint of individual stars on its boundaries, but the bulk of the cluster remained unresolved.

Moving west from Shaula by 7°, we come to our next stop, 11th-magnitude **NGC 6256**. Look for it 1.7° northeast of 3.0-magnitude Mu¹ (μ¹) Scorpii. Even if some references also attribute this cluster's discovery to Dunlop, John Herschel's logs note that he observed it on June 28th and again on June 29, 1834 — and Herschel's description matches that of the NGC entry.

I examined this small cluster with my

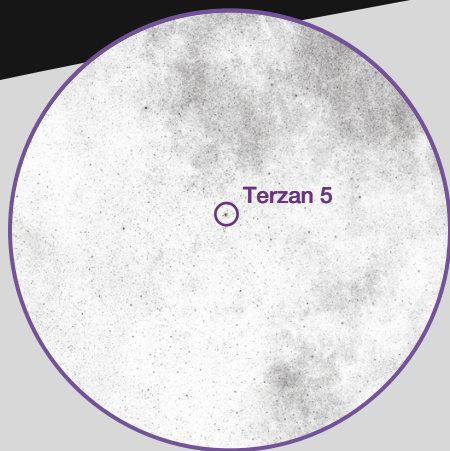
30-inch Dob at 229× and 300×. Averted vision helped me see it best — it appeared roughly triangular in shape, mostly unresolved, though its center was a bit more conspicuous. Overall, the cluster is of moderately low surface brightness. An earlier observation with my 18-inch f/4.5 Dob resulted in a less reliable detection. I needed averted vision to see anything at all, and my notes describe it as small, faint, and round with a gradually brighter center. But I could only detect it less than 50% of the time.

On June 8, 1837, John Herschel also discovered our next target, **NGC 6453**, reporting it to be “a highly condensed nebulous mass . . .” and noted it was “resolvable.” With my 30-inch Dob at 111×, I could only distinguish stars on

Galactic Center Globulars

Object	Constellation	Mag	Size/Sep	Distance (l-y)	RA	Dec.
NGC 6380	Scorpius	11.3	3.9′	13,000	17 ^h 34.5 ^m	−39° 04′
NGC 6256	Scorpius	11.3	1.5′	33,300	16 ^h 59.5 ^m	−37° 07′
NGC 6453	Scorpius	9.6	3.5′	33,000	17 ^h 50.9 ^m	−34° 36′
Terzan 2	Scorpius	14.3	0.6′	6,800	17 ^h 27.6 ^m	−30° 48′
Terzan 5	Sagittarius	13.9	2.4′	47,600	17 ^h 48.1 ^m	−24° 47′
Terzan 9	Sagittarius	16.0	0.2′	45,000	18 ^h 01.6 ^m	−26° 50′
Haute-Provence 1	Ophiuchus	12.5	1.2′	29,700	17 ^h 31.1 ^m	−29° 59′

Angular sizes and separations 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. Magnitudes are visual.



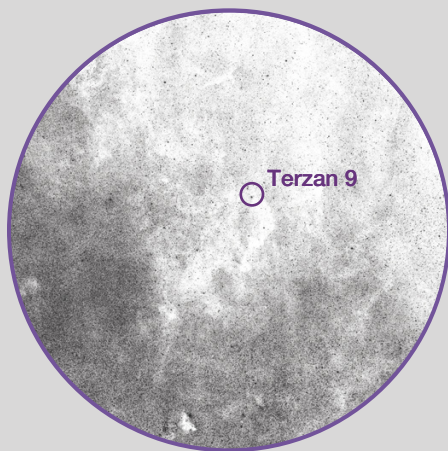
the periphery of this small globular. But it was nevertheless fairly easy to detect and, at magnitude 9.6, moderately bright, and displayed a dense core.

NGC 6453 sits just on the northwestern edge of the open cluster M7 making it a cinch to find. It's about 35,800 light-years from us, far behind the Messier object, which is less than 1,000 light-years away.

A Trio of Terzans

In the 1960s and '70s, Turkish-French astronomer (of Armenian descent) Agop Terzan conducted a survey of the plane of the Milky Way in the infrared, and while doing so discovered 11 globular clusters in the constellations of Sagittarius and Scorpius. These clusters appear small and are heavily obscured by dust. I've attempted all 11 Terzan globulars with my 30-inch Dob with only limited success. Three of the clusters stand out, though, and I think they merit covering here.

Terzan 2 is in Scorpius, and you'll find it 56' south of the 4.3-magnitude star 45 Ophiuchi. It's just south-southeast of a splash of stars designated van den Bergh-Hagen 228. Even though some references conflate the two clusters, studies show they are separate, physical objects. In my 30-inch Dob at 300× with averted vision, the globular eventually materialized as little more than a faint smudge. I could sometimes convince myself that I was seeing two distinct objects, but my confidence in that was low. In my 18-inch at 236× the



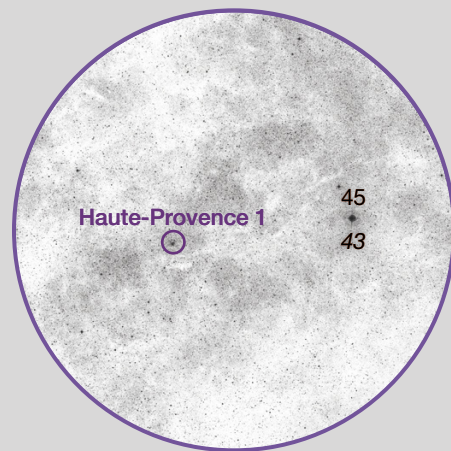
cluster wasn't reliably visible. Occasionally I detected a hint of it, but I think that's only because I knew it was there.

At a little less than 2,000 light-years from the galactic center in Sagittarius, **Terzan 5** is one of the closest globulars to our galaxy's core. To find it, scan about 6° east of 3.3-magnitude Theta (θ) Ophiuchi or 3.6° west-southwest of M8. An 11th-magnitude star sits 50" southeast of its core. Using my 30-inch at 111×, the cluster appears as a faint glow with a few resolvable stars that may be foreground field stars. I detected it best with averted vision, but there were moments when I spied it with direct vision. This cluster briefly bore the designation Terzan 11 until astronomers realized that it was a rediscovery of Terzan 5 (the original Terzan 12 is now known as Terzan 11). Some references still confuse them, however.

Another contender for the closest globular to the galactic center is **Terzan 9** — estimates place it around 2,300 light-years from the core. Look for it around 3.7° north-northwest of 3.0-magnitude Gamma² (γ²) Sagittarii, also known as Alnasl. In my 30-inch, I needed 433× to detect this object with any certainty. Employing averted vision, it appeared as a faint, round patch of nebulosity with a slightly brighter arc near its center.

One More for Good Measure

Our last stop is a tiny globular with the interesting name of **Haute-Provence 1**. It's located in Ophiuchus near the



border with Scorpius, some 50' east-southeast of 45 Ophiuchi.

French astronomer Jean Dufay discovered the cluster in 1954, which is named for the Haute-Provence Observatory in southeastern France. It's sometimes referred to as Dufay 1 as well as van den Bergh-Hagen 229.

Through my 18-inch at 118×, Haute-Provence 1 appears small and faint — basically a fuzzball. Higher powers of 197× and 262× didn't help to resolve it. In my 30-inch at 111×, it presented a peppery texture as if its stars were on the verge of materializing, but I couldn't distinguish individual members.

I observed these faint globulars at a latitude 31.6° north and under Bortle 4 skies. I should add that my old eyes are decades past their prime. Your results will certainly vary, but no matter how good your skies or how young your eyes, I can predict that you, too, will find these particular globulars quite challenging. Give them a try.

■ Contributing Editor **TED FORTE** has enjoyed years of seeking out challenging faint fuzzies at the limits of visual detection.

FURTHER READING: For information on the visual properties of NGC objects as well as their discovery histories, go to Contributing Editor Steve Gottlieb's website deepskygottlieb.com. You'll also find a searchable database for a variety of catalogs, including the *Index Catalogue* and the *Uppsala General Catalogue*, among others.

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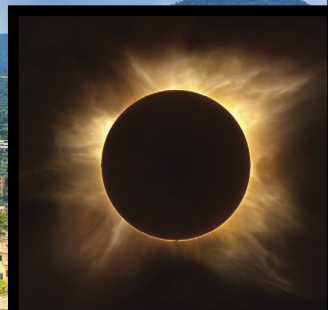
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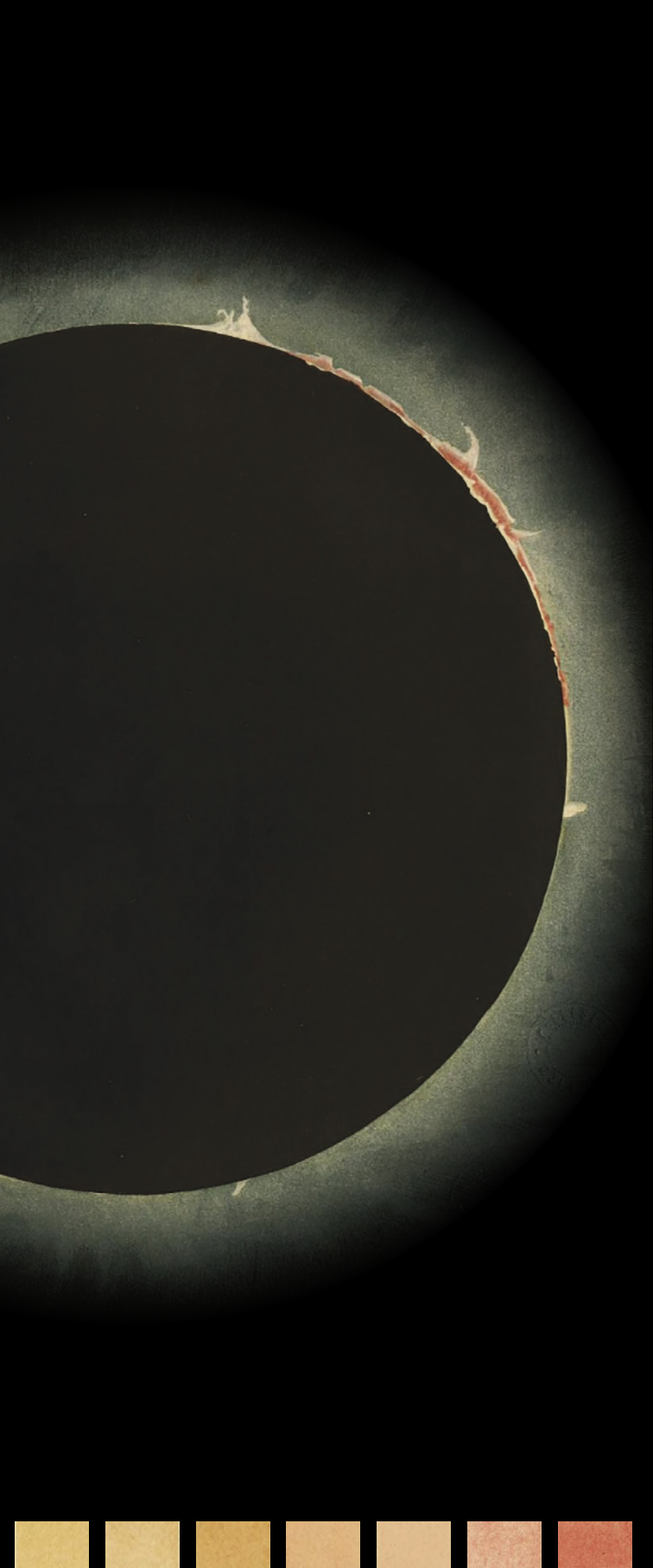
De la Rue and the Eclipse of 1860



DE LA RUE / PHIL. TRANS. PART I,
P. 333 (1862) / PUBLIC DOMAIN

Scale of colors with
which the prominences
were compared





On August 12, 2026, the daytime sky above the Spanish town of Rivabellosa will fall dark — just as it did on July 18, 1860.

As the summer sun beats down, the smell of burning straw fills the air.

Flames spread quickly through the dry crop fields, edging toward Warren De la Rue's precious clutter of instruments. Months of careful preparation for this eclipse — lenses, clockwork mechanisms, chemical plates, and a fragile wooden hut to house them — are all suddenly in harm's way.

With just 20 minutes to go before first contact, De la Rue's plans, and the small fortune he's put toward realizing them, are about to go up in smoke.

But the stakes are more than financial. A scientific mystery is waiting to be solved.

Solar Prominences

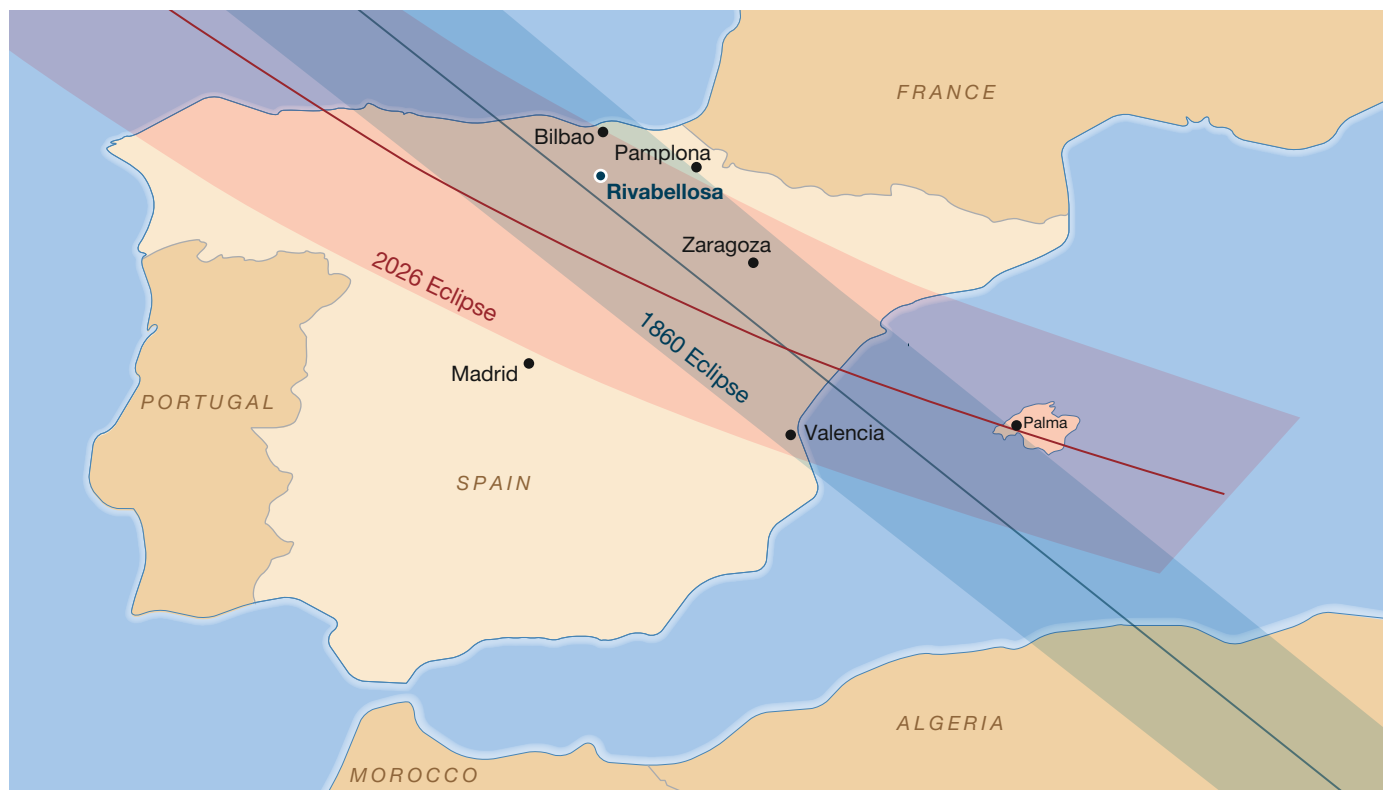
When a total solar eclipse swept across Europe in 1842, astronomers were astonished by a sight few had ever reported in detail before. Rising from the edge of the eclipsed Sun were strange crimson structures — luminous shapes that seemed to jut out into space like flames or jagged peaks.

"They somewhat resemble the snowy tops of the Alpine mountains when colored by the rising or setting Sun," wrote Francis Baily. "Perhaps the color of peach blossom would more nearly represent it." No one could agree on what they were.

The spectacle was as puzzling as it was beautiful. The structures appeared to cling to the edge of the Moon's silhouette, making it impossible to tell where they truly belonged. Some astronomers suspected they were effects caused by the Moon's rugged edge. Others argued they might be atmospheric illusions created by the sudden darkness of totality. Observations from the eclipse of 1851 seemed to suggest the structures belonged to the Sun.

The evidence remained inconclusive because astronomers still largely relied on hurried sketches made during a few frantic minutes of totality. British astrophotographer Warren De la Rue believed that photographing an eclipse might finally settle the fevered debate once and for all.

◀ **TOTALITY** De la Rue's color drawings of the eclipsed Sun just after the beginning (*left*) and before the end (*right*) of totality. He made the drawings after the eclipse using images from the photoheliograph, along with sketches and colored diagrams he drew based on his observations through a 3-inch refractor. The corona, which was too faint to photograph, is an approximation. De la Rue painted streaks of color around his diagram to compare to his view of the prominences in the telescope while making color sketches.



▲ **HISTORY REPEATS** The total solar eclipse on August 12, 2026 (in red), will pass over many of the same places in Spain as did the total solar eclipse of July 18, 1860 (in blue) — including Rivabellosa. Shaded areas show locations that see totality; solid lines indicate maximum eclipse.

The Journey

De la Rue left England from Plymouth on July 7, 1860, aboard the *HMS Himalaya*, bound for Spain's north coast. Tucked into the ship's cargo hold were almost two tons of astronomical and photographic equipment, neatly stashed into 30 separate packages.

Parts of the manifest read like a witch's brew:

1 Half-ounce bottle of Pyrogallic Acid

1½-pound bottle of Hyposulphite of Soda

2 oz Crystals Nitrate of Silver

Such was the alchemy of early photography.

The ship's commanding officer, Captain John Herbert Seccombe, must have been thankful for such a quiet and undemanding cargo. Just a year earlier, Seccombe had sailed the *Himalaya* back from North Africa, transporting a menagerie of gifts from the Emperor of Morocco to Queen Victoria. The floating zoo had consisted of one lion, one leopard, six ostriches, one gazelle, six horses, two mares, and an animal resembling a mountain sheep. On the voyage to England, the lion had escaped from its cage and rampaged across the main deck. Seccombe and members of his crew fashioned a lasso from a length of rope and successfully recaptured the beast,

returning it to its cage. A gaggle of astronomers and their odd equipment were far less troublesome by comparison.

Seccombe and the *Himalaya* safely delivered the astronomers to the port of Bilbao, but there was still the small matter of the journey to the village of Rivabellosa (also spelled Ribabellosa), 110 kilometers (70 miles) inland. Horses and carts took to a steep pass through the dramatic limestone mountains of the Sierra Salvada. Perhaps erring on the side of understatement, De la Rue described the journey as "very trying to our chronometers."

Nor had the journey come cheap. On the advice of George Airy, the British Astronomer Royal, De la Rue had applied to the British government for a grant to cover the cost of the trip, equipment, and his assistants.

De la Rue asked for, and was given, the sum of £150 (about \$21,000 in today's money). The expedition ended up costing £450, with De la Rue having to make up the difference from his own — admittedly deep — pockets.

An Aptitude for Astrophotography

Warren De la Rue was not a professional astronomer in the modern sense. By trade he was a successful businessman, inheriting the family printing firm that would later become the famous banknote printer De La Rue & Co.

But science was his true passion. From his observatory at Cranford in west London, De la Rue had already become one

of the pioneers of astronomical photography. In the 1850s he began systematically photographing the Sun using the new wet-collodion process, producing remarkably detailed images of sunspots and solar structure.

These experiments led him to design the *photoheliograph* — a specialized telescope built specifically for imaging the Sun. Installed at London's Kew Observatory in 1858, the instrument was used to begin the world's first program of routine daily photography of the Sun, creating a permanent record of solar activity.

The telescope was a 3.4-inch refractor on a German clockwork equatorial mount to keep the Sun in the field of view during the full duration of the eclipse. It produced a primary solar image roughly half an inch across, which was then enlarged for capture. In order to image the Sun, a plate holder sat at the heliograph's photographic focus.

The eclipse of 1860 presented an irresistible opportunity to test the instrument under far more dramatic circumstances. If the camera could capture the mysterious red prominences during totality, photography might succeed where two decades of visual observation had failed.

The Setup

After safely arriving in Rivabellosa, De la Rue began scouting for a suitable location to erect his temporary observatory. He soon settled on one of the many threshing floors used by local farmers to process grain. Level, hard, and dry, the floor was ideally suited for the purpose. Once the owner learned of the astronomer's intention he refused payment for its use, even though it meant having to lug his harvest to a more distant station.

And so construction began on De la Rue's photographic solar observatory. Back in England, he had meticulously marked every piece so "that no time need be lost in putting it together again." It was, in effect, a prefab observatory.

Sheets of thick canvas stretched across a wooden frame. Inside, the hut was divided in two. One half, with a removable roof, housed De la Rue's photoheliograph from the Kew Observatory.

While visiting an observatory in Königsberg, Prussia (now Kaliningrad in Russia), De la Rue had seen an earlier daguerreotype photograph of the 1851 eclipse and thought the prominences were too poorly defined to settle the debate. The Kew photoheliograph, by contrast, expanded the Sun's image to nearly 4 inches across — large enough, he hoped, to make the crimson structures measurable, rather than merely visible.

But it was a risk. Spread over a much larger area, the light



◀ **ASTROPHOTOGRAPHER** A portrait of businessman and amateur astronomer Warren De la Rue (1815–1889). The photograph was taken in 1855, five years before his expedition to Spain.

was weakened by a factor of 64, and he could not be sure the instrument would record totality at all. De la Rue was choosing precision over certainty, gambling that a fainter but larger image would succeed where a smaller one had failed.

Like Clockwork

The other half of the hut served as the photographic room, adorned with tables, shelves, and a cistern that could be filled with water from the outside. A second canvas tent placed over this room and kept constantly

damp sheltered the sensitive equipment from the harsh summer sun. This is where the real action took place.

The photographic plates had to be carefully prepared just before exposure, exposed while still wet, and developed immediately. De la Rue and his assistants had to work like a well-drilled Formula 1 pit crew. With totality lasting only minutes, mistakes would be disastrous.

De la Rue had selected a total of 48 glass plates back in London and carefully labeled them alphabetically and numerically. The day before the eclipse, he fastidiously cleaned them before returning them to their individual boxes.

The collodion (nitrocellulose solution) was so sensitive that, even with the aperture stopped down to 2 inches, images of the partially eclipsed Sun were overexposed. In his 1862 lecture for the Royal Society's Bakerian Medal, De la Rue described a simple but ingenious shutter mechanism involving a sliding wooden plate perforated with a square opening. From De la Rue's notebook, we learn:

How it was done

De la Rue used the wet-collodion process — a photographic technique involving coating glass plates with light-sensitive chemicals. The plates had to be exposed and developed within minutes, before the collodion dried and lost its sensitivity. This delicate process explains the chemical cauldron of ingredients packed aboard the *Himalaya*. Compared with earlier daguerreotypes, collodion plates were faster and sharper, while later dry plates would remove the need for such frantic onsite preparation altogether.

Previous to taking the picture, the sliding plate is drawn up just so high that the unperforated part of it completely shuts off the sun's image; it is held in this position by means of a small thread attached to it at one end and looped at the other, the loop being passed over a hook on top of the tube; and the slide is pulled downwards, in opposition to the thread, by means of a spring of vulcanized caoutchouc [rubber] attached to the inferior of the tube.

To actually take the photograph, De la Rue's translator, a man named Clark, would set the retaining thread on fire using a lighted taper. With the thread incinerated, the plate's perforation would then zip across the focus of the telescope, letting light in for less than a second.

But it was fire of a different kind that nearly ended the whole endeavor before it had even begun.

Flirting with Disaster

The blaze that crackled through the adjacent fields just 20 minutes before the eclipse began had been inadvertently started by Juan, a local man employed as an assistant. The astronomer later described his Spanish assistant as "excellent and handy . . . and very ingenious in expedients whenever any temporary arrangements had to be made."

De la Rue had earlier used a lucifer match — a primitive friction match coated in wax — to smoke a piece of glass so that Juan could view the eclipse safely. Soon, Juan was replicating the process for the growing crowd of 200 villagers — a throng so large that five local guards mounted on horseback were required to keep them from rushing the heliograph. Many had wrongly assumed De la Rue's location was the only place to view the eclipse. The hubbub prevented De la Rue from hearing the beats of the chronometer used to time the photographs. Thanks to Juan's smoked-glass plates, the people could view the eclipse from a nearby hill, leaving De la Rue to his task.

Demand for smoked glass was so great that Juan frantically discarded the used matches into the nearby fields without fully extinguishing them. Fortunately, De la Rue caught the smell of burning straw and quickly doused the flames with water. He would later reflect that they were mere minutes from disaster. Had the wind been blowing in the other direction, he may not have been so fortunate.

The fire was not the only potential setback De la Rue encountered that day. First thing that morning, the weather had looked far from favorable. "I am free to confess that my nerves were in the most feverish state of agitation," he later wrote. "Not the slightest break in the clouds or mist was visible until about 10 o'clock, when a streak of clear sky gave us the first faint gleam of hope."

Fortunately, the clouds stayed away. De la Rue even had time to point one of his other telescopes a few miles to the west, where he could see another party of astronomers had set up their own eclipse-viewing station on a low hill.

And as for imaging totality and acquiring usable photos of the prominences, De la Rue didn't know if it would work.

He'd practiced on the Moon before the trip, but with very poor results. Hedging his bets, De la Rue planned to sketch the eclipse as well, just in case the photographs didn't come out.

Totality

Slowly but surely, the Moon began to encroach upon the solar disk. The eclipse De la Rue had traveled nearly 1,300 km to see had finally begun. De la Rue took upwards of 40 short-exposure photographs of the partial eclipse. During totality, the shutter mechanism was dispensed with, and an assistant covered and uncovered the telescope lens manually for two 60-second exposures.

While his assistants labored away at the heliograph, De la Rue made drawings of totality at a borrowed 3-inch achromatic refractor. He did permit himself the briefest of looks at the sky with the unaided eye during the 3 minutes of totality. "I was so completely enthralled that I had to exercise the utmost self-control to tear myself away from a scene at once so impressive and magnificent."

The changing colors of the sky appeared painted with an artist's palette:

Immediately surrounding the corona, the sky had an indigo tint . . . while lower down it appeared to me to be modified by a tinge of sepia. It became red as it approached the horizon, close to which, and just above the mountains, it was of a brilliant orange. The mountains appeared, by contrast, of an intensely dark yet brilliant blue.

Even Jupiter and Venus joined the party, appearing as bright stars to the east of the Sun.

The spectacle silenced the gathered crowd. De la Rue recalled: "The stillness was so sudden as to be perfectly startling; then the ear caught the sound of the village bells . . . and this circumstance added much to the solemn grandeur of the occasion."

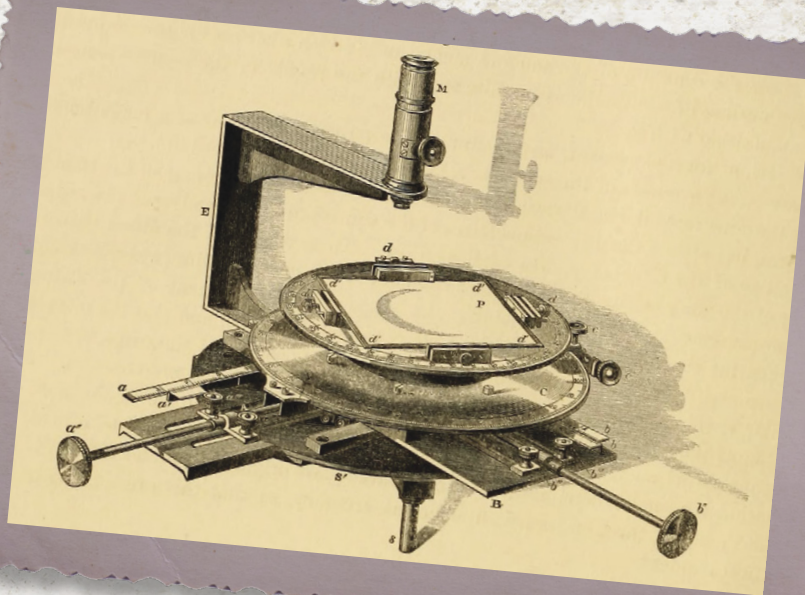
Yet beauty and grandeur were not the point of the expedition. What mattered was whether the photographs

► **THE KEW PHOTOHELIOGRAPH** The first astronomical instrument specifically designed for photographing celestial objects was designed by Warren De la Rue and built in 1857. Note that the smaller end is the objective; the larger end houses the plate holder.

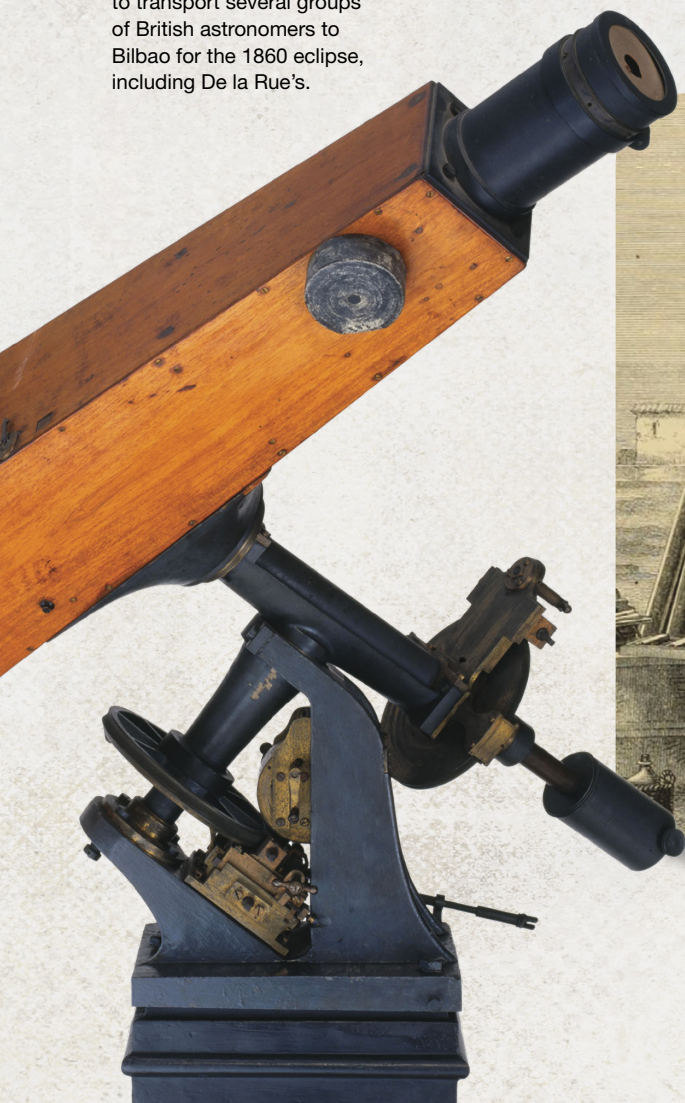




▲ **HMS HIMALAYA** The British Admiralty provided the HMS *Himalaya* in order to transport several groups of British astronomers to Bilbao for the 1860 eclipse, including De la Rue's.

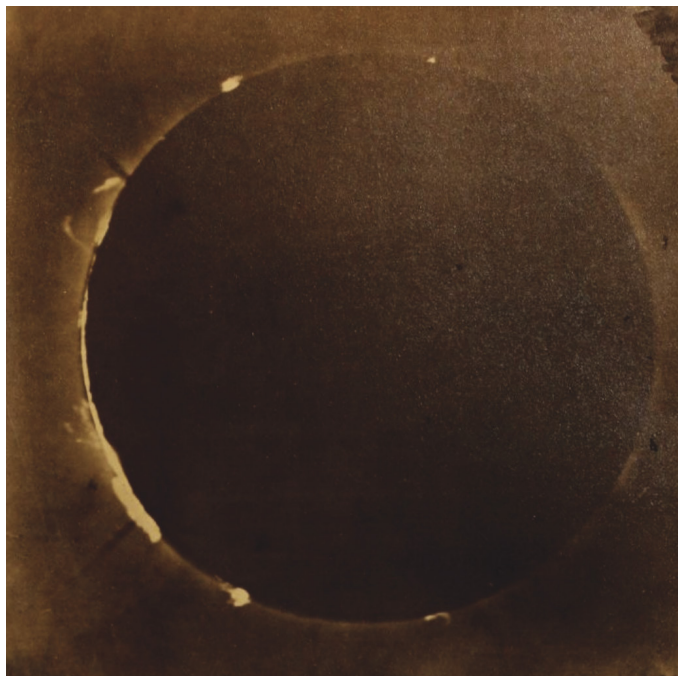


▲ **MEASURING INSTRUMENT** This device, also invented by De la Rue, enabled him to measure the position angles of solar prominences to the nearest arcminute.



▲ **THE ECLIPSE OBSERVATORY** Warren De la Rue and his assistants gather around the Kew photoheliograph. The front wall of the shed was removed to take this photo. De la Rue is on the far left. The doorway on the far right leads to the darkroom.

HMS HIMALAYA: HENRY SPERNON TOZER / PUBLIC DOMAIN / VIA WIKIMEDIA COMMONS; MEASURING INSTRUMENT AND OBSERVING SHED: DE LA RUE / PHIL. TRANS. PART 1, P. 333 (1862) / PUBLIC DOMAIN (2); KEW PHOTOHELIOGRAPH: SCIENCE MUSEUM GROUP / SCIENCE PHOTO LIBRARY; BACKGROUND: HERE / SHUTTERSTOCK.COM; WHITE IMAGE FRAME: CQVIDEO / SHUTTERSTOCK.COM; PURPLE PHOTO FRAME: GOSTEVA / SHUTTERSTOCK.COM



▲ **POSITIVE COPIES** De la Rue's original negatives were photographed with an enlarging camera, adjusted to bring out details of the prominences, and then copied for his expedition report using a monochrome printing technique called *mezzotint* that produces shades of gray.

had captured the mysterious prominences and what they might reveal about their true nature.

The Photographs

Not every plate came out perfectly. Some were compromised by the weather, noted as “through a cloud” or “shaken by wind.” Other times it was human error — “forgot to uncover plate” appears twice in the notes of an observing assistant.

But the real problems began once De la Rue returned to England and its notoriously cloudy skies.

The original collodion images were negatives. The two photographs of totality were so dark that their details could only be examined when held up to bright sunlight. “Those who remember how remarkably dull and wet the year 1860 was in England will readily understand that the selected days were few and far between,” he later wrote.

De la Rue had copies of the two totality images made by Negretti and Zambra, London instrument makers who three years later would take the first aerial photograph of the city from a hot-air balloon. These copies proved prudent. One of these original images started to decay, and when De la Rue tried to revarnish it, the collodion expanded and crinkled, spoiling the original negative. De la Rue later lamented the situation. “Something is always lost in copying — the damage to the original negative is unfortunate.”

Between the lack of sunlight and troublesome plates, it took De la Rue almost a year to complete his analysis.

Measurement

The idea was simple. During totality, the Moon moves steadily across the face of the Sun. If the crimson prominences were features of the Moon — mountains illuminated by sunlight or some other lunar effect — they should shift position along with the Moon's edge as the eclipse progressed. If they belonged to the Sun, they would remain fixed as the Moon slid past them.

To determine this, the prominences' positions had to be measured precisely on the two photographs taken during totality. De la Rue designed a bespoke measuring instrument for the task. He entrusted its construction to Troughton & Simms, a London firm that earlier in the century had built instruments for George Everest (namesake of the world's tallest mountain) during the Great Survey of India.

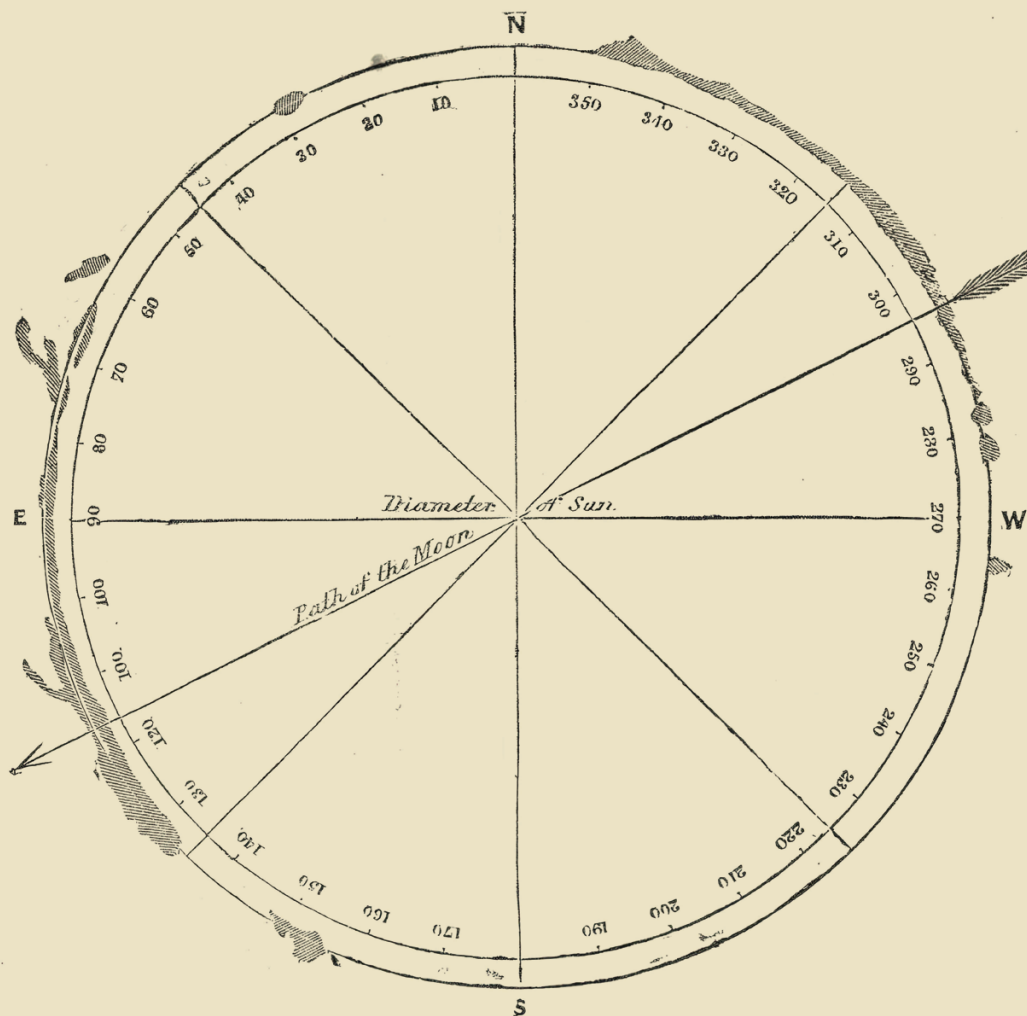
When De la Rue compared plates taken at the beginning and end of totality, the Moon's dark outline had clearly shifted across the solar disk. The prominences themselves had not moved; their shapes and positions remained fixed relative to the Sun's edge as the Moon crept steadily onward.

To strengthen the case, De la Rue compared his photographs to less-detailed shots taken 500 km away by Italian astronomer and Jesuit priest Angelo Secchi (*S&T*: Feb. 2025, p. 26). The prominences appeared in strikingly similar positions, additionally proving that the effects did not originate in Earth's atmosphere.

The conclusion was unavoidable: The mysterious crimson flames did not belong to the Moon at all. They were enormous structures rising from the Sun itself. When he presented his results to the Royal Astronomical Society in 1861, the debate that had begun with the eclipse of 1842 was finally settled. The strange crimson “tongues of fire” were part of the Sun.

Revealing the Sun

De la Rue's expedition provided one of the earliest demonstrations of the power of photography in astronomy.



▲ **DYNAMIC SUN** De la Rue produced this diagram by tracing, etching, and printing the prominences seen in his two totality photos. He traced the southeastern edges of the prominences in the first image (beginning of totality) and the northwestern edges of prominences in the second (end of totality). In tracing the second image, he took out effects of the telescope being bumped twice by his assistants. The inner circle is the Sun's limb. The outer circle is the Moon's position at mid-eclipse.

For decades, eclipse observations had relied on hurried drawings — impressions that could always be dismissed as errors of the eye or hand. De la Rue's photographs provided a permanent record that could be examined long after the eclipse itself had passed. Photographs could show the prominences with, in his words, “a precision as to contour and position impossible of attainment by eye observations.”

De la Rue's photographs also revealed details that observers had not noticed at the telescope. One faint prominence, described by De la Rue as a curved projection and nicknamed “the boomerang,” appeared clearly on a photographic plate even though it had been invisible to the eye at the time. Photography, De la Rue concluded, was capable not only of preserving phenomena seen by observers, but of revealing structures that emitted light beyond the limits of human vision.

Warren De la Rue died in 1889 at age 74. A Royal Astronomical Society obituary written at the time by Edward Ball

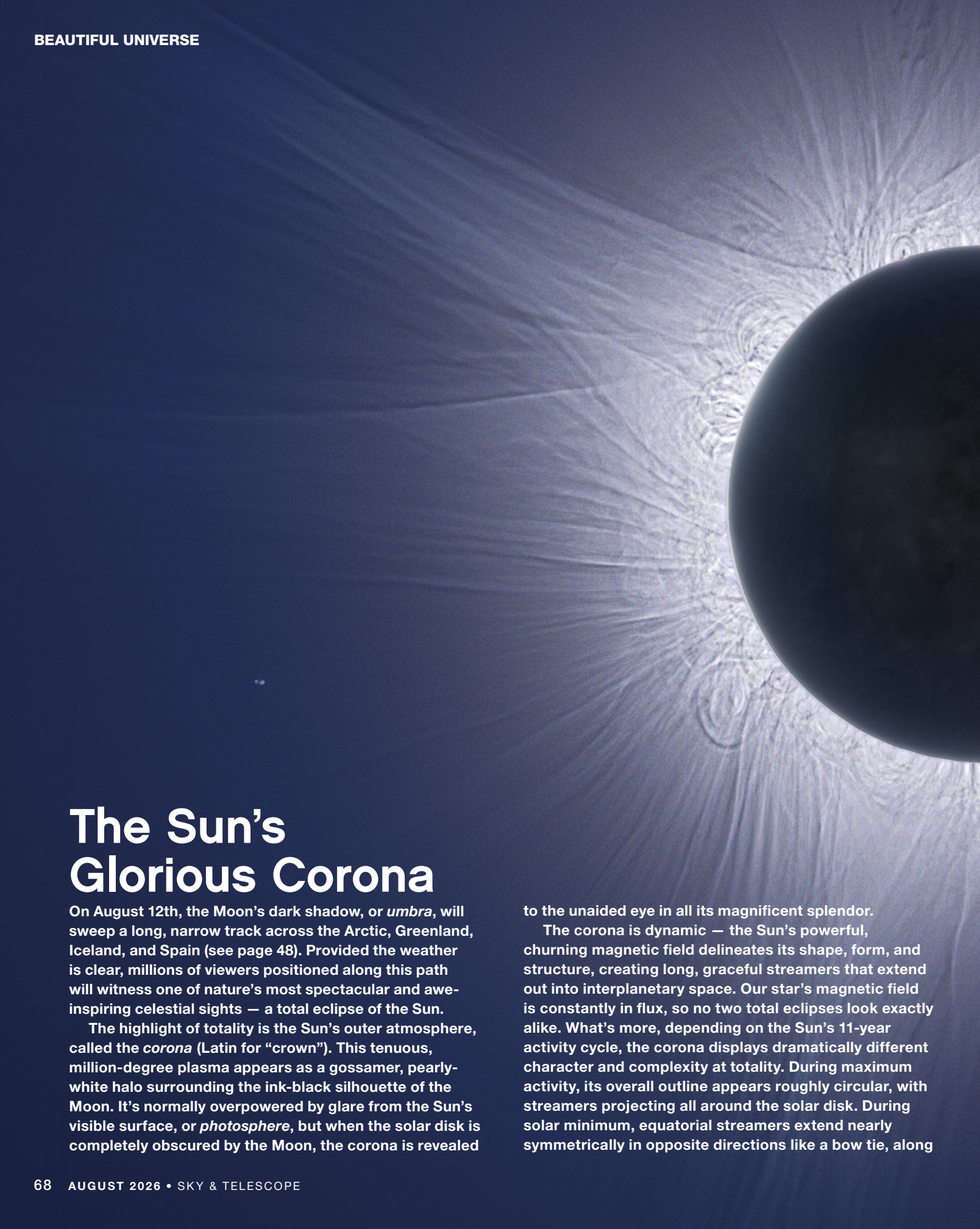
Knobel held up his work in 1860 as his crowning achievement. “In the history of celestial photography in this country, Mr De la Rue stands pre-eminent.”

At the time of his death, the true nature of the structures De la Rue photographed remained unknown. Revealing them as vast arcs of incandescent gas suspended above the Sun by powerful magnetic fields would take many decades.

But thanks to De la Rue's expedition to Rivabellosa, astronomers had finally answered their long-standing riddle. And the proof had come from a couple of fragile photographic plates exposed during a few precious minutes of darkness on a summer's afternoon in Spain.

Thank goodness the fire in the nearby field was put out.

■ **COLIN STUART** is a multi-award-winning astronomy author and speaker, and the namesake of asteroid 15347 Colinstuart (1994 UD). Find out more about him at www.colinstuart.net and on social media (@colinstuartspace).



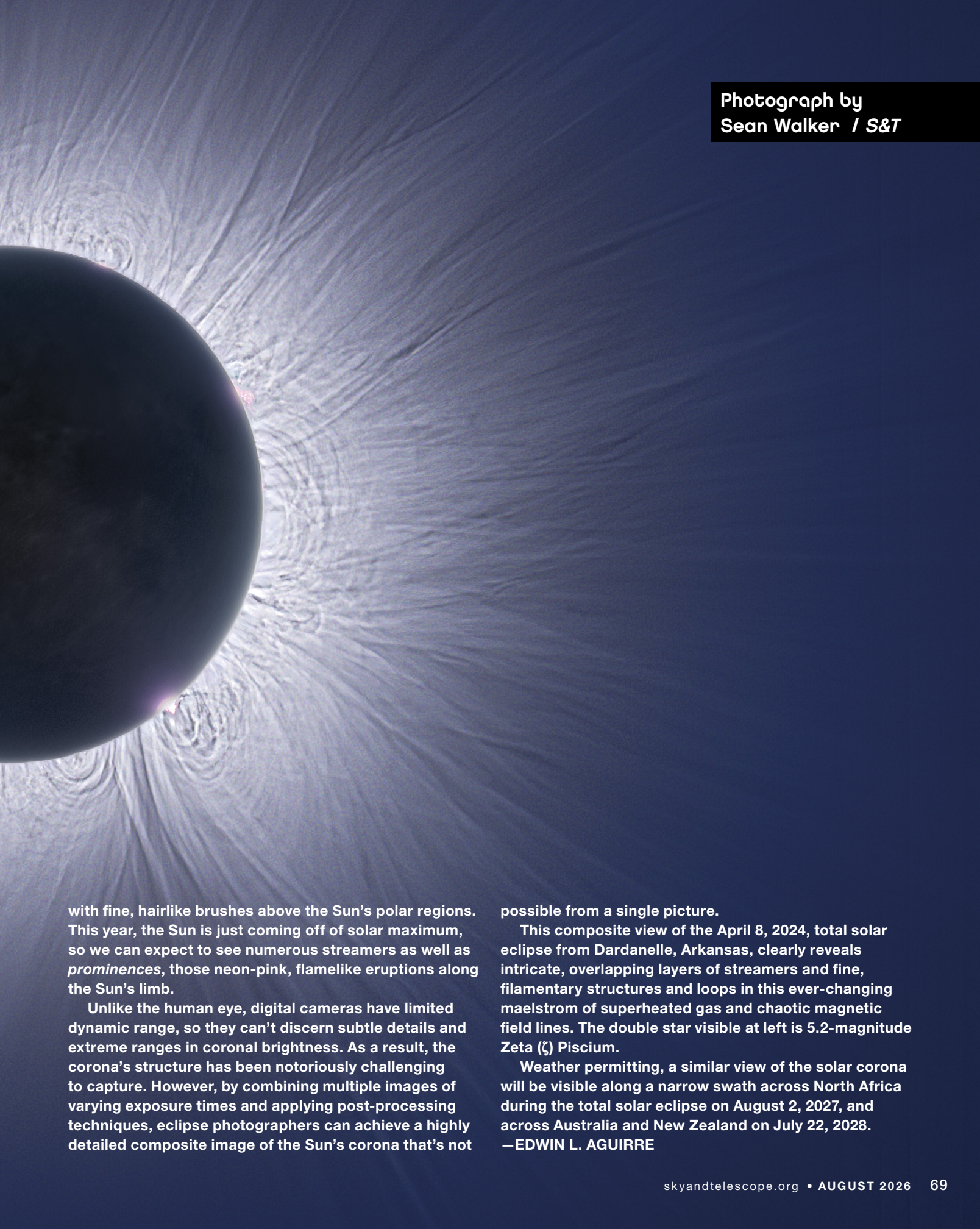
The Sun's Glorious Corona

On August 12th, the Moon's dark shadow, or *umbra*, will sweep a long, narrow track across the Arctic, Greenland, Iceland, and Spain (see page 48). Provided the weather is clear, millions of viewers positioned along this path will witness one of nature's most spectacular and awe-inspiring celestial sights — a total eclipse of the Sun.

The highlight of totality is the Sun's outer atmosphere, called the *corona* (Latin for "crown"). This tenuous, million-degree plasma appears as a gossamer, pearly-white halo surrounding the ink-black silhouette of the Moon. It's normally overpowered by glare from the Sun's visible surface, or *photosphere*, but when the solar disk is completely obscured by the Moon, the corona is revealed

to the unaided eye in all its magnificent splendor.

The corona is dynamic — the Sun's powerful, churning magnetic field delineates its shape, form, and structure, creating long, graceful streamers that extend out into interplanetary space. Our star's magnetic field is constantly in flux, so no two total eclipses look exactly alike. What's more, depending on the Sun's 11-year activity cycle, the corona displays dramatically different character and complexity at totality. During maximum activity, its overall outline appears roughly circular, with streamers projecting all around the solar disk. During solar minimum, equatorial streamers extend nearly symmetrically in opposite directions like a bow tie, along



Photograph by
Sean Walker / S&T

with fine, hairlike brushes above the Sun's polar regions. This year, the Sun is just coming off of solar maximum, so we can expect to see numerous streamers as well as *prominences*, those neon-pink, flamelike eruptions along the Sun's limb.

Unlike the human eye, digital cameras have limited dynamic range, so they can't discern subtle details and extreme ranges in coronal brightness. As a result, the corona's structure has been notoriously challenging to capture. However, by combining multiple images of varying exposure times and applying post-processing techniques, eclipse photographers can achieve a highly detailed composite image of the Sun's corona that's not

possible from a single picture.

This composite view of the April 8, 2024, total solar eclipse from Dardanelle, Arkansas, clearly reveals intricate, overlapping layers of streamers and fine, filamentary structures and loops in this ever-changing maelstrom of superheated gas and chaotic magnetic field lines. The double star visible at left is 5.2-magnitude Zeta (ζ) Piscium.

Weather permitting, a similar view of the solar corona will be visible along a narrow swath across North Africa during the total solar eclipse on August 2, 2027, and across Australia and New Zealand on July 22, 2028.

—EDWIN L. AGUIRRE

Four Scopes for New Observers

For \$200 or less, you can buy a complete telescope for first-person contact with the Moon, planets, and deep-sky showpieces.



VINYL. FILM. PAPER AND INK. Even in our world of super-smart digital devices, young and old alike continue to revel in the tactile simplicity of analog tools. There's a simple magic in capturing music from the airwaves, or starlight with a pair of lenses. And we all know how contagious wonder can be: Turn that yellowish "star" into a ringed world, and you may turn that neighbor or passerby into a lifelong skywatcher.

Sky & Telescope editors are often asked for scope-buying advice for a budding amateur. So we looked at what's available today and selected to review four telescopes, each retailing for less than \$200 and sold as a complete system: Instruments with mounts and eyepieces, ready to be aimed and looked through with what's in the box. We picked what appeared to be telescopes with reasonably sturdy mounts and decent eyepieces. And we chose them from manufacturers Celestron and Explore Scientific, companies with track records of serving both the beginner and aficionado markets. (The companies loaned us the review units but were otherwise uninvolved.)

Like many whose stargazing journey began with Halley's Comet, I recently celebrated my 40th anniversary as a telescope owner. I've looked through a wide range of instruments, big and small. Yet I found these four scopes quite rewarding. The two achromatic refractors delivered sharp views to the

◀ These four observing packages, each costing less than \$200, offer a lot for a first-time observer. We looked at three tripod-mounted scopes as well as a tabletop Dobsonian. With the exception of the small stool holding the Celestron Moon Mission 100mm Dobsonian in the foreground, each scope comes with everything required to begin observing after some minor assembly.

ALL IMAGES BY SEAN WALKER / S&T

edge of the field of view, without much *false color* (the purplish halo that lesser lenses will paint around the Moon, planets, and bright stars). The reflectors, for their part, gathered enough light to bring many celebrated nebulae into view; one (the Explore Scientific 114-mm Newtonian) is a well-rounded, flexible performer and, as of this writing, an unbelievable bargain.

Alongside high-school senior Alden MacNulty, a budding astrophysicist, we used these instruments to view Jupiter, the Moon, the Pleiades star cluster, and the Orion Nebula. Our fieldwork took place under the light-polluted skies of metro Boston on winter nights.

With an optional, higher-power eyepiece (where needed), one could spend years exploring the sky with any one of these telescopes. That said, each required some degree of assembly, adjustment, and/or accessorizing to fulfill its promise. Read on, and you should

be able to choose an instrument that may not only inspire a lifelong observer but can also remain useful beyond the first years.

Celestron AstroMaster 70AZ

A Well-Provisioned Portal to Other Worlds

If you're looking for a telescope that's easy to assemble and produces crowd-pleasing views, Celestron's AstroMaster 70AZ is our top pick. It's a long-focus refractor with a solidly built, easy-to-use tripod and alt-azimuth mount. Weighing 5 kg (11 lbs) in all, this scope has an aperture of 70 mm (2¾ inches) and a focal length of 900 mm, or f/12.8. Its adjustable tripod holds the eyepiece at standing height for a child, but the average adult will likely choose to use the telescope while seated.

To guide first-time set up, Celestron printed informative visuals on the

inner lid of the product box. The included manual was likewise clear and well-illustrated. The only real hitch was that our test unit's mount came too tight to be moved left-right (that is, in azimuth). It was easy to loosen with an 8-mm hex wrench I had lying around. After this minor adjustment, the mount was the best of the four we tested, with its easily adjusted azimuth and altitude (up-down) stiffness. But the initial tightness might stymie a first-time telescope owner — it isn't addressed in the instructions, and the hex key isn't provided.

With its decent, if basic, 20-mm and 10-mm eyepieces (providing 45× and 90×, respectively) and erect-image 90° prism diagonal, the AstroMaster revealed bold equatorial cloud bands and subtle polar shading on Jupiter, with all four Galilean satellites appearing as starlike points of light. It resolved subtle textures in the crater rays adorning the near-full Moon and brought the Pleiades into sharp focus from edge to edge. Targeting the Orion Nebula, the 70AZ resolved the four brightest members of the Trapezium star cluster in the nebula's core. While the edge of the Moon wasn't quite as sharp as in the 80-mm Explore Scientific scope, there was no obvious false color.



▲ The Celestron AstroMaster 70AZ is a long-focus achromat with a sturdy, easy-to-aim alt-azimuth mount.



▲ *Top:* The AstroMaster 70AZ includes an erect-image star diagonal, 10- and 20-mm eyepieces, and Celestron's excellent StarPointer red-dot finder. *Bottom:* The instructions for the AstroMaster 70AZ are clear, concise, and printed right on the box.

Celestron AstroMaster 70AZ

U.S. Price: \$199.95
celestron.com

What We Like

Clear manual and website
Sturdy, smooth-moving mount
Rewarding planet views with provided eyepieces

What We Don't Like

No wide-field eyepiece provided
Accessory tray is too shallow to hold items safely

**Prices subject to change*

A good telescope isn't much use if you can't point it at the desired target. Celestron's StarPointer red-dot reflex sight was easily the best we reviewed with our beginner scopes. Its optical window has just the right amount of transparency, and its dimmable red LED image produces a small and sharp target. The finder is easily adjusted to align with the main telescope with its pair of easy-to-grasp knobs. Along with the smooth, stable mount, this made target-finding a joy despite the telescope's relatively narrow field of view.

As with all the scopes reviewed here, the optical tube connects to the mount via a short, Vixen-style dovetail, which has become the industry standard for small scopes.

While I would personally have preferred slightly lower-power eyepieces, the Celestron AstroMaster 70AZ should provide beginners with a wide range of rewarding observations. What's more, its relatively robust construction makes it the likeliest of all our test models to hold up after years of use.

Explore FirstLight 80mm Refractor Telescope with Twilight Nano Mount

Surprisingly Sharp Views

Around 1990, I bought an 80-mm refractor kit for something like \$350 (nearly \$900 in today's dollars). I had to assemble the telescope and then buy a laundry list of accessories in order to actually use it. Fast-forward to 2026, when I unboxed a \$130 telescope of the same aperture, shipped with everything I needed to start observing. The Explore FirstLight 80mm Refractor with Twilight Nano Mount is an incredible bargain.

I was frankly awed by the views through this instrument. The scope snapped into focus more surely than any of the other units we reviewed. Its whole-disk Moon views were the best, and it took higher magnification (64× with an additional 10-mm eyepiece) without a hitch. The nearest of Jupiter's four moons readily stood apart from the gas giant even at 26×, using the

included 25-mm Plössl eyepiece. (This telescope's 80-mm achromatic objective has a focal length of 640 mm, making its f/8 focal ratio a nice compromise between wider fields of view and higher magnification.) I noticed little to no false color and minimal scatter: The Moon appeared white and gray, surrounded by dark sky.

The usual downfall of an inexpensive telescope is a shaky, wobbly mount. But Explore Scientific supplies this refractor with its stable, smooth Twilight Nano alt-azimuth mount. It's nearly the equal of Celestron's, though not quite: You have to adjust the altitude friction with a crescent wrench or socket driver, which isn't provided, and there seems to be no way to adjust the azimuth tension (which fortunately came just about right). Even so, the mount is leaps and bounds better than what's found on a typical department-store scope. Like Celestron's mount, the Twilight Nano really isn't tall enough for an average adult to comfortably use while standing, even with the tripod legs fully extended.

Explore FirstLight 80mm Refractor Telescope with Twilight Nano Mount

U.S. Price: \$129.99
explorescientific.com

What We Like

Sturdy, smooth-moving mount
Sharp, widefield views with provided eyepiece

What We Don't Like

Plastic tube clamp seems flimsy
Tinted window on reflex sight
Inadequate instructions for assembly

**Prices subject to change*

► The Explore Scientific FirstLight 80mm Refractor comes on the company's solid Twilight Nano mount, a 90° prism star diagonal, and a 25-mm Plössl eyepiece, as well as a smartphone eyepiece adapter.



In both of the Explore Scientific models we reviewed, there's more plastic than we'd like. The tube clamp holding the refractor seemed a weak point — I wouldn't be surprised to see it break after moderate use. Owners should always take the time to remove the scope and tube clamp from the mount; don't try to put the rig into your car or closet fully assembled.

This product's biggest roadblock is the reflex sight included to point the telescope at its targets. The accessory's glass window is tinted so heavily that I couldn't see most of the winter sky's bright stars through it. Alden discovered a usable workaround for this by keeping both eyes open and then alternating between them, blinking one, then the other, several times over while centering targets in the reflex sight. I'd recommend replacing it with a better model. We later discovered that Celestron's StarPointer reflex sight (\$24.95) was easy to fit on the FirstLight's finder post and only requires a small screwdriver to make the switch.



◀ **Top:** The FirstLight 80-mm scope's single plastic tube ring flexes when attempting to move the scope by grabbing the tube assembly rather than the Twilight Nano mount's handle.

◀ **Bottom:** The focuser on the 80-mm refractor was smooth and came to focus with the supplied prism diagonal and 25-mm Plössl at the position shown above.

▲ The red-dot finder included with both Explore Scientific FirstLight telescopes uses a tinted-glass window that blocks light from all but the brightest objects in the sky. Fortunately, both FirstLight scopes accept Celestron's inexpensive StarPointer finder.

Explore FirstLight 114mm Newtonian Telescope with Twilight Nano Mount

A Versatile Performer at a Rock-Bottom Price

With its 114-mm (4½-inch) aperture — the largest reviewed here — and included 25-mm Plössl eyepiece, the Explore FirstLight 114mm Newtonian Telescope showed fainter stars than any of the other instruments we reviewed. It comes with the same easy-to-use Twilight Nano alt-azimuth mount that supports the 80-mm refractor, and the FirstLight Newtonian would be our top choice for hunting down star clusters, nebulae, and galaxies, along with the occasional comet.

The telescope's 500-mm focal length (f/4.4) provides very wide-field views, though those views display some *coma*, where stars in the outer part of the field are distorted and blurry, an optical aberration inherent in all short-focal-length parabolic mirrors. In addition, brighter stars exhibit six diffraction spikes, which occur as starlight scatters off the secondary mirror and its support struts. The refractors we reviewed do a much better job of rendering stars as tack-sharp, pin-points of light. But this f/4.4 reflector comes out ahead when pursuing deep-sky objects. And while its full-aperture images of the Moon and planets are indistinct, the provided sub-aperture mask (a smaller, off-axis hole in the front telescope cover) sharpens up the views nicely without too badly starving them of light.

Of the three tripod-mounted telescopes we reviewed, we found this one the easiest to slew from target to target and to nudge along to track objects as the Earth turns. It's also the only unit that provides convenient viewing for a standing adult — the eyepiece position at the top of the tube helped a lot. So did being able to rotate the tube (after slightly loosening the tube rings) to point the eyepiece upward.

Sadly, this otherwise very user-friendly system sports the same confounding reflex sight that gave us



Explore FirstLight 114mm Newtonian Telescope with Twilight Nano Mount

U.S. Price: \$99.99
explorescientific.com

What We Like

Sturdy, smooth-moving mount

Larger aperture brings more deep-sky objects into view

Optical tube can be rotated to optimize eyepiece position

What We Don't Like

Distorted stars at the edges of the field of view

Tinted window on reflex sight

Inadequate instructions for assembly

**Prices subject to change*

▲ The Explore FirstLight 114mm Newtonian Reflector with Twilight Nano Mount had the largest aperture in this review and is the only one costing less than \$100. It comes with the same accessories as the FirstLight 80mm.



refractors described above. I recommend removing the optical tube from the mount before moving the instrument. As with its 80-mm sibling, this scope begs for an additional 10-mm or 12-mm eyepiece for higher-power views. Fortunately, both are priced so affordably that you can buy another eyepiece and keep your expenses well under \$200.

Celestron Moon Mission 100mm Tabletop Dobsonian

A Take-Anywhere Tool for Surfing the Sky

Given its name, it's somewhat ironic that the Moon Mission reflector placed last when it came to observing our natural satellite. Not that you can't enjoy the Moon whatsoever: With its decent 20-mm and 8-mm eyepieces (providing 20× and 50×, respectively), this scope brings the entire lunar disk into view, with enough detail to identify the maria, larger craters, and a few mountain ranges. As with any Newtonian reflector, this scope's images appear upside-down, but they aren't flipped left-for-right, and this makes it easy to compare eyepiece views with Moon maps or star charts.

Unfortunately, this telescope also underperformed its peers when it came to viewing the planets and deep-sky showpieces. Jupiter was an indistinct blob when viewed with the telescope's full 100-mm (4-inch) mirror, due in part to diffraction around the secondary mirror and its thick support vanes. With the sub-aperture, off-axis hole in the lens cap stopping down the scope to 1 inch, I was able to see Jupiter's two main equatorial belts and three of its four Galilean moons at 50×. But the dim, low-contrast lunar and planetary views through this stopped-down reflector were no match to those seen through any of the other reviewed products. (As with the other reviewed units, I used this one to observe Jupiter when its innermost moon, Io, was about 20' from the gas giant's limb.)

At its full 100-mm aperture, the tiny Dob showed the Orion Nebula's glowing core as brightly as the refrac-

▲ *Above:* Both the primary and secondary mirrors of the FirstLight 114mm include collimation screws to enable observers to adjust the mirrors when necessary.

► *Top right:* The FirstLight 114 includes an extension tube on its rack-and-pinion focuser to place eyepieces at the proper distance to reach focus.

► *Bottom right:* Both Explore Scientific FirstLight telescopes come with the company's versatile Twilight Nano Alt-azimuth mount. It accepts telescopes weighing up to almost 7 kg (15 lbs) that connect with a Vixen-style dovetail mounting bar.

headaches with the FirstLight refractor: Its glass window is tinted like sunglasses, and hardly any stars can be seen through it. I sometimes aimed at Jupiter and the Orion Nebula by sighting along the telescope tube. I'd recommend replacing the finder immediately as noted with the FirstLight 80mm.

At 9 kg, this instrument was a bit more than I wanted to carry with one hand using the convenient opening in the Twilight Nano mount arm, and it was more top-heavy than the two

Celestron Moon Mission 100mm Tabletop Dobsonian

U.S. Price: \$179.95
celestron.com

What We Like

Rock-solid mount

Optical tube and mount both interchangeable

Clear instructions with additional maps and software

What We Don't Like

Challenging to aim when used on or near the ground

Underwhelming views of the Moon and planets

**Prices subject to change*



◀ Celestron's Moon Mission 100mm Dobsonian Telescope comes with 8- and 20-mm eyepieces, a StarPointer red-dot finder, and a Moon filter.

▲ The Moon Mission's secondary mirror can be collimated using a 2-mm hex wrench (not included), but its primary is permanently mounted with no adjustment capabilities.

tors. Unlike them, however, it couldn't quite resolve the compact Trapezium star cluster at the nebula's heart. The issue is that the tilt of the telescope's primary mirror can't be adjusted, and the secondary mirror requires a small hex wrench to adjust (which isn't provided). This is just as well, as it's easier to make things optically worse than better when collimating a reflector if you're unfamiliar with the process. But this did mean that I couldn't tweak the collimation in the field. Our test unit wasn't grossly out of alignment, but at its short focal ratio of $f/4$, even a slight misalignment makes the difference between a sharp, pleasing view and one that's mushy. It would be nice to be able to fine-tune both of its mirrors' positions.

Where this tiny, 5-lb scope shines is the ease with which it can be moved from target to target. As with all the others we reviewed, this optical tube can be used on a wide range of telescope mounts, thanks to its industry-standard dovetail (the metal wedge that the mount clamps on to). Unlike the other scopes, the Moon Mission tube can also

be attached to a regular photo/video tripod with a standard $\frac{1}{4}$ -20 bolt, and it's light enough for this to actually work. The optical tube can even be handheld for sweeping Milky Way star fields or scanning for comets when paired with its 20-mm eyepiece.

Meanwhile, the tabletop Dobsonian mount can be easily adjusted to have just the right amount of friction in altitude, and it's remarkably immune to vibrations. (I did have to tighten the azimuth motion with a pair of optional crescent wrenches; as with every other scope we reviewed, this one-time tweak wasn't explained in the instructions.) Placed upon the right support — say, a picnic table or a sand-filled, five-gallon paint bucket — this tabletop Dob lets you find and track targets with ease. Finally, it's the best of our reviewed models for squeezing into a jam-packed car or closet.

Final Thoughts

When it comes to buying a solid, serviceable first telescope, these are arguably the best of times. With their steady, smooth-moving mounts,

respectable eyepieces, and intuitive aiming aids, the scopes reviewed here all provide rewarding alternatives to the shaky, hard-to-focus, 500× “hobby killers” littering the market. They can be easily pointed to desired targets, they don't wobble much when used, and they can be set up in minutes.

What's more, their industry-standard hardware allows them to grow with a beginner's interest: The optical tubes are usable on many other mounts, and many other telescopes, in turn, are compatible with these mounts. Optional eyepieces can be swapped in for wider fields or higher magnification. The finders on the Explore Scientific scopes can also be replaced with Celestron's StarPointer or other models available online. With a bit of patience and a good guidebook (or, dare we say, this magazine!), any of these telescopes could launch a lifetime of learning under the stars.

■ In the 40 years since he bought his first telescope, science teacher JOSHUA ROTH has probably owned and used at least that many (though not all at once).

Build a Smart Finderscope

Create a Raspberry Pi-powered finder for your telescope.

FROM FOGGED OPTICS to elusive faint fuzzies, our hobby is full of friction. So many nights are spent battling humidity, having equipment fall apart, batteries dying, or losing things in the grass. These are often the driving forces behind what we build. And for one inventive amateur, this friction has led to a futuristic means of finding his way around the night sky.

Richard Wolff-Jacobson, a software engineer and avid visual observer from California, has been tracking down deep-sky objects for more than 30 years with commercial and home-built telescopes alike. A recurring challenge in his sessions under the stars was the time

and energy spent on finding each new target. His solution called for reckoning with existing methods. *Star-hopping* — finding faint fuzzies by walking the view through star patterns seen on charts — is reliable, and many astronomers swear by their Telrad, a reflex finder that projects a reticle at infinity. And finderscopes, punching several magnitudes fainter, are ubiquitous. (I prefer my large reflectors to have both a Telrad and a right-angle, correct-image finderscope side by side.) But star-hopping is also time-consuming and demanding, especially under bright, urban skies. Meanwhile, a telescope equipped with digital

setting circles is pretty reliable, but setup and alignment can be intensive and fiddly. And Richard's own setting circles on his 16-inch f/4 Dobsonian often left him guessing if a marginal object was even in the eyepiece field of view. "When observing is smooth, it's magical," he notes. "When it's not, I'd spend half the night troubleshooting instead of observing."

Richard wanted a simpler experience, without the set-up friction. And he wanted to have more certainty on where his scope was pointed. Since he's experienced with coding and has hardware on hand — notably, a collection of Raspberry Pi boards (tiny, single-board computers that often drive DIY projects) — his answer was *plate solving*. The technique determines the coordinates of a celestial object by comparing star patterns in an image to a database of known star positions.

Richard attached a camera module to the board and aimed it out a window, writing the software right onto the Pi. This allowed him to get the exposure as well as the field of view (adjusted only by swapping lenses) just right, and he could test his setup against a fast plate-solving program called *tetra3!* (<https://is.gd/tetra3>). This software reads star patterns in an image, identifying the precise aim point of whatever camera took the image. After just a few hours, Richard had all the settings dialed in and could reliably get the right ascension and declination out of an image in less than a second.

◀ A PiFinder is shown mounted on a home-made Dobsonian reflector. The device's compact form and self-contained interface make it adaptable to a wide range of instruments. Many users find that once this electronic finderscope is installed, traditional finder combinations become optional.

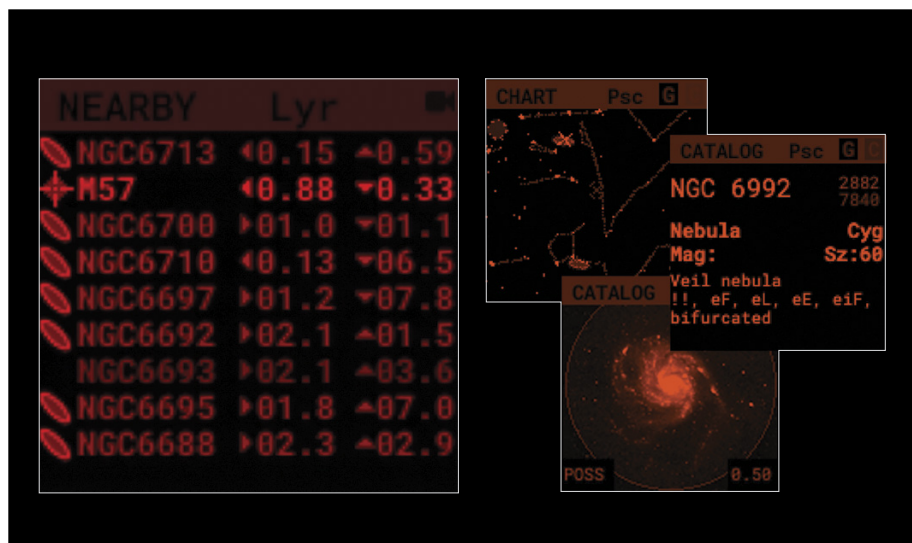


ALL PHOTOS ARE COURTESY OF RICHARD WOLFF-JACOBSON

This was what he needed. He built a rough prototype using a custom board with an OLED display and a keypad. He also added accelerometers to give the device movement feedback between plate solves. And when he finally got it all integrated, bundled in a 3D-printed housing, and working, it was time to try it out under a real sky. Richard was thrilled: “It worked way better than I expected — I was honestly surprised.” He found that it was almost as smooth as the push-to experience with his digital setting circles, but it just worked as soon as he turned it on. To him, it felt less like operating equipment, more like using a finder to guide the scope.

Iteration is a beautiful thing in open-source DIY projects. Many folks have asked about the files for my earliest projects, but each was an irreducible hodgepodge of stuff from the garage, hardware store trips, some glue, and a lot of hope. For a project to work well out in the wild, it needs a simple bill of materials and a nice building guide. Richard handled all of this. His device, aptly named PiFinder, is well documented and has seen frequent updates, often at the hands of a community that sprang up around it.

Richard was floored with the response. He shared it with his astronomy club, published it on GitHub (<https://is.gd/PiFinder>) for others to make, and later shared it on the Cloudy Nights forum. Then the emails started coming in. By now, there are



▲ Left: This PiFinder OLED display shows a list of “nearby objects” around your telescope’s aimpoint. Here, the objects are listed with directions on where to go and by how much in right ascension and declination. Another screen can show the same nearby objects with their apparent magnitudes and angular sizes. Right: Some examples of the PiFinder’s various interfaces. They include detailed star charts, object overviews, and even image references for many catalog objects, all presented in a dimmable, red OLED display to help preserve night vision.

hundreds of these PiFinders out there. He fondly recalls the surreal feeling of seeing his work adorning strangers’ telescopes at star parties.

PiFinder now includes extensive catalogs, Wi-Fi integration to talk with planetarium apps, and even a logging function with a cheeky, five-star rating system for deep-sky objects, all wrapped up in a dimmable, red user interface. The experience of using the PiFinder isn’t unlike a traditional finder. A detailed star chart with a reticle pattern updates in real time, and you can watch it while steering the tele-

scope, like staring down a Telrad finder. But the PiFinder has a zoom button. It fits into a scope’s finder shoe, aligns with little fuss, and gives any old scope instant push-to finding.

This finder lets a stargazer ditch the charts or a planetarium app, and arguably even the finderscope. The community response was incredible, but Richard’s only real goal was to design a device he loved using. Much like a comfy chair or tracking platform, with the PiFinder attached time at the eyepiece has gone way up. “It made my observing more fluid, more patient . . . with more time actually looking through the eyepiece,” Richard says.

He adds: “My hope is that other people will find this combination of functionality useful, will build their own PiFinder and help the whole project improve by making suggestions and potentially contributing to the software. It’s a pretty easy build with off-the-shelf parts and beginner-friendly soldering.”

To learn how to make (or buy) your own PiFinder, go to pifinder.io/about.

■ Contributing editor JONATHAN KISSNER has already duct-taped a PiFinder to his ancient C11.

► The PiFinder uses a small camera (its lens barrel is visible sticking out at right) to view the sky. The camera can be mounted in front of, to the left of, or to the right of the device’s housing so the display screen and push buttons would suit the position of the telescope’s eyepiece/focuser.





DAWN DISPLAY

Greg Meyer

Comet PanSTARRS (C/2025 R3) sports a long ion tail as it rises above saguaro cacti in the early morning twilight outside of Phoenix, Arizona, on April 15th.

DETAILS: Canon EOS 6D Mark II DSLR with 300-mm lens at f/4. Total exposure: 115 seconds at ISO 12800 for the sky and $\frac{1}{40}$ second for the foreground.



◁ STELLAR REEMERGENCE

Peter Anderson

Earth's umbra casts the Moon in a ruddy orange hue at 11:18 UT on March 3rd. The 7.4-magnitude star GY Leonis just emerged from occultation at the north-eastern limb (bottom) as it appeared from the photographer's location in Brisbane, Australia.

DETAILS: Sky-Watcher Evostar 150ED refractor with Canon EOS 90D DSLR camera. Total exposure: 4 seconds at ISO 400.

▽ THE GHOST OF CASSIOPEIA

Dave Doctor

Emission and reflection nebula IC 63 resides roughly 23' northeast of 2nd-magnitude Gamma Cassiopeiae (top right), also known as Navi. Radiation from the blue-white variable star is slowly eroding this spectral cloud of gas and dust.

DETAILS: Orion Optics AG14 astrograph with QHY268M CMOS camera. Total exposure: 28 hours and 55 minutes through Astrodon color and hydrogen-alpha filters.



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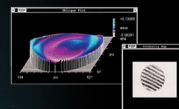


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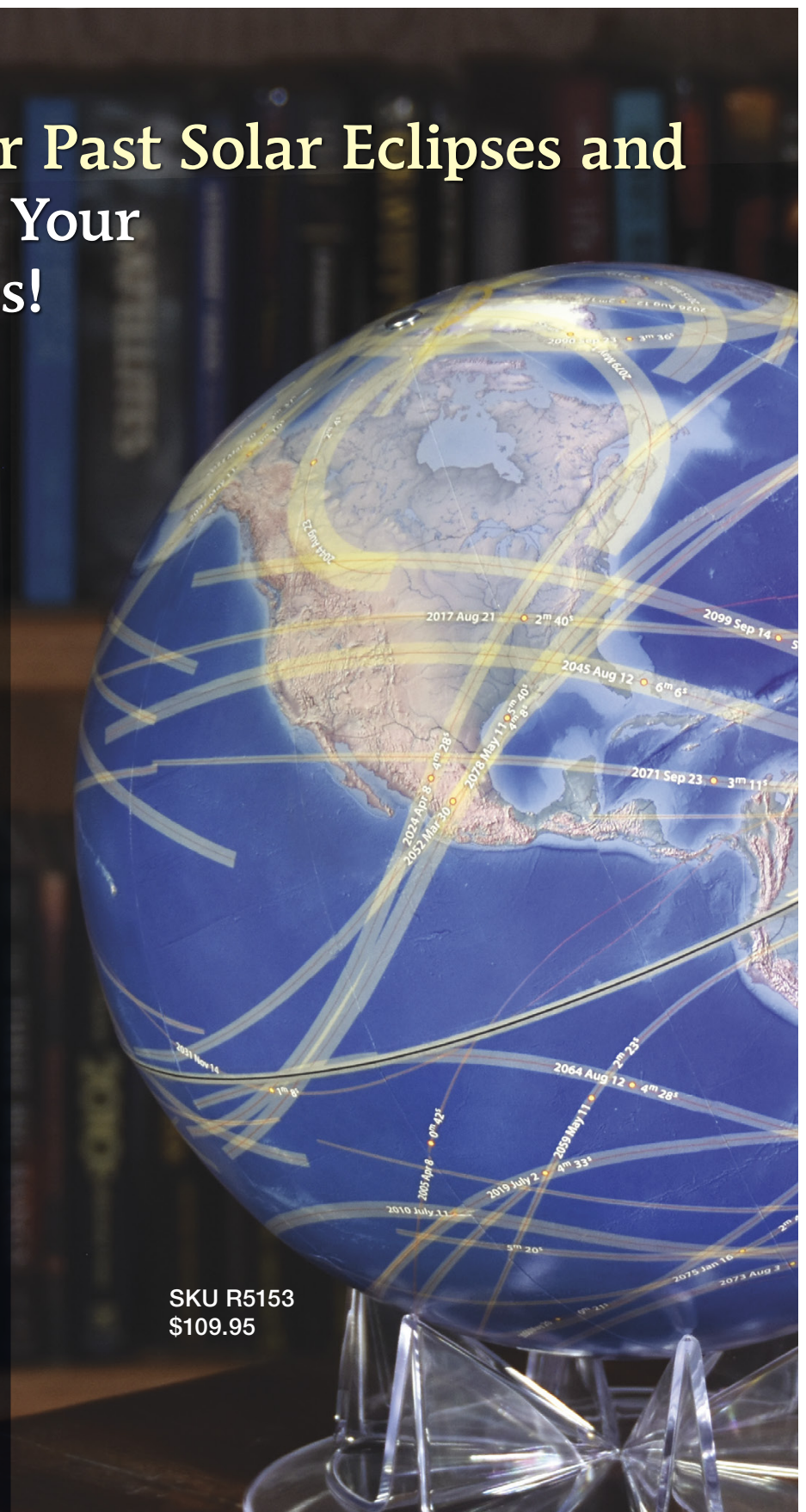
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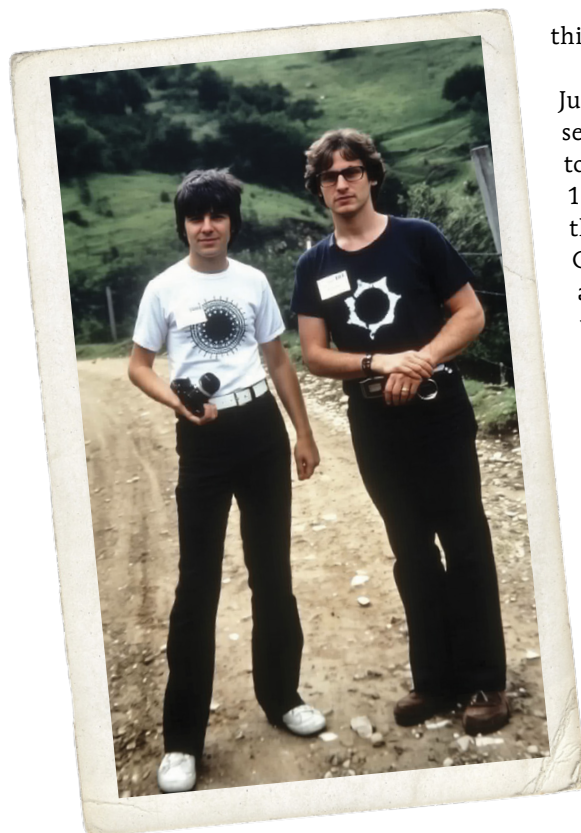
Turning the Eclipse Wheel

This month's solar eclipse evokes fond memories for a veteran eclipse chaser.

WITH THE TOTAL solar eclipse of August 12th fast approaching, my thoughts turn to my eclipse-chasing buddy of more than 50 years, Glenn Schneider, who sadly passed away last year. We met as teenagers volunteering at New York's Hall of Science and immediately connected when we discovered we both shared a fierce passion about eclipses. In October 1977, we organized and led a tour group to observe a total eclipse in Colombia, South America.

We were both only 21.

Glenn was the first to coin the term *umbraphile*. Literally, it means "shadow lover." He once noted that "Umbraphillia is not only an addiction, but an affliction, and a way of life. The real *raison d'être* for many of us."



Every umbraphile is aware of the *saros* — Greek for "repetition." Indeed, eclipses tend to repeat themselves at intervals of 18 years and 10⅓ or 11⅓ days, though they recur at different locations on Earth. A chain of such related eclipses is known as a *saros* series. Seeing two consecutive members of a series is "to complete a *saros*."

Then there's the *exeligmos*, or "turning of the wheel" in Greek. That's when, after three *saros* repetitions totaling 54 years and 33±1 days, a solar eclipse of similar characteristics will occur in a location close to the eclipse before it.

For an umbraphile to complete an *exeligmos* is a daunting endeavor, taking more than half a century and tasking one to follow the Moon's shadow by traveling around the world.

But this month, I hope to achieve this rare feat.

My very first total solar eclipse — July 10, 1972 — belonged to *saros* series 126. For that event, I managed to coax my grandfather into driving 1,300 kilometers, from The Bronx to the Gaspé Peninsula in southeastern Quebec, where totality was to last a little more than 2 minutes. Skies were mostly overcast, yet almost magically a tiny opening in the clouds passed over the Sun just after totality began, affording me my first view of the solar corona.

After that, I was hooked!

On July 21, 1990, once again I encountered a member of *saros* series 126. This time, I needed to use all my powers of persuasion to coerce a major airline, American Trans Air (ATA), to alter the itinerary of its regularly scheduled

◀ The author with Glenn Schneider in Colombia in on their first eclipse adventure together.

For an umbraphile to complete an *exeligmos* is a daunting endeavor, taking more than half a century.

Honolulu-to-San Francisco route so that it would intercept the Moon's shadow in midflight over the Pacific. The sticking point was that the flight's departure had to be delayed by 41 minutes to place the aircraft on just the right course. It turned out my sales pitch was effective, and passengers onboard a Lockheed L-1011 Tri-Star jet experienced 73 seconds of totality.

On August 1, 2008, the next member of *saros* 126 came on stage. For this eclipse, Glenn found a travel agency based in Düsseldorf, Germany, that chartered flights taking passengers over the North Pole. He alerted them about the eclipse and offered to draw up a flight plan in which an Airbus A330-200 would experience 175 seconds of totality en route to the Pole. Later I penned an article about this adventure for *Natural History* magazine: an article that would eventually win the Popular Writing Award of the Solar Physics Division of the American Astronomical Society.

I couldn't have done it without Glenn.

Now on August 12th, *saros* 126 again returns, and I'll be waiting for it, this time on a cruise ship in the Balearic Sea.

And I'll be all set to "turn the wheel" for me . . . and for Glenn.

■ **JOE RAO** is a contributing editor for *Sky & Telescope*. The upcoming total eclipse will be his fifteenth.

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