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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY
JULY 2025

Inspiring Outreach

skyandtelescope.org

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THE NEXT WAVE IN
HARMONIC MOUNTS
OFFICIAL TELESCOPE COMPANY OF AMERICAN MENSA
MENSA
SMART CHOICE
Sky-Watcher
WAVE 150i
Sky-Watcher
WAVE 100i
WiFi
Sky-Watcher Wave 100i and Wave 150i strainwave mounts
Sky-Watcher's Wave mounts feature strainwave gearing that provide a lot of power in a little package. The strainwave configuration offers several advantages over traditional mount designs, including low- to zero-backlash and high torque for handling larger payloads.
Unmatched Value
Sky-Watcher is committed to offering top-tier products at competitive prices. The Wave 100i and Wave 150i are no exception, providing professional-grade features without breaking the bank. With these mounts, you get the best of both worlds – high-end performance and affordability.
U.S.-Based Technical Support
Sky-Watcher stands behind its products with exceptional customer service. Our U.S.-based technical support is always ready to assist you with any questions or issues, ensuring you have a seamless and enjoyable experience with your new mount.
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• Built-in Wi-Fi and Bluetooth
• USB-B for PC control
• Red LED backlighting for latitude scale and bubble level
• Quiet, fast slewing up to 7.5°/second
• RA power-off braking function
• Internal homing sensors on both axes
The Sky-Watcher Wave mounts are available now. For a complete list of features and specifications, please visit our web site .
EQ6 AND STAR ADVENTURER TRIPOD ADAPTERS AND WAVE HEAVY-DUTY TRIPOD NOW AVAILABLE!
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This ad is sooooo much better if you imagine the Hawaii 5-0 music playing while you're looking at the wave in the background.
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Be amazed.
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The image on the right is the famous Pillars of Creation (M16) taken with the Wide Field Planetary Camera of the Hubble Space Telescope. The image on the left is taken with a QHY600M-PH Camera through a 7-inch refractor from the author's backyard in Buenos Aires. Courtesy Ignacio Diaz Bobillo. To see the original composition, resolution and acquisition details, visit the author's Astrobin gallery at https://www.astrobin.com/users/ignacio_db/

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ON THE COVER

This summer, share the wonder of the universe with others.
LEAH TISCIONE / *S&T*

ONLINE

BEGINNERS' GUIDE
Print out our free, 10-page handout to give out at star parties and other community events.
skyandtelescope.org/getting-started

ASTRONOMY EVENTS
Check out our events calendar for upcoming star parties and more — and add your own event to the list.
skyandtelescope.org/astronomy-events

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Sharing the Star Bug

ANY ASTRONOMER WHO has witnessed a person's first glimpse of a celestial object through a telescope can vouch for how incredibly moving that experience is. Hearing a child's "Wow!" when they see Saturn's rings, or seeing an adult tear up when they lay their eyes on the Moon's magnified craters, elicits feelings like no other. Sharing the sky is special, and doing so in a crowd at an outreach event makes it even more so.

Of course, observing the Moon and the planets or tracing the constellations' star lines is inspiring in and of itself. But oftentimes what makes the experience truly memorable for the novice is when someone pairs what they're seeing with scientific insights into the objects' origins and the physics that governs them.

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That's where the outreach expert comes in. Not only does this person know how to set up a telescope and point it at objects in the sky, the expert also knows how to capture the public's imagination and hook people so strongly, they come back for more.

It's a skill that might be innate, but we can also develop it with practice. And, undoubtedly, hatching fledgling astronomers is not for everyone. But if you're interested in doing outreach and haven't quite known how to jump into action, this issue is brimming with inspiration to help get you started.

On page 22, Contributing Editor Ted Forte shares tips on ideal targets to show the public during summer months — helpful for seasoned outreach coordinators and beginners alike. If you're a science teacher, you may derive inspiration from Rachel Huchmala's story (page 14) on how the kernel of an idea turned into a network of telescopes in schools across Idaho. You might even be intrigued by David Gamble's techniques on how to entice third graders into looking through an eyepiece (page 84). And there's more! We hope the material within these pages will spark new ideas or maybe even encourage you to expand your efforts.

You don't have to do the work alone, either: Many astronomy clubs run outreach programs. If you're a member of a club, you might already be familiar with their offerings — and if you're not, we encourage you to search the club listings on our website and find a group in your area (**https://is.gd/SandT_Clubs**).

If you have an outreach technique that you'd like to share, or the tale of an experience that moved you, send us your story at **letters@skyandtelescope.org**. We'd love to learn how you communicate the wonders of the universe and inspire the next generation of astronomers and scientists.

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

Founded in 1941 by Charles A. Federer, Jr. and Helen Spence Federer

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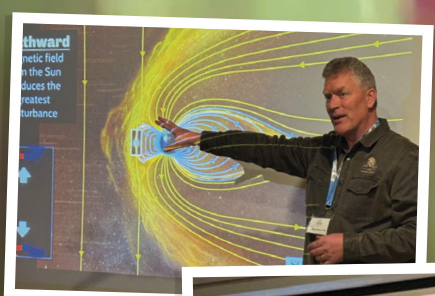

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Little Friend in the Sky

Stephen James O'Meara's "Foxy Canis Minor" (*S&T:* Mar. 2025, p. 45) was fun to read. I love sharing these kinds of stories with the students I teach. But here in the Appalachian foothills we have yet a third persona for Canis Minor: Our favorite Procyon is the ordinary raccoon that shows up at our backdoors at night to scavenge for leftover food. Obviously, we stargazers see them quite often since we tend to keep the same schedules. Here's a cheer for Procyon Lotor, the mischievous and cute little stargazing companions!

George Eberts
Athens, Ohio

At the end of Stephen James O'Meara's wonderful compendium of mythological stories about Canis Major and Minor, he refers to "the shaded area at top" of Johann Bayer's *Uranometria* star atlas's drawing of Canis Minor as "the Milky Way." That band is actually the ecliptic zone, the 8° on either side of the ecliptic through which the Sun, Moon, and planets move. The Milky Way is the lighter band with irregular margins coursing diagonally across the image. Bayer's atlas is in ecliptic projection, so the ecliptic is horizontal in all the plates in which it appears.

Also, although the illustrated version of the *Poeticon Astronomicon* was first printed in 1482 (by Erhard Ratdolt in Venice), its attributed author, Gaius Julius Hyginus, lived in Rome during the time of Augustus and Tiberius more than 14 centuries earlier. The *Poeticon* might include material by him, or it could also have been written by a later Hyginus. In any case, it contains other material, like its constellations, which mirror Claudius Ptolemy's *Almagest*, that could only have been added in the 2nd century AD.

▲ Orion's (right) loyal hunting dogs, Canis Major (bottom) and Minor (top left), follow him across the sky.

Larry Faltz
Larchmont, New York

Rosy Rosette

A note of thanks to Howard Banich for "A Rosette By Any Other Name" (*S&T:* Mar. 2025, p. 20). I was able to get out in late January for my first real observing session since November and spend some time with the Rosette Nebula myself. I appreciated the article's deep dive into this object, and my observing time spent there was well worth it. It grabbed me enough to review the article again the next morning, and I look forward to revisiting all that goodness again soon.

Rod Brown
Nevada City, California

▲ The Rosette Nebula captured by the Dark Energy Camera at the Cerro Tololo International American Observatory in Chile.

I don't often take the time to write to congratulate authors — this must be the third time in my life. But I really, really enjoyed Howard Banich's "A Rosette By Any Other Name." (I liked the pun too of course.) It made me want to try out his combination of a hydrogen-alpha filter and night-vision glasses. Maybe it will bring some things to life here in New York City, where I can't really see many deep-sky objects.

Is there any brand or model of night-vision device he would recommend? Thanks for writing such a neat article!

Robin Paquet
New York, New York

Howard Banich replies: *Although there are quite a few night-vision devices, I've only ever used the PVS-14, so I can't compare it to the others. You might want to check out the "Night Vision Astronomy" forum at* **cloudynights.com** *for more information, plus you can ask questions of those who have used more than one type of night-vision device. One thing night-vision devices all have in common, though, is high cost. But if you want detailed, real-time images of deep-sky objects from your backyard, night vision is a great way to go.*

When Fates Collide

In Emily Lakdawalla's "Europa Clipper Launches for Jupiter's Icy Moon" (*S&T:* Feb. 2025, p. 8), I found something that really confused me: It states that "At mission end, Europa Clipper will prevent contamination of Europa by crashing into Ganymede." Then, in the next paragraph, it states that when JUICE arrives, the two spacecraft will perform joint operations to search for life in Europa and Ganymede's oceans.

If they are going to do that, why would Europa Clipper crash into Ganymede, potentially contaminating Ganymede? Why not crash it into Jupiter?

Steve Carnes
North Oaks, Minnesota

Monica Young replies: *Great question! NASA addresses this on its mission website: "Planetary contamination is not an issue with Ganymede because Ganymede's surface is likely not active today and its ice shell is substantially thicker than Europa's, minimizing contact between the spacecraft and any possible ocean underneath." While I imagine Europa Clipper will leave behind a small bit of damage when it crashes, this won't affect the JUICE mission.*

CANIS MINOR: AKIRA FUJII; ROSETTE NEBULA: CTIO / NOIRLAB / DOE / NSF / AURA, IMAGE PROCESSING: T.A. RECTOR (UNIVERSITY OF ALASKA ANCHORAGE / NSF NOIRLAB), D. DE MARTIN, M. ZAMANI (NSF NOIRLAB)

Croswell's Cornucopia

I was captivated by Ken Croswell's "Gaia Begins a Black Hole Revolution" (*S&T:* Feb. 2025, p. 14). About halfway through, I thought to myself: *This is a very well-written article, I wonder who wrote it?* When I saw Croswell's name, it made perfect sense. He has a wonderful way of presenting highly technical astronomical concepts clearly. He's written so many fine articles for *S&T* that I hope, someday, they get published in one volume. You could title it *Astronomy: How We Know What We Know.*

Hugh Bartlett
Oakland, California

Spurious Stars

In "The Learning Curve" (*S&T:* Jan. 2025, p. 6), Gerald Newsom notes that the rapid wink-out of a star occulted by the Moon would have shown that the star sizes measured by early telescopic astronomers were too large. A good point! Oddly, it seems no one made that observation until Jeremiah Horrocks did it, and his results were not published until 1662. By then, Christiaan Huygens had published his *Systema Saturnium* (1659) in which he stated that star sizes could be indefinitely reduced by inserting a dark filter into the telescope.

Such findings did not always persuade astronomers, though. As I note in my article (*S&T:* Aug. 2024, p. 28), Flamsteed claimed that the observed sizes were real. Well, he made that argument against Huygens and his filtering.

S&T readers who are interested in the details should read my *Setting Aside All Authority: Giovanni Battista Riccioli and the Science against Copernicus in the Age of Galileo*; also "Galileo Between Jesuits: The Fault Is in the Stars," in the Spring 2021 volume of *The Catholic Historical Review*; and "On the Telescopic Disks of Stars: A Review and Analysis of Stellar Observations from the Early Seventeenth through the Middle Nineteenth Centuries" (with Timothy P. Grayson) in the July 2011 issue of *Annals of Science.*

Christopher M. Graney
Vatican Observatory
Louisville, Kentucky

FOR THE RECORD

- In the diagram on page 18 of the March issue, the red arrows in the lower-right (southern) Hadley and Ferrell cells should be blue and vice versa. The direction of the blue arrows in the lower-right polar cell should be reversed. See **https://is.gd/errata25** for the corrected diagram.
- In the chart on page 62 of the March issue, the topmost layer of clouds should be labeled CH_4 (methane), not CH_2.
- The Witch Head Nebula (IC 2118), though illuminated by Rigel, is actually in Eridanus, not Orion (*S&T:* Apr. 2025, p. 16).

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

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

1950

1975

2000

July 1950

Photo First "Just one hundred years ago, on July 16–17, 1850, J. A. Whipple [used] the great 15-inch refractor at Harvard College Observatory [to take] the first daguerreotype picture of a star — Vega. It required an exposure time of 100 seconds. . . .

"Yet seven years later . . . George P. Bond [speculated,] 'What more admirable method can be imagined for the study of the orbits of the fixed stars [and] their annual parallax than this . . . if we could obtain the impressions of the telescopic stars to the tenth magnitude? . . . The intensity and size of the images . . . with the length of time during which the plate has been exposed, measures the relative magnitudes of the stars.'"

So George Bond, soon to succeed his father William as Harvard College Observatory director, glimpsed the revolution photography would bring to astronomy.

July 1975

Faroff Worlds "Astronomers generally agree that perhaps as many as half of all the normal stars in the sky have stellar companions. The sun is a mild exception in being a single star, but it does have a set of planets. . . .

"To shed more light on the fraction of solar-type stars [with] planetary systems, Helmut A. Abt and Saul G. Levy at Kitt Peak National Observatory have made an intensive search for companions to 123 stars. . . . When we take all the short-period binaries (detected and implied), it appears that two-thirds of the primaries have companions of at least 0.07 solar mass. . . . Any astronomical object less massive than 0.07 sun will have too low a central temperature for thermonuclear reactions to operate . . .

"On the basis of these results, a search for . . . signals from civilizations near solar-type stars should concentrate on those stars that seem to lack stellar companions."

Two more decades passed before the first such exoplanet was confirmed (around 51 Pegasi). They now number more than 7,400.

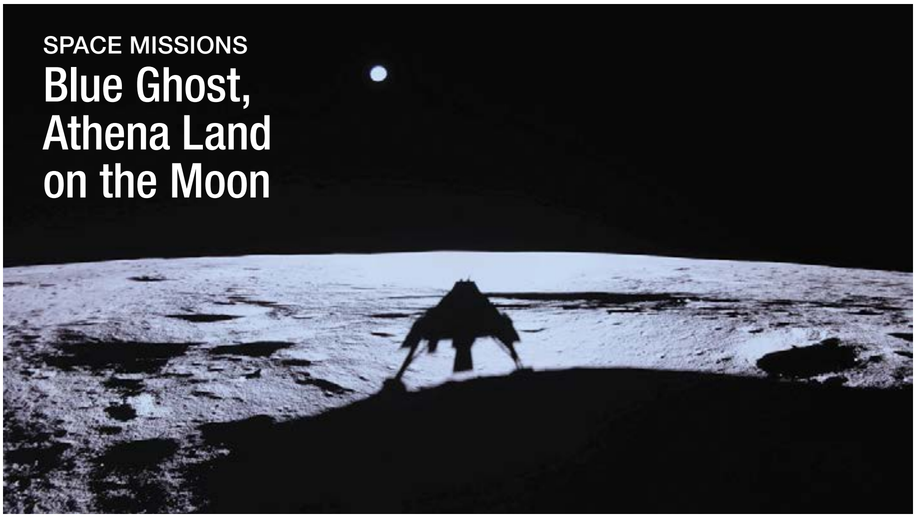
July 2000

Dog Bone "For two decades, Steven J. Ostro (Jet Propulsion Laboratory) has used powerful radar antennas to ping dozens of minor planets from afar. But few if any of those studies can top what he found last November when the main-belt asteroid 216 Kleopatra had a particularly close opposition that brought it into view of Arecibo Observatory's giant radar-equipped dish. . . . 'The asteroid is shaped like a dumbbell,' [he and colleagues write].

"Based on its strong radar reflectivity and the polarization of the returned signal, Ostro's team leans toward an all-metal object . . . Is Kleopatra a huge mass of pure nickel-iron fragments just waiting to be mined by future spacecraft?"

SPACE MISSIONS

Blue Ghost, Athena Land on the Moon



◀ Blue Ghost images its shadow on the surface of the Moon; Earth hangs just above the horizon.

FIREFLY AEROSPACE'S Blue Ghost landed in Mare Crisium on the nearside of the Moon on March 2nd.

The lander is part of NASA's Commercial Lunar Payload Services (CLPS) program, which awards contracts to American companies for the delivery of science and technology to the lunar surface. CLPS itself is part of the larger Artemis initiative to put humans back on and around the Moon. Blue Ghost is the first CLPS mission to accomplish the landing without hiccups.

The lander came within about 100 meters of its target site and sent back its first images of the surface a half hour later. Over the next two weeks, 10 NASA payloads conducted surface operations. The Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity drilled 1 meter (3 feet) into the surface to measure heat flow from the interior. Other surface experiments included the Lunar PlanetVac regolith collector; the Lunar Global Navigation Satellite System Receiver Experiment, which demonstrated communications capability on the Moon; and the Lunar Environment Heliospheric X-ray Imager, which provided a unique perspective of Earth's magnetosphere.

Another high point for Blue Ghost was its capture of a total solar eclipse

SPACE MISSIONS

Two Weeks, Two Missions, Two Mars Flybys

IN THE SPAN OF two weeks, two space missions flew past the Red Planet, capturing glimpses of the world as well as one of its moons, Deimos.

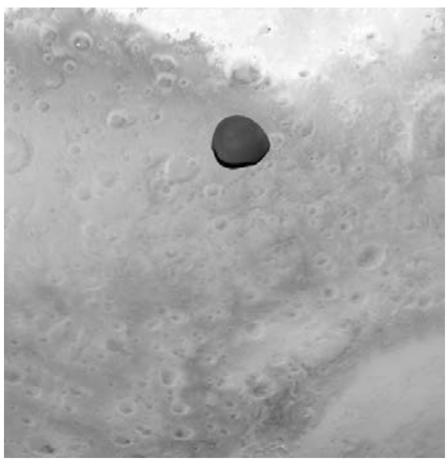
NASA's Jupiter-bound Europa Clipper flew within 884 km (550 mi) of Mars on March 1st, using the planet's gravity to slow its speed around the Sun. The spacecraft will travel a little beyond Mars's orbit and then fall back toward the inner planets, reencountering Earth late next year. Our planet's gravity will deliver the boost needed to enter orbit around Jupiter in April 2030.

Europa Clipper's Thermal Emission Imaging System observed Mars from afar, acquiring calibration data, giving the team confidence about its eventual measurements in the Jupiter system.

The other instrument turned on for the flyby was the Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON), which includes six radio antennas mounted to Europa Clipper's enormous solar arrays. When the spacecraft was being assembled, the solar panels and antennas were too gangly to fully evaluate. The Mars encounter was the first time that all components of REASON were tested simultaneously.

"All our telemetry indicated the instruments acquired the data as planned," says Deputy Project Manager Tim Larson (JPL).

Then, on March 12th, the European Space Agency's Hera mission passed within 5,000 km of Mars for a gravity assist on its way to asteroid 65803 Didymos. It will arrive there late next year for a follow-on investigation of the moonlet that NASA's Double Asteroid Redirection Test spacecraft impacted in 2022 (*S&T:* Jan. 2023, p. 8).



▲ The Asteroid Framing Camera captured dark Deimos against the backdrop of brighter Mars.

As it whizzed by Mars, Hera captured dramatic close-ups of the Martian moon Deimos. The spacecraft came within 1,000 km of the misshapen moon, with three instruments taking advantage of the opportunity for calibration. The first, the Asteroid Framing Camera, took monochrome visible-light images of the moon against a dramatic Martian backdrop. The Hyperscout H imager also observed Deimos and Mars, taking images in 25 bands from visible light to near-infrared to aid our understanding of mineral composition. Finally, the Thermal Infrared Imager measured the surface temperature of Deimos and Mars using mid-infrared wavelengths, informing properties such as texture and porosity.

Now that the flybys are complete, next up for Europa Clipper and Hera will be their Earth and asteroid encounters, respectively, in December 2026.

■ **EMILY LAKDAWALLA & DAVID DICKINSON**

See the images: https://is.gd/HeraMars.

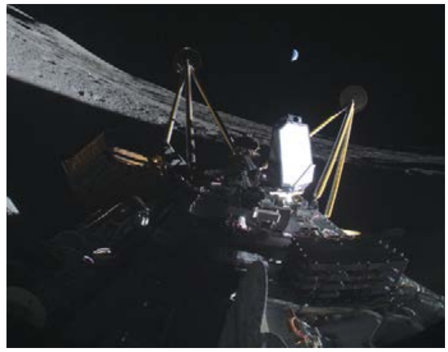
EARTHSHOT: FIREFLY AEROSPACE; DEIMOS: ESA

▶ Earth blocked the Sun's corona from view during totality, while our atmosphere refracted sunlight from a thousand Earth-side twilights. This photo shows a "diamond ring" as the Sun disappeared behind Earth.

from the Moon on March 14th. The mission finished two days later, with the lander working five hours into the lunar night.

Meanwhile, Intuitive Machines launched its second mission for the Moon on February 27th. The company's Nova-C lander, named Athena, entered lunar orbit on March 3rd and snapped images as it descended to the surface on March 6th. The lander touched down just 250 meters from its intended site in the Mons Mouton region near the lunar south pole. Shortly after landing, the spacecraft contacted ground control and began charging its batteries.

However, early indications hinted that Athena had fallen on its side (like the first Intuitive Machines mission in 2024; *S&T:* June 2024, p. 11), a fact soon confirmed by images from the lander itself. While the 2024 mission managed limited charging, Athena landed in a crater. "With the direction of the Sun, the orientation of the solar panels, and extreme cold temperatures in the crater, Intuitive Machines does not expect Athena to recharge," the company said in a statement issued just a day after landing. "The mission has concluded, and teams are continuing to assess the data collected throughout the mission." While Athena was able to complete some milestones, a NASA-built drill that would have mined water ice wasn't able to deploy.



▲ Earth floats between two legs of the second Intuitive Machines mission, which landed on its side in a crater at the lunar south pole.

Two rocket rideshares — AstroForge's Odin, which sought an asteroid rendezvous and NASA's Lunar Trailblazer orbiter — separated from Athena before it landed; both fell silent shortly after.

■ DAVID DICKINSON

To watch the eclipse, visit https://is.gd/BlueGhostEclipse.

SOLAR SYSTEM

First Thermal Images of Mercury from BepiColombo

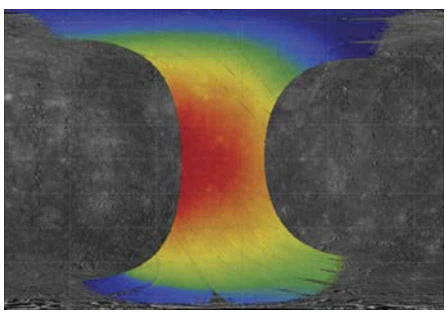
THE BEPICOLOMBO mission heat-mapped a large swath of Mercury's surface during its most recent flyby. At the Lunar and Planetary Science Conference in March, members of Europe's BepiColombo science team revealed views of the innermost planet from the spacecraft's thermal camera.

The Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS) took the data out of it side-looking "space port," a window intended for taking calibration data. After launch, the MERTIS team upgraded the software to repurpose the window during the December 1, 2024, flyby, which took BepiColombo past the planet at an altitude of more than 37,000 kilometers (23,000 miles).

Unsurprisingly, an uncorrected view of the thermal data shows that Mercury is hottest where the Sun's heat is fiercest, with equatorial temperatures reaching a blistering 693 kelvin (788°F). But take out the bullseye pattern, and lots of subtle details appear, many associated with craters. Multiple factors could influence the details of thermal brightness: topography, shadowing, grain size, surface roughness, and mineral composition. It's not yet possible to say for sure, because the MERTIS team must still calibrate their instrument.

Just this one flyby yielded 1.4 million MERTIS spectra. The unusual viewing geometry means these data aren't ideal for science, but they confirm MERTIS's sensitivity, and a little taste of what's to come once BepiColombo enters Mercury's orbit in November 2026.

■ EMILY LAKDAWALLA



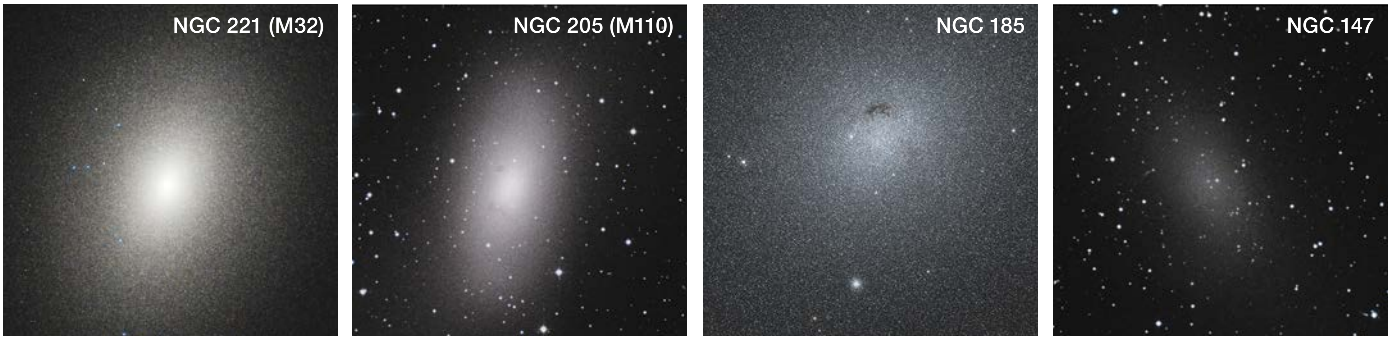
▲ This map shows the brightness temperature across a swath of Mercury's surface. The hottest (red) regions approach 700K.

IN BRIEF

NASA's SPHEREX, PUNCH Launch

Two NASA missions launched on March 11th: the Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx) and the Polarimeter to Unify the Corona and Heliosphere (PUNCH). Both spacecraft deployed into Sun-synchronous low-Earth orbits. SPHEREx will survey the whole sky four times in two years, taking images in 102 bands over infrared wavelengths. The mission will collect data on 100 million stars in the Milky Way as well as more than 450 million galaxies beyond our own. The data will help astronomers investigate the beginning phases of star formation and the nature of cosmic inflation. Meanwhile, the four suitcase-size satellites of PUNCH will work together to provide the first continuous 3D view of the solar corona, enabling scientists to track the solar wind as it sweeps over Earth. Once commissioned, PUNCH will capture images every four minutes in polarized visible light over a 90-degree-wide field of view.

■ DAVID DICKINSON



GALAXIES

Hubble Investigates Andromeda's Aligned Dwarf Galaxies

▲ These Hubble images show four of the 36 dwarfs around the Andromeda Galaxy.

FINDINGS FROM a new Hubble Space Telescope survey of dwarf galaxies around the Andromeda Galaxy hint at a disruptive galactic merger a few billion years ago.

Like the Milky Way, Andromeda is surrounded by dwarf galaxies; however, its galactic ecosystem is far more complex than our own galaxy's. A team of astronomers led by Alessandro Savino (University of California, Berkeley) used Hubble observations gleaned from more than 1,000 orbits to chart 36 of these dwarfs, publishing the results in the February 1st *Astrophysical Journal*.

Half of Andromeda's satellite galaxies appear confined to the same plane, and the brightest of Andromeda's companions might hold clues as to why. The large dwarf M32 could be left over from a much larger galaxy that Andromeda cannibalized a few billion years ago. The Hubble data show that M32 seems to have experienced a burst of star formation around that time.

The disruption wrought by this merger could account for the haphazard configuration of Andromeda's satellite dwarf galaxies. "Everything scattered in the Andromeda system is very asymmetric and perturbed," says team member Daniel Weisz (also at University of California, Berkeley).

That star formation continued to much later times in other dwarf galaxies around Andromeda is equally confounding. Samantha Penny (University of Portsmouth, UK), who was not involved in the research, says this is a standout finding that wasn't expected from theory and computer simulations.

Martin Rey (University of Bath, UK), also not involved in the research, thinks observations like these may also help answer larger questions. "The real story here is about dark matter," he says. The number of dwarf galaxies astronomers observe is at odds with the number predicted to exist by conventional dark matter models. "If you can constrain how stars form and evolve in dwarf galaxies through a survey like this," he says, "then you are directly informing what we can infer about dark matter — that's the bigger picture of the massive effort that this team has done."

■ **COLIN STUART**

SOLAR SYSTEM

Why Mars Is Red

◀ This laboratory analog to Martian dust contains ferrihydrite and basalt.

MARTIAN DUST IS RED because of rust — but what kind of rust? Planetary scientists have long thought its color came from *hematite*, a form of iron oxide. But new laboratory tests instead suggest the red color comes from a different iron oxide called *ferrihydrite* — a compound that contains water yet has survived eons on cold, dry Mars.

"Nobody had ever looked at all iron oxide minerals to compare laboratory data with those from spacecraft," says Adomas Valantinas (Brown University), who led a study published February 25th in *Nature Communications*. Doing so as a doctoral student at the University of Bern in Switzerland, Valantinas found that ferrihydrite best replicated the properties of Martian dust.

This compound forms in cool, moist environments on Earth but changes into other forms of iron oxide under warmer or dryer conditions. To test how ferrihydrite would weather Martian conditions, Valantinas used a simulated analog environment operated by the University of Winnipeg. After exposing ferrihydrite to intense ultraviolet light in a thin, cold carbon-dioxide atmosphere for 40 days, he found that while the compound lost some water, it remained essentially frozen.

A kinetic computer model also demonstrated that the compound could stick around at Mars-like temperatures for billions of years.

"All the evidence confirmed the initial hypothesis, which was surprising," he says. To obtain the best match to Martian dust, he only needed to

ANDROMEDA'S DWARFS: NASA / ESA / ALESSANDRO SAVINO (UC BERKELEY) / JOSEPH DEPASQUALE (STSCI) / AKIRA FUJII / DSS2 (4); MARS DUST: A. VALANTINAS / ESA

NEUTRINOS

Record-Breaking Neutrino Found by Detector in the Mediterranean Sea

A GIANT, UNDERWATER telescope has detected the most energetic neutrino yet observed. Named KM3-230213A, the tiny particle carried more than 30 times the energy of the previous record holder.

Neutrinos are ghostly subatomic particles that rarely deign to interact with ordinary matter. Detecting them requires Herculean efforts, including burying sensors thousands of meters below the surface of the Mediterranean Sea (*S&T:* May 2023, p. 14).

This dark locale, where even sunlight cannot reach, is home to the Cubic Kilometre Neutrino Telescope (KM3NET). It's still under construction, but already consists of two sites: Astroparticle Research with Cosmics in the Abyss (ARCA) and Oscillation Research with Cosmics in the Abyss (ORCA). At each site, hundreds of photomultipliers dangle from hundreds of strings anchored to the seabed.

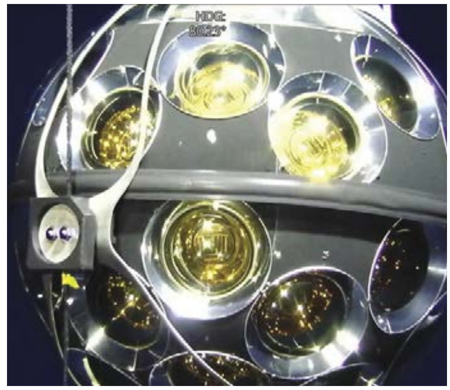
On February 13, 2023, ARCA picked up a single *muon*, an unstable subatomic particle, which triggered more than a third of the site's intricate sensors. Its inbound trajectory coupled with its extreme energy led KM3NeT researchers to conclude that the muon came from a 220 petaelectron-volt (PeV) neutrino striking Earth's atmosphere. The team's results are published in the February 13th *Nature*.

The exact source of this neutrino remains unclear. It could have come from a cosmic accelerator, such as a supernova, gamma-ray burst, or feeding black hole. "We know so little about [these] extreme processes . . . that any extra information we can get is very valuable," says Patrick Dunne (Imperial College London), who was not involved in the research.

Alternatively, this record-breaking neutrino could be *cosmogenic*, produced when high-energy cosmic ray particles interact with background photons that suffuse the universe. If confirmed — a sizeable "if" at this early stage — it would be the first cosmogenic neutrino that astronomers have seen.

It's also possible, given the extremely high energy of this neutrino, that it may have come from somewhere else entirely. "It leads us to question whether it comes from a process we know about or something we haven't seen before," Dunne adds.

Astronomers will need more than a single neutrino to determine which



▲ A spherical detector module deep in the Mediterranean Sea contains 31 photomultiplier tubes. On each of 115 vertical strings dangle 18 such modules.

idea wins out, and more ultra-high-energy discoveries may well follow as KM3NeT's construction continues.

"The scale of KM3NeT, eventually encompassing a volume of about one cubic kilometre with a total of about 200,000 photomultipliers, along with its extreme location in the abyss of the Mediterranean Sea, demonstrates the extraordinary efforts required to advance neutrino astronomy," says Miles Lindsey Clark (French National Centre for Scientific Research).

Going by this early find, we could be handsomely rewarded for those efforts.

■ **COLIN STUART**

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make one addition to his lab mixture: granulated basalt, a dark volcanic rock common on Mars.

Valantinas and colleagues conclude that ferrihydrite might have formed during an oxidative spell during the cold, wet period on early Mars, when liquid water and oxygen briefly became available for such reactions. The compound then remained even after the loss of liquid water as the Martian climate cooled to its current deep freeze.

Briony Horgan (Purdue University), who wasn't involved with this study, says the team's conclusion aligns with previous work. "The best way to really solve this puzzle," she adds, "would be to get a sample of Mars dust into our labs back on Earth."

■ **JEFF HECHT**

KM3NET COLLABORATION

IN BRIEF

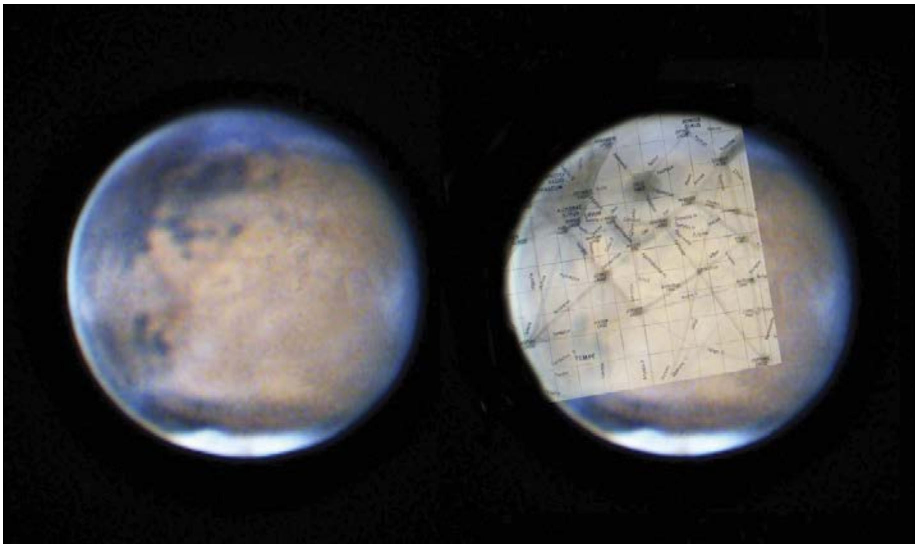
Barnard's Star Has Four Planets

Following decades of disproven claims, astronomers have confirmed that four small exoplanets orbit Barnard's Star, the second-closest star system to Earth after Alpha Centauri. Just 6 light-years away, Barnard's Star is a well-studied 10-billion-year-old *M* dwarf with a mass of 0.16 solar mass. Finding exoplanets around Barnard's Star has been something of a white whale for astronomers for more than half a century. Then, last October, researchers reported the discovery of a planet orbiting Barnard's Star with a period of 3.154 days (*S&T:* Feb. 2025, p. 9). The data hinted at the presence of three other planets, but they couldn't be confirmed. In the March 20th *Astrophysical Journal Letters*, Ritvik Basant (University of Chicago) and collaborators leveraged two years of data collected with the M Dwarf Advanced Radial Velocity Observer of Neighboring Exoplanets (MAROON-X), a spectrograph tailored to the properties of *M* dwarfs, to confirm that Barnard's Star hosts not just one but four planets. The planets are tiny, with minimum masses between 19% and 34% of Earth's mass. They're also in remarkably close quarters, with periods of just 2.34, 3.15, 4.12, and 6.74 days, respectively. None of them are in the star's habitable zone.

■ **KERRY HENSLEY**

Lowellian Mars

Could an optical illusion explain Lowell's folly?



NOT SO ILLUSIONARY (*Left*) On February 4, 2025, Roberto Fontanari's 12-inch Newtonian reflector captured several linear features on the Martian disk. (*Right*) A section of Lowell's 1896–97 map of Mars is superimposed on Fontanari's image for comparison. Evern though nearly 130 years had elapsed, similar details can be seen. South is up.

VISUAL OBSERVERS HARDLY ever record "canals" on Mars anymore. It's no longer in vogue. Besides, who wants to wear the scarlet letters of Mars: *PL,* for Percival Lowell (1855–1916), the prominent American astronomer who imagined an artificial irrigation system crisscrossing the planet — one designed by a dying race of Martians. While the canals are most often associated with Lowell, some earlier observers, including William Herschel (1738–1822) and William Dawes (1799–1868), had rendered canal-like features on Mars.

Seeing fine linear structures on the Red Planet and believing them to be artificial creations are not the same. When NASA scientists compared maps of Lowell's canals to Mariner 9 images, they found that some canals likely correspond to rift valleys, ridge systems, crater chains, and linear surface albedo markings. The others may have been creations by that master illusionist, the eye-brain system, which can, when stimulated in a certain way, create imaginary detail to help us interpret what's really there.

Several theories were put forth to explain why Lowell saw the planet webbed by fine lines. I belong to the camp who believe that Lowell's eyes were extremely sensitive to areas of different contrast on the planet, leading to a border-enhancement illusion known as the *Mach band effect*, after Austrian-Czech physicist Ernst Mach (1838–1916). Mach noticed that when two vertical bands of slightly different shades abut each other, you can see an extra-dark linear line at the edge of the dark band; the reverse occurs at the edge of the light band. Mach bands do not exist, but we see them, nonetheless. They're caused by *lateral inhibition* of the retina — a visual phenomenon that enhances edge perception and increases contrast, enabling us to see an object that might otherwise not be noticed.

▲ **MACH BANDS** Take about 10 seconds to stare at this image and notice how a dark band appears immediately to the right and a light band immediately to the left of the gradient.

Edge-enhancement contrast effects also appear in images. In fact, radiologists are especially aware of Mach bands in X-ray images, as they're known to cause diagnostic errors. Linear features on Mars were also imaged at Lowell Observatory and served to corroborate visual sightings. With that in mind, I scanned images of the current Mars apparition, posted by the Mars Section of the Association of Lunar and Planetary Observers of Japan (**https://alpo-j.sakura.ne.jp/indexE.htm**), with keen interest. I found one face of Mars particularly susceptible to Mach-band effects: the Solis Lacus (the Eye of Mars) and Tharsis regions, which offer a mix of true and illusory linear features.

I was particularly struck by one image taken on February 4, 2025, by Roberto Fontanari of Sant'Orsola Terme near Trento, Italy. It shows a dozen or more dark lines that correlate well with those mapped by Lowell. Of course, owing to the ever-shifting sands of Mars, the appearance of light and dark areas on the planet's surface can change with time, so I didn't expect an exact match. You don't even need Lowell's map to see how Mach bands can create illusory "canal-like" structures. So, Lowell was not so much as wrong in what he perceived, only in what he imagined.

■ Contributing Editor **STEPHEN JAMES O'MEARA** loves to share the visual wonders of the day and night skies with observers of all skill levels.

MARS AND OVERLAY: MARS PHOTO: ROBERTO FONTANARI; OVERLAY: PERCIVAL LOWELL; MACH BAND EFFECT: SEAN WALKER

 by Rachel M. Huchmala

Telescopes for Teachers

A new program in Idaho is helping kids connect with the universe.

Looking up at the night sky has been a part of human culture for as long as we can remember. For me, being able to see the stars and the Milky Way is a reminder of not only how small but also how special we are. When we lose the sky, we lose both reminders — which is why it's such a gift when someone connects us with the sky.

I used to tell people that, growing up in Las Vegas, I saw different kinds of stars than the ones above our heads. But that isn't entirely true. The sky wasn't dark, but I knew just whom to ask if I wanted to know what was out there. My best friend's dad seemed to have this superpower (some may call it a PhD in astrophysics) for unveiling the universe in our night sky. Taking the 10 or so stars we could see from their backyard, he would weave them into the constellations we would have been able to see if there were less light pollution.

A few years later, I moved to Flagstaff, Arizona, the world's first International Dark Sky City. Living in a place that prioritized minimizing light pollution was an eye-opening experience for me. I could see the Milky Way from my backyard every night, which only made me more driven to study the science of the universe and more passionate about saving dark skies. I successfully pursued a PhD and worked to support community outreach efforts throughout my education.

Flash forward to 2023, when I joined the Central Idaho Dark Sky Reserve STEM Network as their postdoctoral fellow. The STEM Network is a partnership between a group of astronomers at Boise State University and the Central Idaho Dark Sky Reserve (CIDSR), a stretch of 3,667 square kilometers (1,416 square miles) that holds some of the darkest skies in Idaho. (For aficionados, the area boasts skies ranging from 1 to 3 on the Bortle scale.) The reserve presents a unique resource to the residents of Idaho and is currently one of only two dark-sky reserves in the United States certified by DarkSky International.

Funded by NASA's Science Activation Program since 2021, the main goal of the STEM Network is to support science, technology, engineering, and mathematics (STEM) engagement efforts throughout the state of Idaho. Professor Brian Jackson (Boise State University) directs the program. The network consists of several mutually supporting strands, all working together to provide public astronomy lectures, stargazing, outreach events, and an Astro Adventurers summer program for elementary school students. All this work is made possible by the incredible team that supports the program.

LEAH TISCIONE / S&T

SEEING STARS The Milky Way adorns the sky over the Central Idaho Dark Sky Reserve.

I work with an outreach team of undergraduate students, Astronomers in Training Assisting the Community (AstroTAC), preparing and supporting them to host star parties, present astronomy activities at local STEM nights, and use our mobile planetarium to bring the stars closer to the community. The AstroTAC students gain in return not only the joy of serving others but also experience with public speaking and scientific communication, skills that are important as they look toward their futures.

I help the AstroTAC students to design new activities, focused on what the students are most interested in. This makes it easier for the students to teach others and allows the students to share their passion. Some of these activities require no more than beads and string — but paired with imagination, they become exoplanet systems. I am amazed by the impact the network is having on communities in Idaho and its success in "spreading the word" about the effects of light pollution.

By spending time interacting with schools in Boise and the surrounding areas, we saw there was an interest in looking up and a need for more resources to share what was to be seen in the sky. Many of the teachers we talked to were quick to comment that their students have a hard time staying engaged when learning about space-related science, because so much of it is intangible. This is where the idea of Telescopes for Teachers began.

The Beginning

Technological advancements have brought a new era of computerized backyard telescopes. Supported by everything from Go To systems to live-view displays that enable multiple people to see a target at once (without messing with the focus knob between each observer), these devices provide budding enthusiasts with a wide on-ramp to help them climb astronomy's learning curve.

One of the companies paving the way is Unistellar. They offer a range of telescope models, with a variety of bells and whistles, but they all have one thing in common: Instead of being a standard optical backyard telescope, they are equipped with CMOS sensors and read out to a smart device. This means that with a small aperture and their "enhanced vision" technology, these telescopes can create clear, color images of deep-sky objects, even in light-polluted areas.

When we set out to offer telescopes to teachers, we knew that we would need equipment that would be easy to use, learn, and teach with. More than this, we also wanted a telescope that would provide views of the cosmos from places like school basketball courts, in both urban and rural areas. Ultimately, we chose the Unistellar eQuinox 2 telescope for our program. The telescope has a 4.5-inch aperture, hosts its own Wi-Fi network for connection, and fits into a hiking backpack for easy transport.

The next step in creating this program was establishing funding to purchase the telescopes and develop the program. In September of 2023, we asked the NASA Science Activation Program (which supports the STEM Network) for an additional $125,000, explaining the need for telescopes in classrooms and that providing this resource for teachers would help students maintain engagement in space-science units. We also outlined how the program was an opportunity for something greater: inspiring students with scientists' stories and enabling them to contribute to research. NASA said yes.

▲ **EXOPLANET BRACELETS** In my favorite activity, participants use beads and string to create their own exoplanet system. We provide them with black beads to represent space, and they choose their own host star (red or yellow bead, to represent a red dwarf or Sun-like star) and exoplanets to complete the system: gas giants, mini-Neptunes, super-Earths, and terrestrial.

On March 6, 2024, I walked into work like any other day. However, when the elevator doors opened into the university's physics department, I knew my day was about to take an unusual turn. My eyes fell on a cluttered hallway lined with palettes. As I wiggled my way between the palettes and the students waiting to enter their physics labs to make it down the hallway to my office, I learned that "my" telescopes — or, more specifically, 50 Unistellar eQuinox 2 telescopes, 50 solar filters, and 50 backpacks to store the equipment in — had been delivered (sans warning). It was a bad day to have worn my nicest sweater to work.

Walking down the hallway and seeing all the boxes transformed this crazy idea we had — to provide telescopes to teachers in Idaho — into a real program. But the real work was just starting.

Bringing Hands-On Astronomy to the Classroom

As it turned out, having 50 telescopes delivered to us was the easiest part of the whole operation. The next challenge we faced was finding storage for 50 telescopes, then finding 50 teachers interested in joining the pilot program. Most

MILKY WAY: ARIANNA JAPALUCCI; BRACELETS: RACHEL M. HUCHMALA importantly, we needed an internal infrastructure to support any participants, meeting them where they were and making sure they all felt comfortable operating the telescope and had access to the appropriate smart device to use it.

We soon received an unexpected windfall. A local news story ran about our program, and overnight almost 100 teachers across Idaho contacted us about participating.

Through a questionnaire we sent to each teacher and a search of school populations, we made our selections. We set forward simple rules: Only one telescope could be loaned to a school, and one teacher had to assume custodianship of it. However, if multiple teachers from a school applied and were selected, we invited all the teachers to the training.

We worked to spread the telescopes across the state, especially to communities our outreach team couldn't easily visit. Ultimately, we were able to reach both rural and urban schools, with varying student populations in every combination of grades, from kindergarten through 12 (see the map on page 19). Because of the range of teachers we selected, we have used the pilot year to learn from the teachers and adapt our programming to best support the concepts and activities that worked in their classrooms.

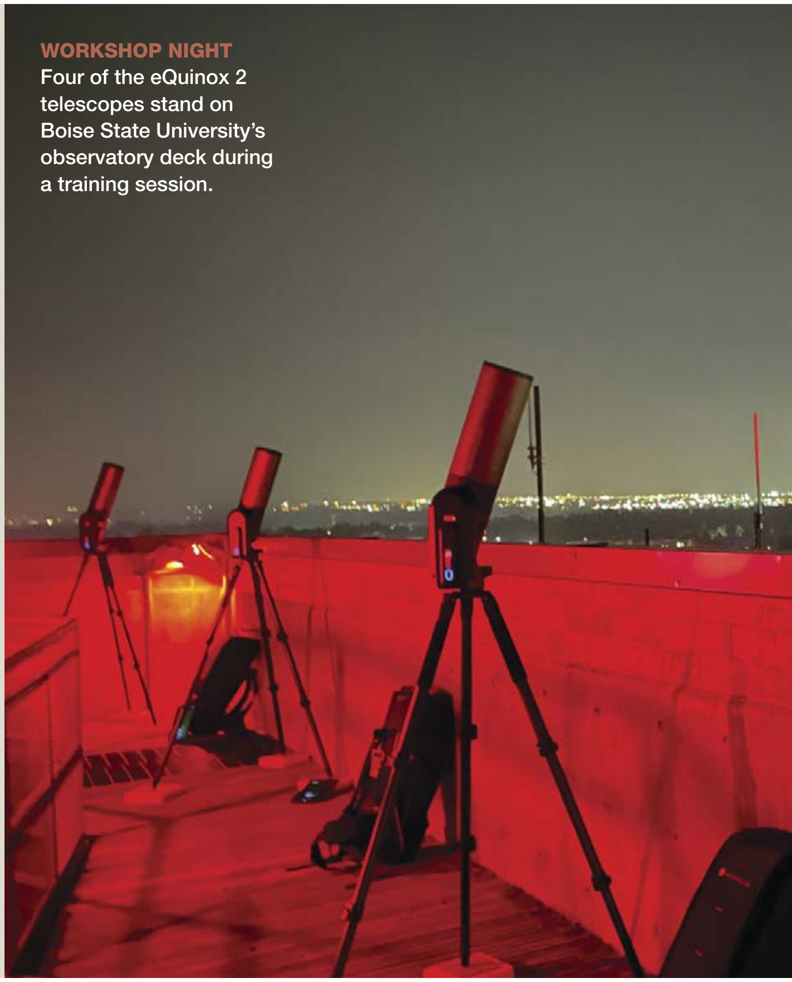
Once we had our participants assembled, it was time to prepare a training procedure. This took the form of a one-night workshop, designed and led by me, involving four hours of classroom learning and two hours of hands-on observing with the telescope. Our workshop covered four main topics: parts of and how to set up the eQuinox 2, basics of telescopes and how the eQuinox 2 compares to other telescopes, preparing for observing, and the study of exoplanets and how the telescope they were holding could collect real data about exoplanets (more on that later). At the end of the night, the newly trained teachers were sent off with their equipment.

In any given workshop we could have kindergarten teachers or 12th-grade teachers, with experience ranging from those who had just started teaching astronomy to others with experience in astrophotography. So we made sure to design a workshop that was flexible, providing teachers with information, leaving time for discussion, and ultimately allowing the educators the space and freedom to decide how to best present the information to their students. This way, I could teach a workshop geared toward the participants that focused on the tools and resources they might need, instead of providing a rigorous structure for teaching one specific topic.

We held 10 training workshops in all, with a total attendance of 57 teachers who all learned the basics of using the

TELESCOPE AND WORKSHOP NIGHT: RACHEL M. HUCHMALA (2)

▼ **READY TO GO** Each telescope comes in a backpack adorned with a Boise State University luggage tag. Inside we also pack a laminated informational page on the telescope's namesake, for the teacher to share with students.



WORKSHOP NIGHT Four of the eQuinox 2 telescopes stand on Boise State University's observatory deck during a training session.

telescope. Hosting these workshops was a chance to meet some of the incredible educators in Idaho, who work so hard for their students. I feel honored that I have been able to meet every participant of our program.

Although we are still only in the first year, we're already hearing from teachers that our telescopes are enabling them to make astronomy more engaging. One of them told me:

> *The Telescopes for Teachers program has given teachers such an amazing opportunity to make science more accessible to students. As an astronomy teacher, I struggle with providing hands-on and tangible experiences for the students, but this program has made that possible!*

Sharing Stories

As a woman in STEM, I have always enjoyed learning the stories of other women in STEM. When presented the opportunity, I decided to name each of our telescopes after a historic woman who has made an influential contribution to physics and astronomy. Thus, the second goal of Telescopes for Teachers was formed: sharing the stories of pioneering women in physics and astronomy.

Our selected individuals span time and geographic location, highlighting women who broke down barriers for the next generation. All of our telescope namesakes can be found on our website (**https://is.gd/cidsr_scientists**), along with a short biography of them and their work.

This recognition is an important aspect of our program: It both provides visibility to scientists whose stories are often overlooked and gives students examples of scientists they might more easily see as role models for themselves. This visibility is important to all students, not just girls, because it shows that with the right amount of perseverance, anyone can gain access to education and become a scientist.

Contributing to Citizen Science

For my postdoctoral research, I study transits of *short-period exoplanets* — worlds that make a quick orbit around their host stars. I do this work as a member of an international scientific collaboration called the Short Period Planets Group, or SUPERPIG for short. Within SUPERPIG, my work has focused on *ultra-hot Jupiters*. This is a class of exoplanets that are Jupiter-size or larger and lie so close to their host star that they complete a full orbit in less than 4 days.

Because of the planets' size and proximity to their stars, when they pass between us and their host star they block

▼ **FAR AND WIDE** The telescopes have found homes across the state (red dots, 47 as of mid-March). The Central Idaho Dark Sky Reserve is the patch in green.

MAP: BEATRIZ INGLESSIS / *S&T*

▲ **DUMBBELL NEBULA** Teacher Sally Pham from Eagle High School used the telescope's "enhanced vision" feature to capture this image of Messier 27 in a Bortle Class 6 area (bright suburbia).

▲ **WHIRLPOOL GALAXY** The author captured this image of Messier 51 and its smaller companion, NGC 5195.

a significant amount of the star's light. This feature makes them good candidates for observations with small ground-based telescopes — even those as small as the ones we're giving out to teachers.

Back in March, after the dust had settled and the palettes were cleared from the hallway, Brian Jackson and I looked at the stack of telescope boxes that now decorated my office. In a moment that could only be described as a light bulb turning on, we found a new way to connect my love of exoplanet science and my passion for community outreach: We realized that we could involve teachers and their students in real science. In turn, their observations could also directly contribute to my own research.

With this realization, we were able to develop the third goal of Telescopes for Teachers: empower teachers and their students to confidently contribute to exoplanet science.

One of the most exciting things about the Unistellar telescopes is the partnership between Unistellar and the SETI Institute, a nonprofit research organization dedicated to understanding the origins and prevalence of life in the universe. Thanks to this partnership, the telescopes are equipped with a special "science mode" that an observer can use to contribute to active research projects being done in astronomy. There are currently six observation campaigns: asteroid occultations, exoplanet transits, planetary defense, cometary activity, cosmic cataclysms, and satellite surveillance.

"The goal is to make anyone a part of the scientific process," Franck Marchis, chief science officer and cofounder of Unistellar, told me when we sat down to chat at the 245th American Astronomical Society meeting this past January. "They don't only record observations, but they also learn about why we care about observing this exoplanet, this comet, or whatever else."

Starting the science mode is simple. When a user decides to conduct an astronomical observation, with the click of four buttons they can take and share their data. They first press a button to accept the target, then a second button moves the telescope. The third button starts the observation, at a given exposure and cadence predetermined by the specific observing campaign. With the click of a fourth button, the data are sent to Unistellar/SETI Institute for analysis. For most projects, a user is notified of their results within 48 hours.

For our program with teachers, we are most interested in Unistellar's exoplanet-transit campaign. We've designed a citizen science program, the SUPERPIG Observing Grid, specifically for participants of Telescopes for Teachers. Its goal is to conduct follow-up observations of ultra-hot Jupiters in search of signs of *tidal decay*. This phenomenon occurs when the gravitational interaction between the planet and the host star causes the planet to slowly spiral in closer to the star. It ultimately leads to the planet's demise (*S&T:* Jan. 2023, p. 14). We call these exoplanets "doomed worlds," and the most popular one is an exoplanet by the name of WASP-12b.

But the change to a doomed world's orbital period happens slowly: It took a decade of observations to confirm signs of tidal decay in WASP-12b's orbit. This means that in order to detect tidal decay in more exoplanets' orbits, we need to establish long-term follow-up observing programs. We intend for the SUPERPIG Observing Grid to be one of these programs.

As this article goes to press, the SUPERPIG Observing

Grid is preparing for its first observations in the spring and summer of 2025. We do not require the teachers to join the citizen-science program, but we hope they will be excited to do so. The teachers that do join will be presented with a number of exoplanet transits that will be visible from their location and invited to collect *light curves* of the events with their students using the telescope and Unistellar's data-reduction tools. We are only just starting out, but ultimately I hope to be able to combine observations taken in my own research with observations from teachers and their students to further our understanding of tidal decay.

In just one year we created a program, distributed telescopes to nearly 50 teachers, and are now working to prepare them for scientific observations. All in all, I hope that this program creates excitement amongst the teachers, fosters a community of science teachers throughout Idaho, and exposes students to the many wonders of astronomy. I am excited to see how our first observing season goes and to learn about all the unique ways the telescopes are being used in the classroom. More than anything, I hope the opportunity to use a telescope gives the students an appreciation for the wonders of the night sky.

▲ **TRIANGULUM GALAXY** Teacher Benjamin Satterwhite took this image of Messier 33 from the Julius Jeker Planetarium in Boise. He says that the program "has allowed students to step out of the classroom and become active citizen scientists." It even inspired the planetarium to build its own telescope library for the local school district.

▼ **A TROOP OF TELESCOPES** The author poses with all 50 telescopes, prior to their distribution.

AUTHOR WITH SCOPES: KAITLYN AUSTIN

■ **RACHEL HUCHMALA** is a postdoctoral fellow at Boise State University. Her research interests include exoplanets, citizen science, and community engagement in space science.

Learn more about the Telescopes for Teachers project: https://is.gd/idaho_tft.

Summer Outreach Treas

Sharing the season's finest and most intriguing sights can inspire a new passion.

I was introduced to astronomy outreach decades ago at a planetarium show where I first met a few members of the Back Bay Amateur Astronomers — a club that serves southeastern Virginia. After the presentation, patrons were treated to views through the planetarium's 14-inch Schmidt-Cassegrain telescope (SCT). I don't remember what we saw that night, but I'll never forget the sense of awe that permeated the crowd. I was hooked and joined the Back Bay group. Even now, many years later, I find astronomy outreach so fulfilling that it's my primary motivation for belonging to an astronomy club.

Nearly everyone is curious about the universe and our place in it. Young people, in particular, are fascinated by astronomy, which can serve as a powerful introduction to the physical sciences. Just about everyone who has participated in outreach has likely inspired a youngster or two. Indeed, it's one of those rare activities that really can change the trajectory of someone's life for the better.

Most of us, however, don't set out to deliberately inspire the next generation of scientists. We do outreach because it's fun and because it's rewarding to share the excitement of someone's first look at Saturn's rings, the Moon's craters, or a comet's tail. It's also a chance to relive our own first experiences.

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PUBLIC SKY Volunteers from the Calgary Centre of the Royal Astronomical Society of Canada show off the night sky to visitors at one of the annual Milky Way Nights presented at the University of Calgary's Rothney Astrophysical Observatory.

ALAN DYER

Making someone's first telescopic view a memorable occasion takes a bit of planning. It helps to select objects that have a certain "wow" factor in the eyepiece or that are remarkable in some other way. Of course, where you view the sky from plays a big role. The level of light pollution and the contours of the local horizon often dictate which objects are accessible. That's why it's important to scout out your location beforehand — ideally both during daylight and at night.

By the Light of a Silvery Moon

With summer's late sunsets, scheduling events to coincide with a first-quarter Moon is a great strategy. That's when the Moon is prominent in the evening sky, which means guests don't have to stay out especially late. Our natural satellite is one of my very favorite outreach subjects. It never fails to impress, even in the smallest telescopes. However, that initial amazement can be short-lived, so it's helpful to come prepared with a selection of lunar features to hold your audience's attention through twilight.

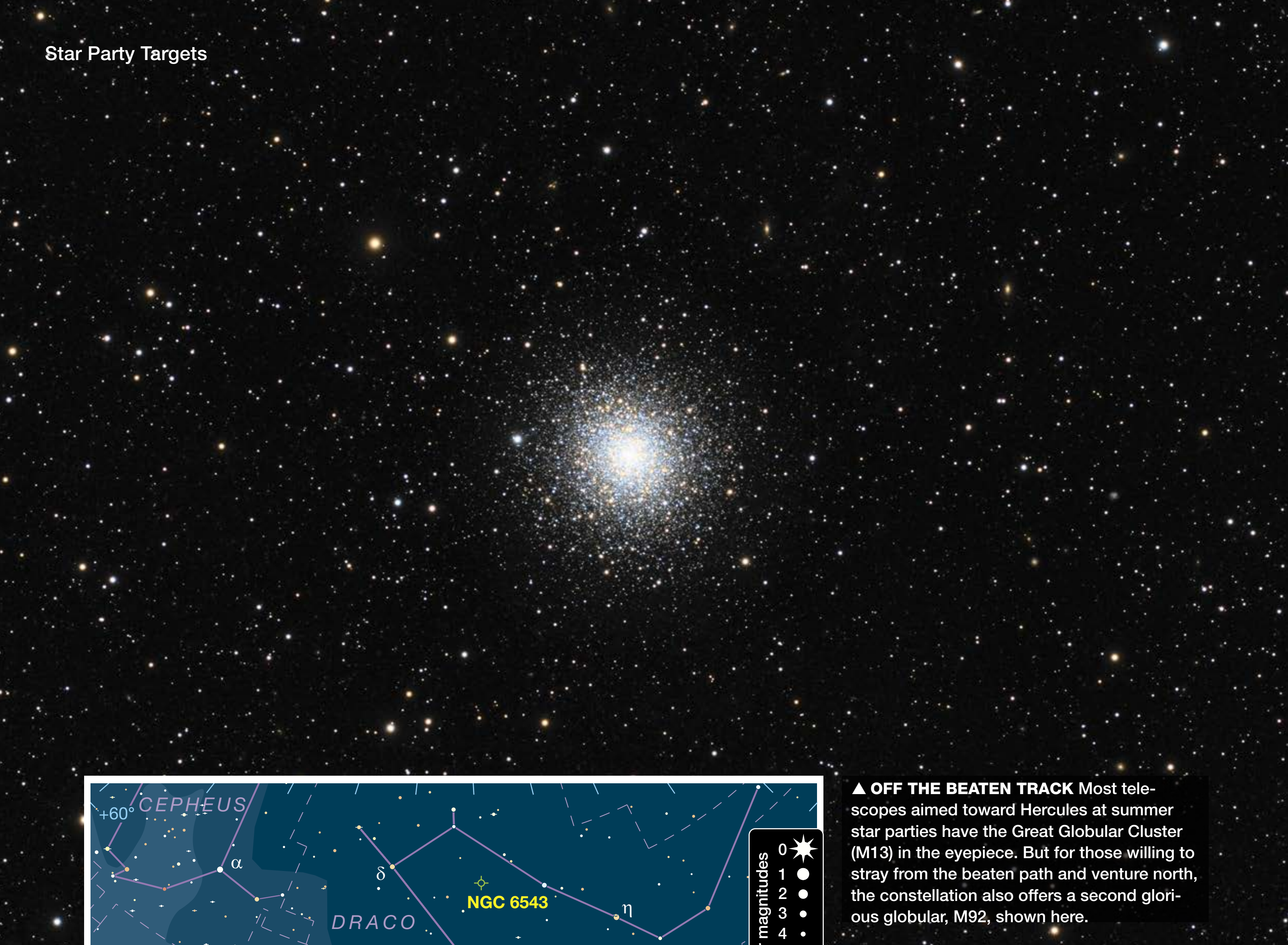
Before each event, I do my homework. A good lunar map is always a big help. I keep Sky & Telescope's *Field Map of the Moon* handy. It comes in two versions: a normal one with lunar north up and west to the left, and one with a mirror-reversed orientation for scopes that utilize a mirror star diagonal, such as SCTs and refractors. A computerized lunar map is also useful because it can be set to show the lunar phase and libration for the date and hour of my event. I find the freeware program *Virtual Moon Atlas* by Christian Legrand and Patrick Chevalley to be an excellent resource. Before an event, select a few features along the terminator and jot down some facts about them, such as their dimensions, ages, and the origins of their names.

The Moon is detailed enough that it could be the entire focus of your outreach event, but if you're fortunate enough to be at a dark site, you might choose a night when it sets early enough that you can also delve into the deep sky.

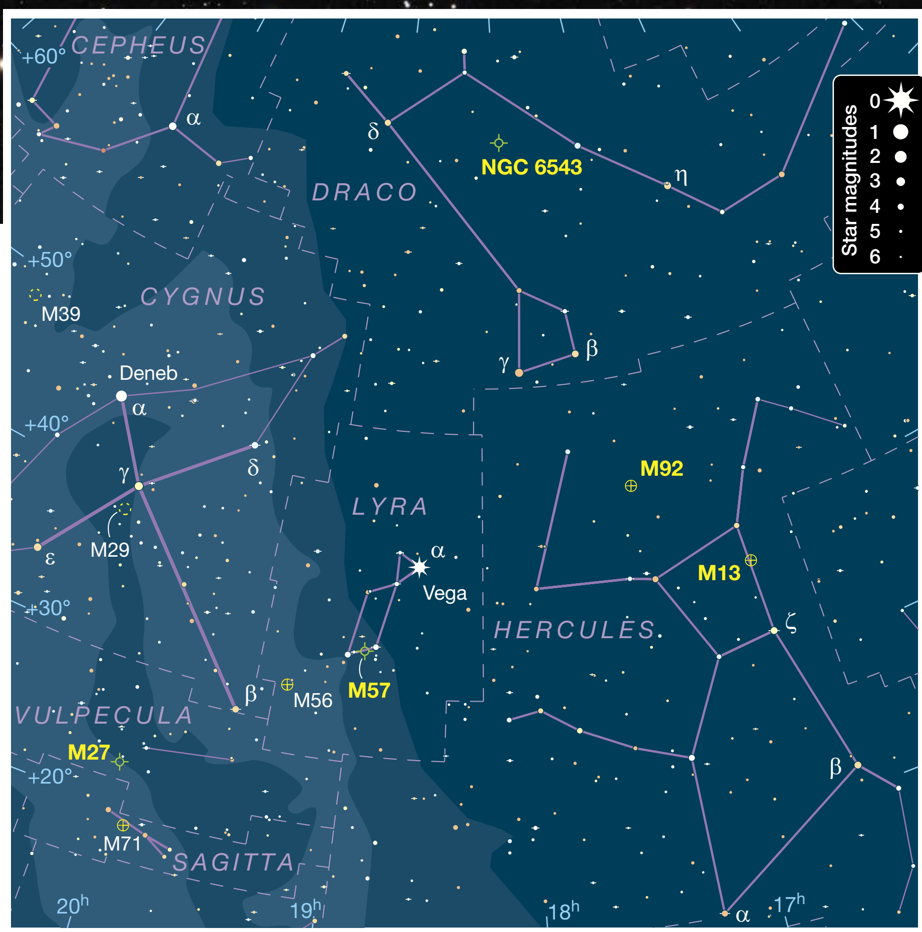
Exploring the Home Galaxy

The summer Milky Way contains many remarkable individual targets, but in its entirety it's also a splendid naked-eye showpiece. Members of the public visiting a dark-sky site may be completely unaccustomed to seeing it. A green laser pointer is the perfect tool for tracing out the Milky Way's contours. The first flash of your laser will invariably evoke surprise and curiosity about the device itself, but a word of caution is in order: Laser pointers can be dangerous and must be used responsibly (see the safety note on page 21 of the February 2023 issue of *Sky & Telescope*; see also **https://is.gd/laserpointers**). I like to use my laser to point out the home galaxy, starting from the southern horizon, going high overhead across the spine of Cygnus, the Swan, then north to where it fades away low in Perseus. Describing the Milky Way as the steam from the Sagittarius Teapot always prompts a smile or two.

It's also worth spending some time describing specific sections of the Milky Way. I direct attention to the



▲ **OFF THE BEATEN TRACK** Most telescopes aimed toward Hercules at summer star parties have the Great Globular Cluster (M13) in the eyepiece. But for those willing to stray from the beaten path and venture north, the constellation also offers a second glorious globular, M92, shown here.



◀ **HERCULES AND BEYOND** Anyone setting up a telescope for a public event will be familiar with many of the best and brightest summer deep-sky objects. Both well-known Hercules globular star clusters (M13 and M92) are sure to delight visitors. The region covered by this chart also contains a trio of notable planetary nebulae: M57 (the Ring Nebula), M27 (the Dumbbell Nebula), and NGC 6543 (the Cat's Eye Nebula).

galactic center — a spot about 4½° west-northwest of 3rd-magnitude Alnasl, or Gamma (γ) Sagittarii, the tip of the Teapot's spout. You might explain how interstellar dust blocks our view of the Milky Way's true center. Next, highlight the dense haze that is the Sagittarius Star Cloud, about 7° north of the top of the Teapot, or trace out the Great Rift. Any of these can lead to a discussion of the structure of our home galaxy and provide

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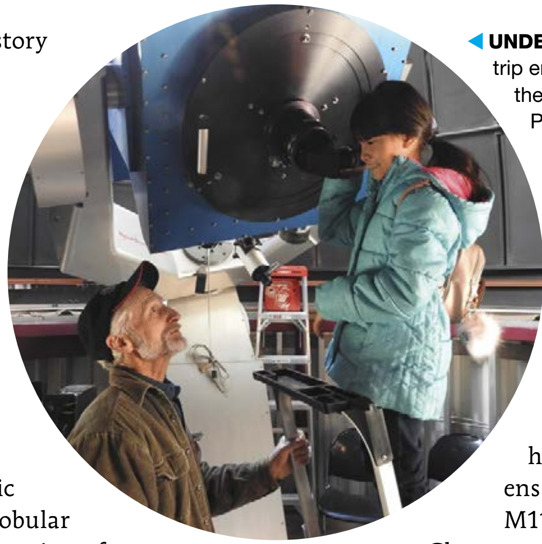
a convenient opening to relate the history of humankind's understanding of the galaxy's structure. You might relate how we get the name Milky Way from the ancient Greeks, or how Galileo was the first to demonstrate that its hazy glowing band is actually composed of innumerable unresolved stars, or that William Herschel was the first to try and map our galaxy's shape. I like to relate the story of how astronomer Harlow Shapley used the distribution of globular clusters to establish the Sun's location far from the galactic center. The fact that the number of globular clusters increases as we look in the direction of Sagittarius is easy to demonstrate.



◀ **UNDER THE DOME** A student on a school field trip enjoys a daytime view of the planet Venus with the 20-inch Ritchey-Chrétien reflector of the Patterson Observatory. The facility is located in Sierra Vista, Arizona, and is used mainly for public outreach.

TED FORTE

Going Globular

Summer evenings are ideal for introducing people to the wonders of the deep sky. The Great Globular Cluster in Hercules, **M13**, is an obvious choice to begin with. At magnitude 5.8 and with a diameter of 20′, it's nothing short of spectacular in large scopes and is easily seen even in binoculars. In dark skies, it's even detectable with the naked eye (see page 45). If you can comfortably reach southerly declinations, Sagittarius globular **M22** is even more impressive. It spans 32′ and shines at magnitude 5.2.

At many outreach events, visitors typically visit each telescope in turn and are often met with the same target at multiple stops. That's why I venture off the beaten track a bit and highlight different objects. When other scopes are showing M13, I go about 9½° northeast to **M92**. There is something about this 14′-wide, 6.5-magnitude bauble that I think is prettier than its better-known neighbor. See if your guests don't agree.

To explore even farther off the beaten track, I aim my scope at another favorite sight — two globular clusters that fit comfortably in the same field of view. The duo are located about ½° northwest of Gamma Sagittarii. The larger cluster **NGC 6522** is 16′ west of the smaller but slightly brighter **NGC 6528**. At magnitudes 9.9 and 9.6, respectively, they're a bit more challenging than the usual outreach targets. You really need at least a 10-inch scope and reasonably dark skies to show them well, but they can be a real treat under the right circumstances. William Herschel discovered the pair in June 1784, and recent estimates place them at roughly the same distance, 26,000 light-years away.

Milky Way Wonders

There is such a profusion of rich and varied open clusters in the summer sky that choosing just one to show people is a daunting task. My own favorite is **M11** in Scutum. Walter Scott Houston called it "a carpet of sparkling suns . . ." and that's certainly an apt description. You might tickle your guests' imaginations by relating a calculation made by astronomer Robert J. Trumpler. According to his estimate, an observer near the center of M11 would see a sky populated with several hundred 1st-magnitude stars and dozens rivaling Sirius in brightness.

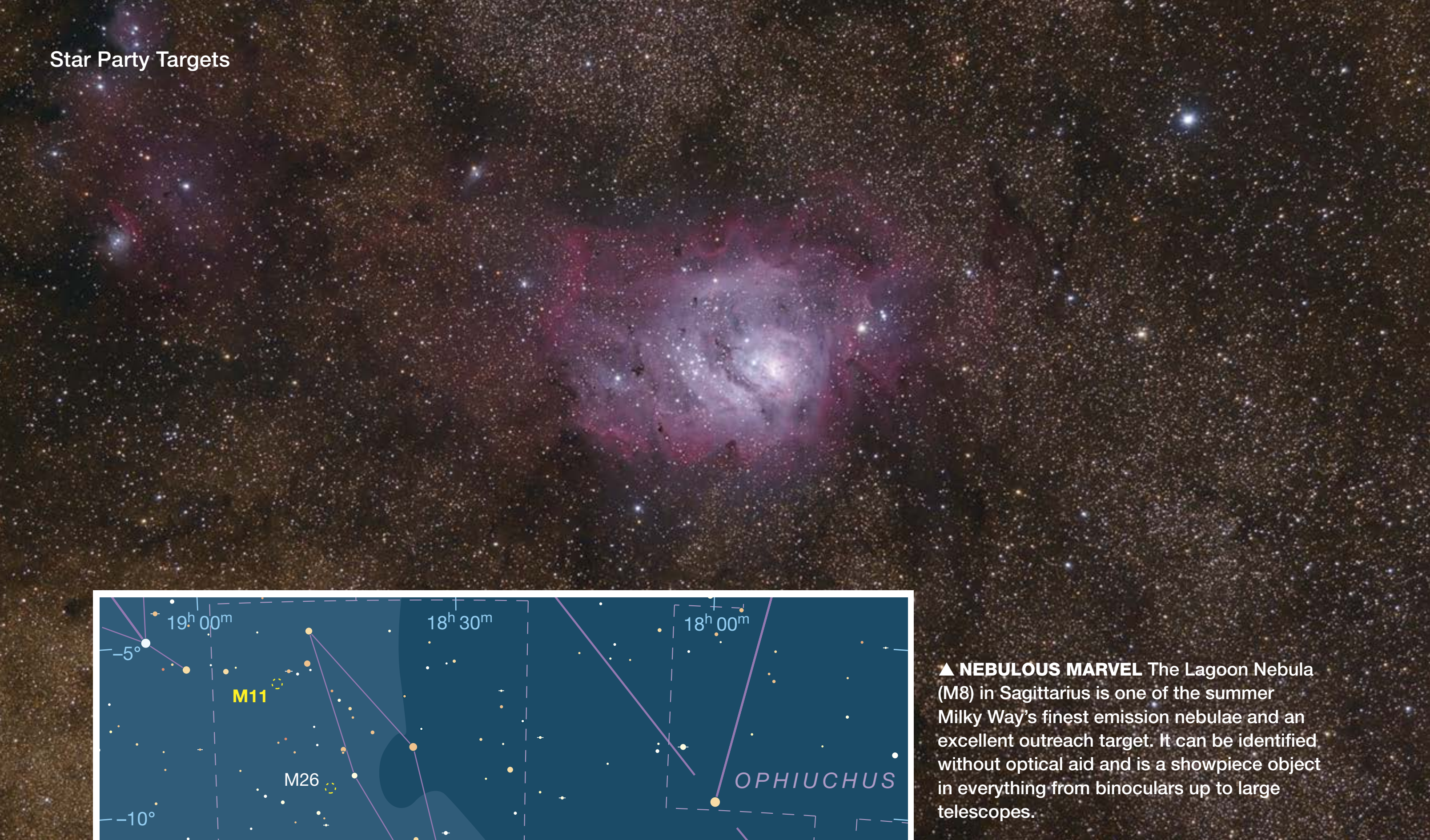
M11 is also known as the Wild Duck Cluster, a name that relates to the pronounced V shape (like a flock of ducks in flight) that it displays in small telescopes. This gem is one of the richest and densest clusters in our sky, containing about 2,900 stars. Of these, some 500 are brighter than 14th magnitude, which means they're within reach of mid-sized scopes. Your audience may be interested to learn that the cluster is fairly young, having formed about 300 million years ago, and that gravitational interactions will scatter the cluster's stars in the distant future. That's an excellent opening to explain how stars in open clusters are born and then drift apart over time.

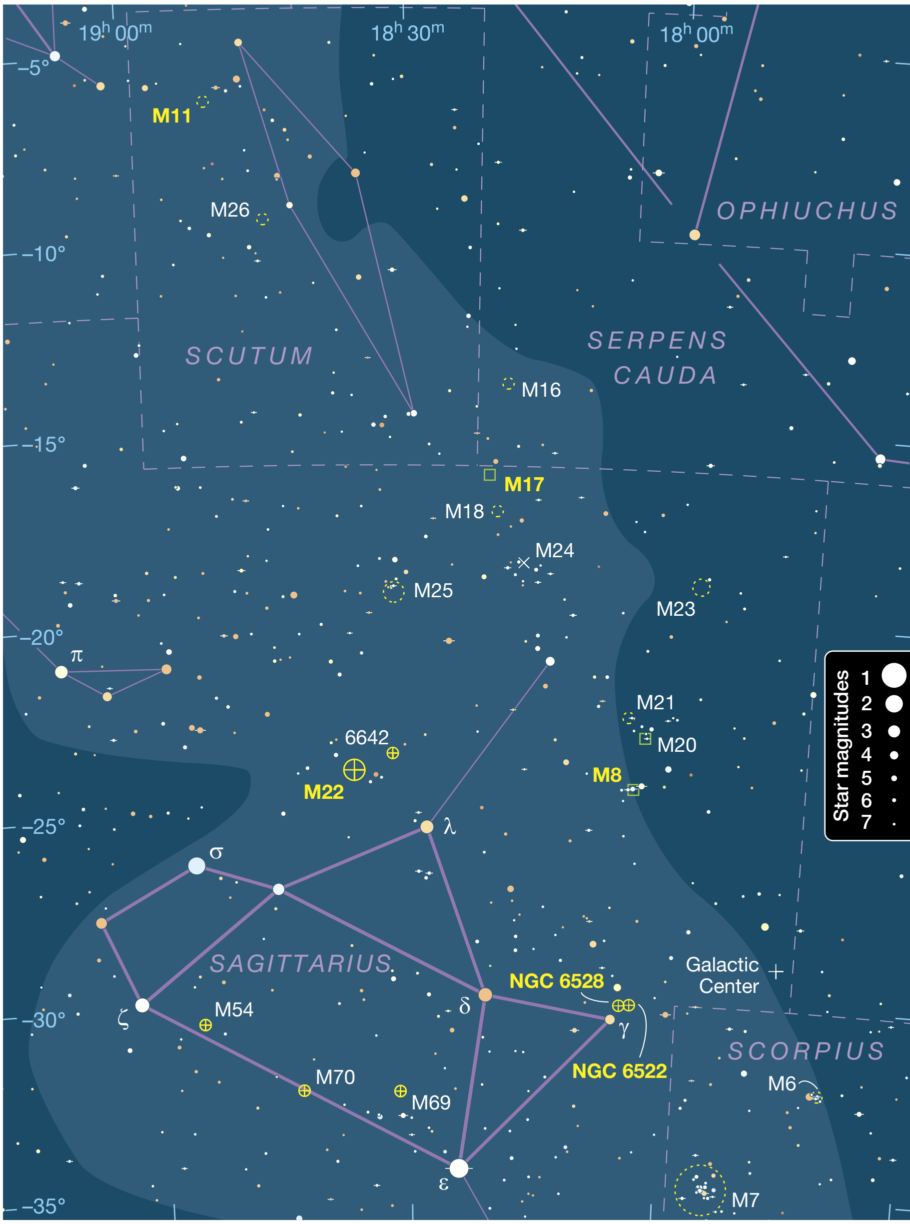
When the discussion leads to the clouds of gas and dust responsible for birthing stars, there are countless examples at hand. But while star-forming nebulae are plentiful, most are rather diffuse and subtle in the eyepiece. Some will require the use of filters to be visible at all. Several models are available to enhance the contrast of such objects by preferentially passing certain wavelengths of light while blocking those produced by natural skyglow and artificial light. My choice for general use is an ultra-high contrast (UHC) filter. I find it the most versatile filter in my collection. It's effective on most nebulae without blocking as much light as an O III filter, which has a narrower bandpass.

The Swan or Omega Nebula (**M17**) in Sagittarius is a particular favorite of mine. It's quite easily seen without a filter, but adding one enhances it so effectively that at public events I like to share the view with and without the filter so observers can appreciate the difference. The brightest portion of M17 resembles a check-mark shape. To my fellow Contributing Editor Stephen James O'Meara, its swan form appears to be "swimming in a faint mist rising from a black pool."

The Swan is a vast star-forming region similar to the Orion Nebula and spans roughly 15 light-years. It's estimated that it contains enough material to make 800 suns. There are about 35 stars visible that are part of the nebular complex, and there must be many more buried within the obscuring gas and dust.

While many nebulae populate the summer sky, their telescopic appearance might not meet expectations. Many





▲ **NEBULOUS MARVEL** The Lagoon Nebula (M8) in Sagittarius is one of the summer Milky Way's finest emission nebulae and an excellent outreach target. It can be identified without optical aid and is a showpiece object in everything from binoculars up to large telescopes.

◀ **SOUTHERN COMFORT** The southern Milky Way is an especially rich hunting ground packed with outreach delights. Sagittarius in particular is home to many superb deep-sky objects, including the Lagoon Nebula (M8) and a host of globular clusters, the brightest of which is M22.

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of your guests will have seen colorful photographs of some of these objects, and the eyepiece version is likely to pale by comparison. That's why I've recently become a great fan of the electronically enhanced perspective created with a night-vision device like the PVS-14 monocular. It can provide views that rival those photographs for certain objects. And one that really blossoms in the device is the Lagoon Nebula, **M8**. While this Sagittarius object is visually wonderous with just a UHC filter, the night-vision device used with a hydrogen-alpha filter provides an incredible enhancement. As an added advantage, the enhanced view can easily be captured with a smartphone camera — something outreach visitors are always keen to try. The device makes it a simple affair to capture a decent image, and guests come away with a treasured memento of their experience.

Tap Into Your Passion

Enthusiasm is the greatest gift an outreach astronomer can offer their audience. It's positively infectious, and never more so than when you're showing things that you personally find exciting. So, if there's a particular type of deep-sky object you especially enjoy, don't hesitate to share your favorite examples.

For me, those are planetary nebulae. Of course, on summer nights the standouts are Lyra's Ring Nebula, **M57**, and Vulpecula's Dumbbell Nebula, **M27**. Both are certain to be in every astronomer's repertoire. However, the summer sky is replete with many less famous planetaries.

Some of your guests might be familiar with the Cat's Eye Nebula, **NGC 6543**, in Draco. Just the fact that it has an evocative nickname lends it extra appeal. However, the eyepiece view might prove a letdown thanks to a widely distributed Hubble Space Telescope image. The brightly colored and intricately textured object they're expecting will be absent and won't look at all like a cat's eye. But this gives you a chance to explain all the reasons why Hubble images are so different from views in a backyard telescope.

But there's more than visual appeal to consider. An impassioned description of objects like the Cat's Eye can inspire novices to delve deeper and gain a greater appreciation for what they are seeing. Here is an object of remarkable, if subtle, beauty — one of the most intricate planetary nebulae known. Though the Cat's Eye Nebula itself is only 1,000 years old, the star at its center has experienced multiple outbursts at 1,500-year intervals and radiates at an unimaginably hot temperature of around 100,000 kelvin — about 17 times hotter than the surface of our Sun. Facts like these help viewers employ their imagination and more fully appreciate what they are seeing. That's why it's so important to do some prep in advance of an outreach event — just having a few interesting facts at your fingertips can really enliven the presentation.

▲ **FOXY NEBULA** The Dumbbell Nebula (M27) in Vulpecula, the Fox, is perhaps the sky's best known planetary nebula. Unlike most examples of this class of object, M27 is both relatively bright and reasonably large. Those factors combine to make it a star-party staple and a hit at public viewing events.

Stargazers have become an endangered species in our brightly lit modern world. Relatively few people have looked through the eyepiece of a telescope or scanned the skies with binoculars. The heavens were a source of wonder and inspiration to our ancestors, but many people have lost that connection. Reintroducing them to the night sky is the goal of astronomy outreach. It's a worthy endeavor and one I think you'll find rewarding if you give it a try.

■ Contributing Editor **TED FORTE** has served as the outreach coordinator for two different astronomy clubs. After all these years, he still finds public outreach to be the most rewarding and enjoyable part of the hobby.

Summer Targets

Object	Name	Type	Constellation	Mag	Size	RA	Dec.
M13	Great Globular in Hercules	Globular cluster	Hercules	5.8	20′	16h 41.7m	+36° 28′
M22	—	Globular cluster	Sagittarius	5.2	32′	18h 36.4m	–23° 54′
M92	—	Globular cluster	Hercules	6.5	14′	17h 17.1m	+43° 08′
NGC 6522	—	Globular cluster	Sagittarius	9.9	9.4′	18h 03.6m	–30° 02′
NGC 6528	—	Globular cluster	Sagittarius	9.6	5.0′	18h 04.8m	–30° 03′
M11	Wild Duck Cluster	Open cluster	Scutum	5.8	11′	18h 51.1m	–06° 16′
M17	Swan or Omega Nebula	Bright nebula	Sagittarius	6.0	20′ × 15′	18h 20.8m	–16° 10′
M8	Lagoon Nebula	Bright nebula	Sagittarius	4.6	45′ × 30′	18h 03.7m	–24° 23′
M57	Ring Nebula	Planetary nebula	Lyra	8.8	3′ × 2′	18h 53.6m	+33° 02′
M27	Dumbbell Nebula	Planetary nebula	Vulpecula	7.4	6.7′	19h 59.6m	+22° 43′
NGC 6543	Cat's Eye Nebula	Planetary nebula	Draco	8.1	20″	17h 58.6m	+66° 38′

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

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The Moving Stars of Frank Ross

A century ago, one diligent astronomer discovered three of our closest stellar neighbors in a single year.

◀ **EAGER OBSERVER** Frank Ross appears wistful in a photo from around 1920, at which time he was working on the physics of the photographic process for Eastman Kodak. But he longed to get back into astronomy.

▲ **RUDDY NEIGHBOR** Discovered in 1925 and just 11 light-years away, Ross 128 is a red dwarf, the most common stellar type. It's shown here in a composite of visual and near-infrared images.

Future starship captains — meaning possibly you — will need an excellent map of the nearest stars. After all, before setting sail, you'd better know that Alpha Centauri is a lot easier to reach than distant Deneb.

But astronomers who will never leave Earth also value our stellar neighborhood. The closer a star, they realize, the easier it is to observe everything about it. It's especially easy to measure such a star's distance: The closer it is, the larger its *parallax*, which is the tiny shift in its celestial position when observed from different vantage points as Earth circles the Sun. This distance, in turn, reveals other crucial properties, such as how much light the star emits into space — its *luminosity* — and from that its diameter. Moreover, only nearby can we hope to detect all stars that exist, down to even the most feeble.

Finding the *nearest* stars, though, is surprisingly difficult. You might think that all you have to do is examine the brightest stars, because the closer they are, the more dazzling they look. Ergo, the brightest stars must be the nearest. Brilliant Alpha Centauri and Sirius are indeed nearby. But other luminaries, such as Deneb, are so far away that even today we don't know exactly how far they are.

Furthermore, this approach actually excludes most of our nearest neighbors, simply because they emit relatively little light. In fact, most of the stars within just a dozen light-years of us are invisible to the naked eye.

So what to do? Answer: Ignore a star's brightness and instead examine its *motion* through space. Every star has a different velocity relative to the Sun. But how we perceive this velocity depends in part on the star's distance. The closest stars usually seem to move fast, whereas the ones farther away appear to hold steady. It's like what you see when driving down the highway: Nearby road signs whiz by quickly, whereas distant mountains appear to shift more slowly.

Astronomers call this apparent movement *proper motion* (*S&T:* June 2022, p. 30). In the 1910s, large proper motions led to the discovery of three dim stars. Their parallaxes then proved each to be a near neighbor: Proxima Centauri, whose distance of 4.25 light-years makes it the very closest individual star to the Sun; Barnard's Star, 5.96 light-years away; and Wolf 359, which is 7.86 light-years away. All three are red dwarfs, much fainter, cooler, and smaller than the Sun.

But in a single year a century ago — 1925 — an American astronomer named Frank Ross managed to ferret out three additional red dwarf neighbors from the stellar background, all three of which shine within just a dozen light-years of the Sun. This is the story of how Ross did it.

The Life of Frank Ross

Frank Elmore Ross was born in 1874. A native of San Francisco, he earned both his bachelor's degree (1896) and doctorate (1901) from nearby Berkeley — but his PhD was in mathematics, not astronomy. Accordingly, his early work in astronomy was highly mathematical. For example, he computed the orbits of several satellites around Jupiter and Saturn. Later, from 1916 to 1924, he was a research physicist at Eastman Kodak in Rochester, New York. There he designed lenses that proved especially useful to astronomers. But Ross wanted to get back into astronomical research.

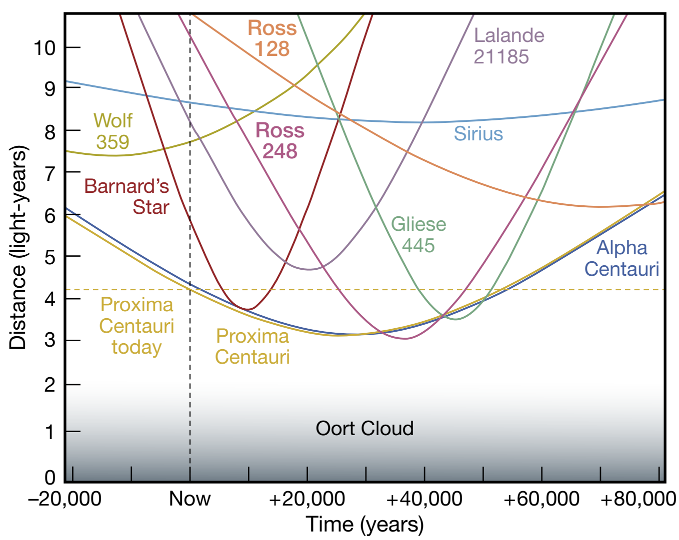
He got that opportunity with the death of the great Yerkes Observatory astronomer Edward Emerson Barnard. In 1916 Barnard had discovered the nearby red dwarf that now bears his name. Barnard's Star is still the star with the largest proper motion of all.

Barnard died in 1923, after which Yerkes director Edwin Frost sought someone to carry on the work. In particular, Frost wanted the new hire to take photographic plates of the sky with the observatory's 10-inch wide-field telescope, which benefactor Catherine Bruce had funded. The incoming astronomer could then compare the new plates with the ones that Barnard had taken, in order to find stars with large proper motions.

Ross began working at Yerkes Observatory in late 1924. He and his family moved into Barnard's house, which Barnard had willed to the observatory. The rent was $50 a month, 15% of Ross's salary.

Ross used a device known as a blink comparator to compare his plates with Barnard's. This machine rapidly alternates the view between two plates covering the same part of the sky but taken on different nights. As the view switches back and forth in the device's eyepiece, stars that are stationary remain fixed in place. In contrast, a star with a large proper motion exhibits what Ross called "a slashing motion across the retina." In this way, he discovered numerous faint stars with large proper motions.

He also ran into problems. "Truly the photographic plate is a good servant but a tricky master," he wrote in the *Astronomical Journal* in 1926. He found, for example, that a dried drop of water on a plate could shift the recorded star posi-



▲ **CLOSE CALLS** Two of our nearest neighbors, Alpha Centauri and Ross 248, will come within about 3 light-years of us during the next 40,000 years.

RED STAR: SLOAN DIGITAL SKY SURVEY; ROSS: LICK OBSERVATORY ARCHIVES; GRAPH: ADAPTED FROM HARTMUT JAHREISS "DIE SONNENUMGEBUNG" IN *UNSERE KOSMISCHE HEIMAT (STERNE UND WELTRAUM*, JANUARY 2006), ROGER SINNOTT tions, thereby introducing spurious proper motions. "If residual drops of water are allowed to remain on the glass side of the plate when it is placed in the drying cabinet, defects of the kind in question will appear on the emulsion directly opposite each drop," he wrote. One of these that landed near several stars gave them all the same incorrect proper motion, alerting him to the problem. As Ross noted, though, what if the drop affected just one star? Who would know?

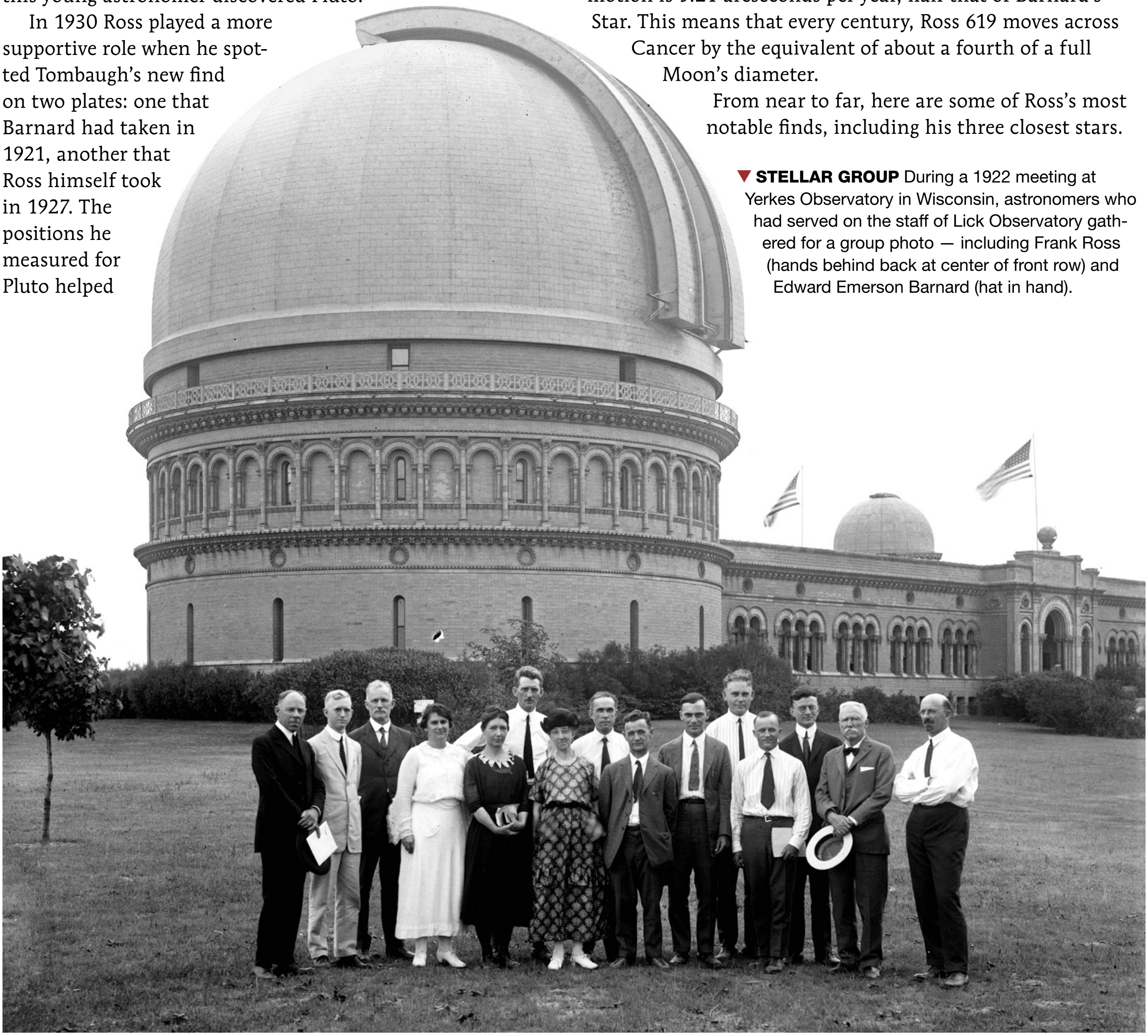
In late June 1929, Ross visited Lowell Observatory in Flagstaff, Arizona, where a young Clyde Tombaugh was also using a blink comparator — not to find nearby stars but instead a distant planet predicted to exist beyond the orbit of Neptune. "Young man," Ross told him, "I am afraid you are wasting your time. If there were any more planets to be found, they would have been found long before this." Eight months later, this young astronomer discovered Pluto.

In 1930 Ross played a more supportive role when he spotted Tombaugh's new find on two plates: one that Barnard had taken in 1921, another that Ross himself took in 1927. The positions he measured for Pluto helped astronomers refine the distant object's orbit around the Sun.

Ross discovered his first proper-motion star, named Ross 1, in 1924 and his last, Ross 1069, in 1939. "He wasn't deterred by the long hours of exposures at the Bruce telescope," Yerkes astronomer Georges Van Biesbroeck wrote in 1961, a year after Ross had died at age 86. "In fact he seemed to enjoy them as well as the many hours of plate comparisons with the 'Blink' comparator, the same instrument with which Barnard had found his record large proper-motion star." Altogether Ross covered more than half the sky in discovering his 1,000+ high-proper-motion stars. His plates also revealed hundreds of variable stars.

The star he identified with the largest proper motion was Ross 619, a nearby red dwarf in the constellation Cancer, the Crab. According to the Gaia spacecraft, the star's proper motion is 5.21 arcseconds per year, half that of Barnard's Star. This means that every century, Ross 619 moves across Cancer by the equivalent of about a fourth of a full Moon's diameter.

From near to far, here are some of Ross's most notable finds, including his three closest stars.



▼ **STELLAR GROUP** During a 1922 meeting at Yerkes Observatory in Wisconsin, astronomers who had served on the staff of Lick Observatory gathered for a group photo — including Frank Ross (hands behind back at center of front row) and Edward Emerson Barnard (hat in hand).

HANNA HOLBORN GRAY SPECIAL COLLECTIONS RESEARCH CENTER, UNIVERSITY OF CHICAGO LIBRARY

All of them are within reach of a 6-inch telescope used under reasonably dark skies.

Ross 154: Nearby Youngster

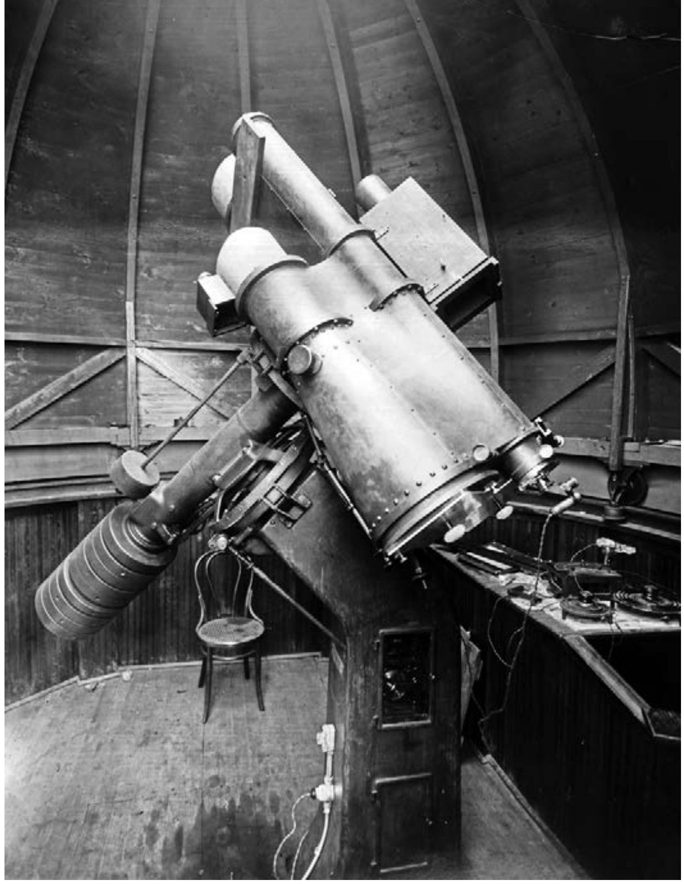
The nearest of Ross's discoveries is remarkable for its youth. Ross found the star, number 154 on his list, in 1925. He blinked a plate that Barnard had taken in June 1904 against one from August 1925. Ross 154 shines at magnitude 10.4 just north of the Sagittarius Teapot, as shown on page 32.

In 1937, Walter O'Connell, working at Yale University Observatory's southern station in Johannesburg, South Africa, discovered that this star has a large parallax. His measurement is similar to Gaia's modern value, which indicates a distance from Earth of just 9.7 light-years.

"This parallax places the star as sixth among the stellar systems in order of distance from the sun. . . ." O'Connell wrote in the *Astronomical Journal*. Ten years later, in 1947, Willem Luyten (University of Minnesota) found the even-closer binary Luyten 726-8, and in the 2010s Kevin Luhman (Pennsylvania State University) discovered two brown dwarf systems closer than either, pushing Ross 154 to ninth-nearest stellar system.

Of all the stars within a dozen light-years of Earth, Ross 154 has the most regular orbit around the Milky Way's center. This is a sign that Ross 154 is young. Stars are usually born with circular orbits around the Milky Way's center near the galactic plane. Over time, though, spiral arms and giant molecular clouds jostle stars from their original paths. But Ross 154 still has a very circular orbit and clings to the galactic plane, which means this star is probably less than a billion years old.

Furthermore, Ross 154 spins fast — once every 2.8 days — and spews out flares. Both of these traits are also signs of youth. In fact, it's even possible this star is so young that it does not yet employ nuclear reactions. Instead, it may shine simply because gravity is slowly squeezing its gas. Compression heats up the gas, making the star hot enough to glow — with no nuclear fusion needed (see the sidebar on page 16 of the February 2021 issue). The Sun itself shone brightly via gravity power for many millions of years. Born with less mass than the Sun, a red dwarf like Ross 154 lingers longer in this gravity-powered state.



▲ **PHOTOGRAPHIC WORKHORSE** The Bruce telescope at Yerkes Observatory had two objective lenses — 10-inch and 6¼-inch doublets — so that photographs of the same region of sky with different plate scales could be recorded simultaneously.

Ross 248: Long-Distance Voyager

In contrast, Ross's next nearest find, number 248, is a much older red dwarf. He also discovered this star in 1925. It's in the constellation Andromeda, and Gaia parallax data indicate that this ruddy sun lies 10.3 light-years from Earth.

Nine of Frank Ross's Stars

Star	Discovery	Constellation	Distance (l-y)	Spectral type	Magnitude	RA	Dec.
Ross 128	1925	Virgo	11.0	*M*4	11.2	11^h 47.7^m	+0° 48′
Ross 154	1925	Sagittarius	9.7	*M*3.5	10.4	18^h 49.8^m	–23° 50′
Ross 248	1925	Andromeda	10.3	*M*5	12.3	23^h 41.9^m	+44° 11′
Ross 451	1926	Draco	81	*M*0	12.2	11^h 40.3^m	+67° 16′
Ross 484	1926	Virgo	150	*K*	10.8	13^h 18.9^m	–3° 04′
Ross 614	1926–27	Monoceros	13.4	*M*4.5	11.1	6^h 29.4^m	–2° 49′
Ross 619	1927	Cancer	22.1	*M*4.5	12.8	8^h 12.0^m	+8° 46′
Ross 780	1927–28	Aquarius	15.2	*M*3.5	10.2	22^h 53.3^m	–14° 16′
Ross 974	1937	Virgo	510	*G*5	12.8	13^h 2.0^m	–2° 05′

Distances, spectral types, and visual magnitudes are from recent catalogs. Right ascension and declination are for equinox 2000.0.

Ross 248 spins slowly and has a distinctly elliptical orbit around the Milky Way's center, both signs of old age. The star may even be a member of the galaxy's *thick disk*, the stellar population that formed before the Sun and most of its neighbors did. If so, Ross 248 is between 8 and 13 billion years old (*S&T:* Aug. 2023, p. 34).

Because of its odd orbit, Ross 248 is currently racing toward our solar system and will pass nearest the Sun around AD 38,000 at a distance of about 3 light-years, dislodging Alpha Centauri as the closest star system to us. Even then, though, the speedy red dwarf will be too faint for the naked eye to see, shining at 10th magnitude.

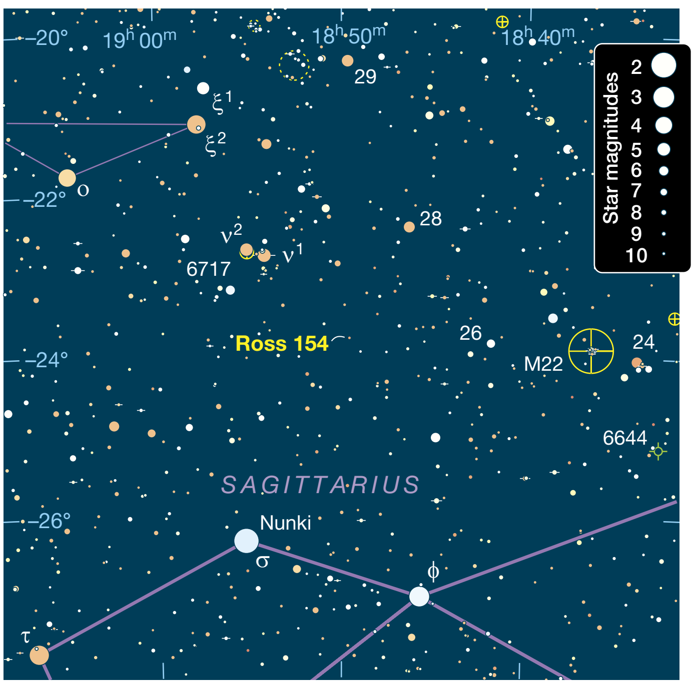
Ross 248 will pass even closer to Voyager 2, the magnificent interplanetary spacecraft that explored Jupiter, Saturn, Uranus, Neptune, and beyond. In AD 42,000, Ross 248 will be just 1.7 light-years from Voyager 2, closer than will any other star in the foreseeable future.

Ross 128: A Nearby Planet

In 2017, astronomers discovered a planet around Ross 128, yet another red dwarf whose proper motion Ross detected in 1925. This star lies 11.0 light-years from Earth in the constellation Virgo, the Virgin. The planet is a super-Earth, somewhat larger and more massive than our world, and it orbits close to its little red sun every 9.9 days.

Ross 154, Ross 248, and Ross 128 are all single red dwarfs. These small-number statistics reveal a larger trend: According to the latest data from nearby-star expert Todd Henry (Georgia State University), nearly three-fourths of red dwarfs are single. And most stars — again, about three-fourths of them — are red dwarfs.

It therefore follows that single stars abound. Henry's analysis indicates that about half of all stars are single, whereas the other half have at least one stellar partner. So there's nothing unusual about the solitary nature of our Sun. About half of all yellow *G*-type stars like the Sun have partners, and about half of them don't.



▲ **YOUTHFUL NEIGHBOR** With a visual magnitude of 10.4, Ross 154 — the very nearest of Frank Ross's stars — is not difficult to find telescopically in Sagittarius. The little red sun is so young that it might still be in the process of contracting toward main-sequence starhood.

Ross 614: From Hot to Not

At one time Ross 614 was quite the rage among astronomers — so much so that the July 1955 issue of this magazine devoted two full pages to the system. Why all the fuss? Located just 13.4 light-years away in Monoceros, the Unicorn, Ross 614 is double, consisting of two red dwarfs that orbit each other. As a result, each star's gravity tugs the other, revealing the masses of both.

Observations once suggested that Ross 614B, the dimmer sibling, had the lowest stellar mass known, only about 8% that of the Sun. This put the star close to the boundary between red dwarfs and what were later called brown dwarfs. Unlike red dwarfs, which first use gravity and then nuclear fusion to shine for a long time, brown dwarfs aren't massive enough to sustain any nuclear reactions they ignite. Instead, after glowing as gravity squeezes and heats their gas, brown dwarfs fade from view as they radiate their energy away.

But Ross 614B is no longer so special. Later observations raised the estimated masses of both stars. The modern figure for Ross 614B's mass is 11% that of the Sun, safely above the dividing line between red and brown dwarfs.

Ross 780: A Red Dwarf "First"

You may well have heard of Ross 780, but probably not by that name. The star is 15.2 light-years from Earth in the constellation Aquarius, the Water Bearer.

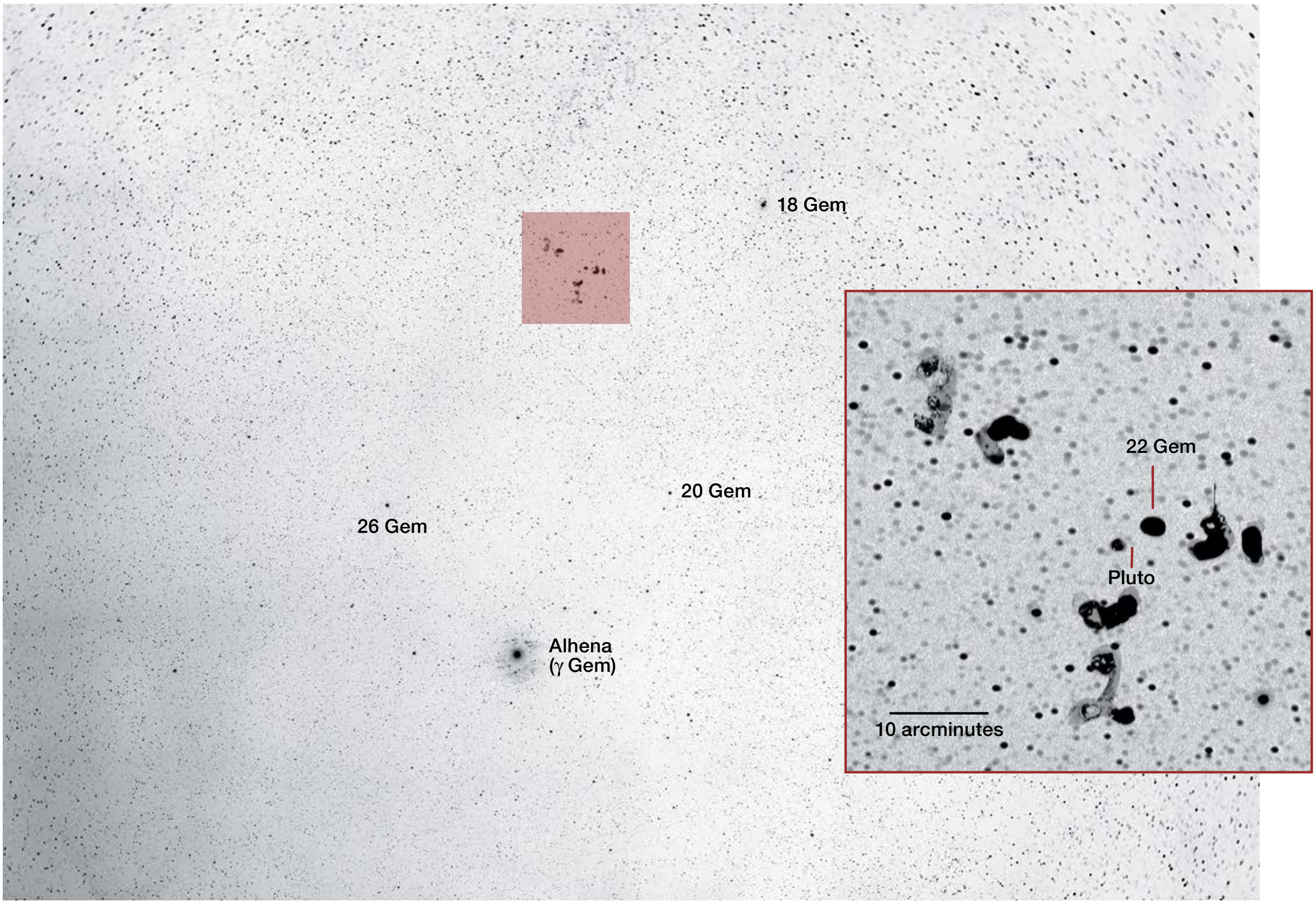
Because Ross 780 is so close to us, German astronomer Wilhelm Gliese included it in his famous *Catalogue of Nearby Stars,* which provides data on stars out to a distance of 72 light-years. Ross 780 was star number 876 in Gliese's catalog. In 1998, after finding that the red dwarf possesses a gas-giant planet, the discoverers chose to call the star Gliese 876 rather than Ross 780. It was the first time anyone had spotted a planet around a red dwarf, proving that these small stars can have planets just as larger stars do.

Ross 974: Wrong-Way Star

Not all of Ross's stars are so nearby. Even a distant star can have a large proper motion if it's moving on a radically different path than the Sun's.

Take Ross 974, for example, which Ross discovered in Virgo in 1937. Gaia data indicate that the star is 510 light-years from Earth. Despite being so distant, the star has a large proper motion because it's moving the "wrong way" around our galaxy.

If you were north of the Milky Way, you'd see our galaxy's



▲ **SERENDIPITY** An image taken by Edward Emerson Barnard on January 28, 1921, faintly reveals the presence of Pluto (arrowed) within a triangle of three stars (including 7th-magnitude 22 Geminorum just to Pluto's right). This prediscovery photo helped determine the 248-year-long orbit of the newfound planet after its discovery by Clyde Tombaugh in 1930.

YERKES OBSERVATORY PLATE ARCHIVE

disk rotating in a clockwise direction. The Sun and most of its stellar neighbors are likewise racing around the galactic center clockwise. (In contrast, Earth and its siblings are moving counterclockwise around the Sun.)

But Ross 974 never got the memo. It doesn't belong to the galactic disk; rather, it's part of the *halo,* a primitive population of stars that have wild orbits around the galactic center. Ross 974 is going backwards — counterclockwise — opposite the direction of the Sun.

If that weren't enough, its orbit is extremely elliptical. At times the star is just a few thousand light-years from the Milky Way's center. At other times, though, the star ventures some 40,000 light-years away from the galactic center. Nevertheless, unlike most other halo stars, Ross 974 stays close to the Milky Way's plane.

Ross 974 is spectral type *G,* like the Sun, but it emits less light. That's because it's what's known as a *subdwarf.* Like the Sun, subdwarfs generate energy by converting hydrogen into helium at their centers, but their low *metallicity* (the proportion of elements heavier than hydrogen and helium) alters their luminosity and color. As a result, on the Hertzsprung-Russell diagram — a plot of luminosity against spectral type — subdwarfs form a sequence parallel to but below the metal-rich main sequence that includes the Sun.

Some of Ross's other discoveries are subdwarfs, too. For example, Ross 484 is a *K*-type (orange) subdwarf situated 150 light-years from Earth in Virgo, and Ross 451 is an *M*-type (red) subdwarf 81 light-years away in the constellation Draco, the Dragon. Both stars are members of the Milky Way's halo, carrying news from a more primitive era.

Ross himself lived during a more primitive era as well. Today the Gaia spacecraft provides proper motions and parallaxes for countless stars. But the discoveries Ross made a century ago paved the way for identifying some of our most intriguing stellar neighbors.

■ Contributing Editor **KEN CROSWELL** is the author of eight books, including *The Alchemy of the Heavens, Magnificent Universe,* and *The Lives of Stars.* He wrote about the nearby star Wolf 359 in the May 2024 issue.

 by N. G. Boeck

The Cosmic Cookbook

Complicated molecules in interstellar space offer new insights into the chemistry of the universe.

COSMIC CARBON This artist's impression shows the molecule cyanopyrene, a version of the carbon compound pyrene that replaces one of the molecule's hydrogen atoms with a carbon-nitrogen pair (yellow). Pyrene may have been an important "delivery box" of carbon during the solar system's formation.

But outer Space,
At least this far,
For all the fuss
Of the populace
Stays more popular
Than populous
Robert Frost (1874–1963)

If only Robert Frost had been an astrochemist.

In a sense, of course, he was right. Compared with the air we breathe, space is essentially empty: Less than one atom per cubic centimeter exists in the sparsest sections of the *interstellar medium* (ISM). That's a tiny fraction of the 10 million trillion (or so) molecules per cubic centimeter in Earth's air at sea level.

Yet chemically speaking, space is stuffed with stuff — molecules of ever-increasing complexity. They pile together in cold clouds that can become dense enough to collapse and create stars. Those stars, in turn, help create more chemical stuff through phenomena like fusion reactions and supernova explosions. And the cycle continues over billions of years, building more and more molecules.

That stuff in space tells stories. How do cold spaces in the universe become warm? How do warm spaces become star-forming regions? How do stars beget solar systems? Astrochemists — scientists who search for molecules in spaces' various corners, from dense, cold clouds to planet-forming disks and even comets and asteroids — study these kinds of questions. Their work relies on identifying the unique signals emitted by each kind of molecule as it jiggles and spins, interpreting why those molecules exist in the places where we're finding them.

Slowly, researchers are assembling the ingredients that make up the grand celestial cookbook of the universe — and, contrary to Frost's claim, make space quite "populous," indeed. In fact, one of the field's most powerful tools utilizes science found in your own kitchen.

If It Spins, It Sings

Microwaves are a form of electromagnetic radiation, sometimes lumped in with the radio part of the spectrum. Their wavelengths are much longer than visible light, ranging from 1 millimeter to 1 meter — many thousands of times longer than the 380 to 700 nanometer range that the human eye can see.

These waves make some types of molecules rotate, increasing their energy. In a microwave oven, we use this property to heat food. Asymmetrical molecules with a feature called a *permanent dipole moment* (see tipbox) spin around as they try to line up with the electric fields of the microwaves zinging through the oven at all angles. The resulting rotations, collisions with other molecules, and vibrations transfer energy to the molecules. That's the energy that warms your food.

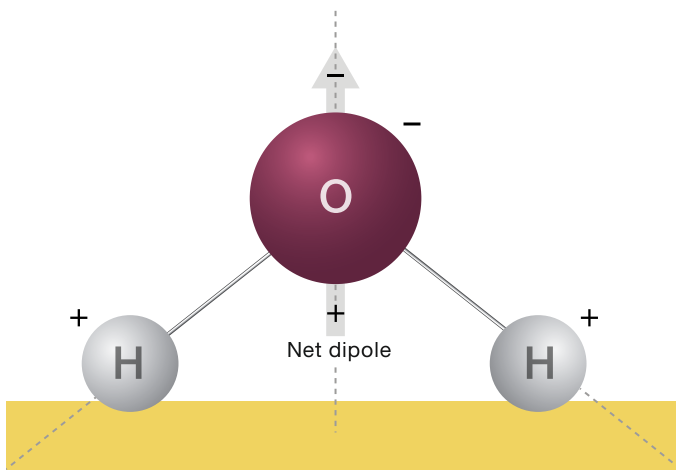
In the coldest, most unforgiving environments in deep space, molecules with dipole moments also rotate (mostly due to collisions with hydrogen gas). When they inevitably slow down, they emit that extra energy as microwave photons, which fly off into space. Here on Earth, radio telescopes like the Green Bank Telescope in West Virginia and Chile's Atacama Large Millimeter/submillimeter Array (ALMA) pick up those photons.

The photons' wavelengths are unique to the molecule. That's because the energy necessary for a molecule to transition from one rotational state to another is *quantized*: It comes in specific, discrete amounts, each one corresponding to a specific wavelength (or frequency), the cosmic equivalent of custom measuring spoons.

By recording the wavelengths of the photons emitted from a specific area of space and comparing these to known values, astrochemists can identify with exquisite precision the identity of the molecule sending out those signals via rotational energy transitions — that is, if they already know what they are looking for.

A Universal "Molecular Inventory"

And therein lies the challenge. Astrochemists cannot simply take a spectrum of a cloud in space and identify each and every molecule in that spectrum. Many molecules contribute too few photons to be distinguishable from background noise, and many others have never been measured before in a lab on Earth — a necessary first step when searching for new chemicals in the cosmos.



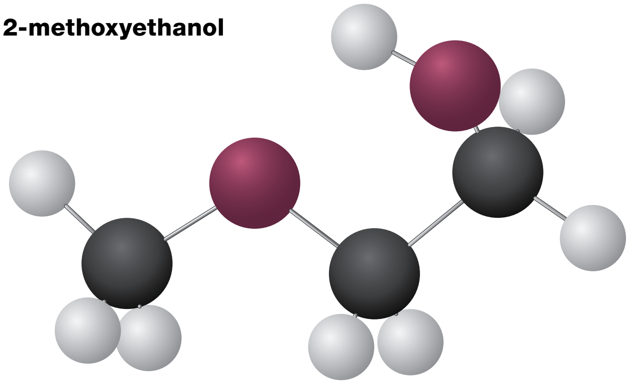
Dipole Moment

When a molecule has a *dipole moment*, it means that electrons in the molecule are not distributed symmetrically. Electrons are negatively charged, so this setup creates two "poles" within the molecule of opposite charges. The dipole moment is a measurement of the difference in positive and negative charges and the distance between those charges. Water (shown) is one of many substances with a strong permanent dipole moment.

CYANOPYRENE ILLUSTRATION: NSF / NSF NRAO / AUI / S. DAGNELLO; WATER MOLECULE: BEATRIZ INGLESSIS / S&T, SOURCE: PAUL MCCORD / UNIVERSITY OF TEXAS

So these scientists work backwards. They theorize which molecules they expect to find in a particular area of space based on which other molecules they've already found there. Just as if you see flour, yeast, salt, and water on a kitchen counter, you may expect someone to start making a loaf of bread, if you see simple molecules made of carbon, hydrogen, and oxygen stuck together in certain ways, then you can

2-methoxyethanol



▼ **CAT'S PAW NEBULA** Astronomers have found 2-methoxyethanol in NGC 6334I, a region just north of the paw pad at the 10 o'clock position in this image. The larger nebula (NGC 6334) is a vast stellar nursery. The image combines visible and near-infrared wavelengths.

expect to find more complex assemblages made of the same basic structures, too.

Once investigators identify a candidate molecule, they turn to the lab. They obtain (or create) the molecule and measure its rotational spectrum in a microwave spectrometer. The instrument collects photons popping out of the molecule as it switches between rotational states. The resulting spectrum serves as a sort of molecular barcode, differentiating that molecule from all others in the universe.

From there, investigators search for that barcode in space. “We point our [radio] telescope at whatever interstellar object we’re interested in,” says Zach Fried (MIT). “And if we look at it long enough, we can collect a ton of different photons from all of the rotational emissions from the molecules in the gas in that region of space.”

After correcting the signals to allow for the fact that the molecules are themselves in motion (which shifts the microwaves’ frequencies for the same reason that a siren’s pitch rises or falls as it moves toward or away from you), the researchers compare the spectra to the theoretical spectra found in the lab. When they find a match, presto! A new interstellar molecule has been found.

The first interstellar molecule, methylidyne (a carbon atom bound to a hydrogen atom), was identified in 1937 using a method known as optical absorption spectroscopy. It took until 1963 — the year of Robert Frost’s passing — for scientists to find a molecule in the ISM using rotational spectroscopy: hydroxyl, made of an oxygen bound to a hydrogen atom.

Since then, so many molecules have been identified in space that astrochemist Brett McGuire (MIT) maintains a universe-wide “molecular inventory” to keep track of them: the Census of Interstellar, Circumstellar, Extragalactic, Protoplanetary Disk, and Exoplanetary Molecules. The most recent edition, updated in 2021, included 241 molecules made up of 19 different elements, from simple two-atom molecules like carbon monoxide (CO) to the 60-carbon, soccerball-like compound known by the fabulous name of buckminsterfullerene (C_{60}).

New Ingredients in the Stellar Cookbook

Thanks to the work of McGuire and others, the interstellar chemical inventory continues to expand. Some of the newest ingredients are carbon compounds that are helping astrochemists piece together the chemistry that underlies star and planet formation.

Fried, a graduate student in McGuire’s lab, used rotational spectroscopy to discover the molecule 2-methoxyethanol ($C_3H_8O_2$) in NGC 6334I, a star-forming region in the Cat’s Paw Nebula in Scorpius. Located some 5,500 light-years from Earth, NGC 6334I is a classic stellar nursery, an ideal location in which to interrogate the chemistry of forming stars.

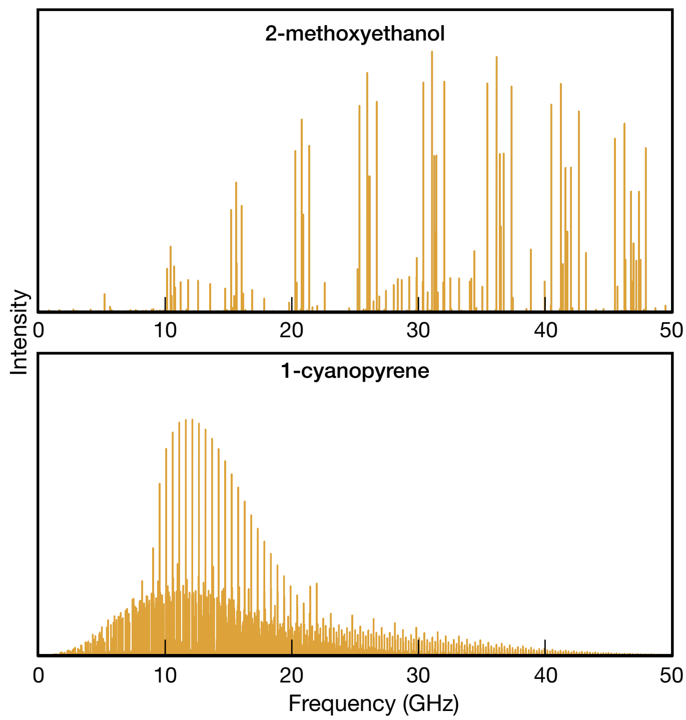
Chemists name molecules by describing their structure. In this case, the molecule is the combination of an ethanol molecule and a *methoxy group,* an oxygen bound to a carbon and three hydrogen atoms. (The “2” refers to the location of the carbon atom where the ethanol-methoxy bond exists.)

“The thing that’s exciting about 2-methoxyethanol is the methoxy group is a component that’s seen in quite a few molecules surrounding forming stars,” Fried explains. “They’re in the same sort of chemical family.”

Astrochemists had already identified several smaller “methoxylated” atoms, including the methoxylated versions of methane, methanol, and formaldehyde, in the same stellar nursery. The existence of yet another methoxylated molecule, the largest one found to date, suggests that the methoxy group might play a key role in the development of complex molecules in space during the star-formation process.

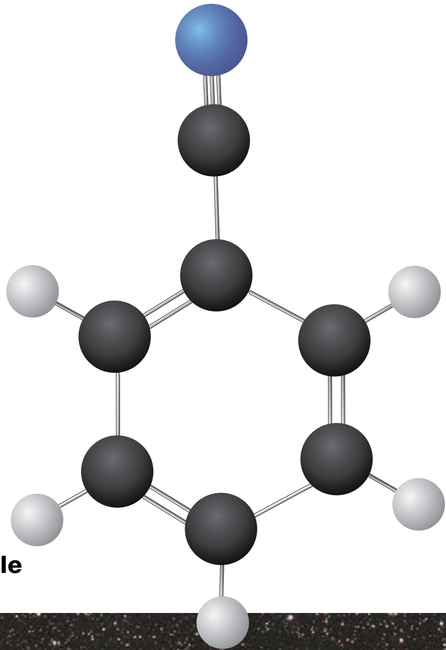
But apparently not everywhere. Fried expanded the study to look for the same molecule near IRAS 16293–2422B, a young, low-mass protostellar system in the constellation Ophiuchus that often serves as a proxy for studying the formation chemistry of our own solar system. The researchers found much less 2-methoxyethanol in IRAS 16293B — so much so that they were left wondering what made the two regions so chemically different.

Fried and his team have some ideas, but no definitive answers yet. Perhaps the temperature of the cosmic dust that’s mixed in with the gas in each region impacts the reactions. (Chemical reactions play out on grain surfaces, and the study of dust grains and their role in chemical synthesis is an active area of astrochemistry.) Or perhaps certain reactions are more efficient in one location than another.



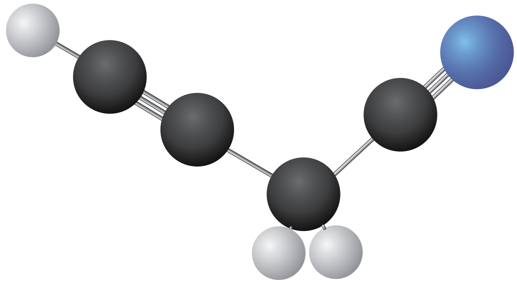
▲ **BARCODES** The emission spectra for 2-methoxyethanol *(top)* is dramatically different than that for 1-cyanopyrene *(bottom)*. Both spectra are for the molecules at a temperature of 5 kelvin, but for clarity the molecular abundances have been scaled to make the maximum intensities similar. (A frequency of 20 GHz corresponds to a wavelength of 15 mm.)

2-METHOXYETHANOL: BEATRIZ INGLESSIS / *S&T*, SOURCE: ZACH FRIED / MIT; CAT’S PAW NEBULA: DSS2 / WIKISKY.ORG; SPECTRA: ZACH FRIED / MIT

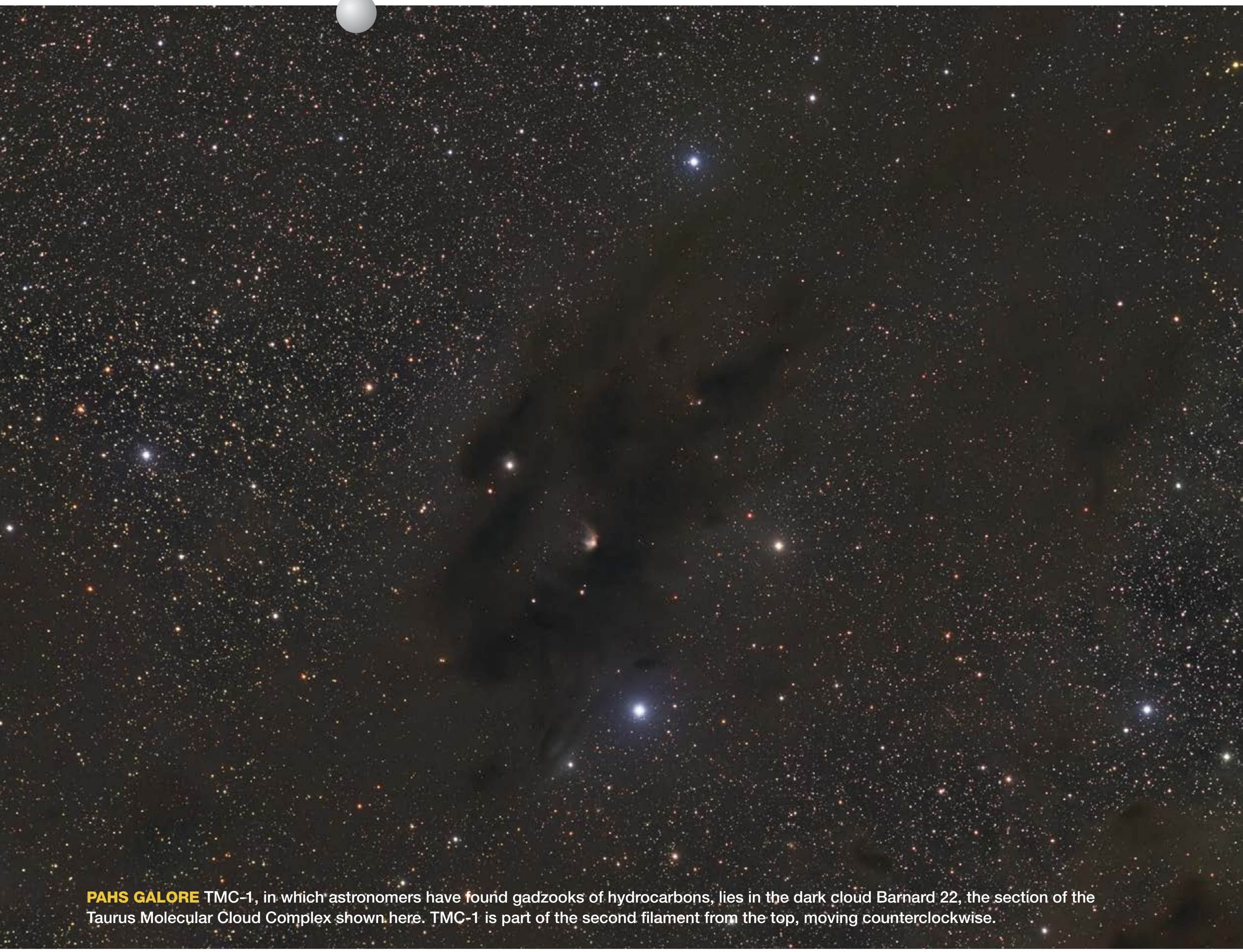


Benzonitrile

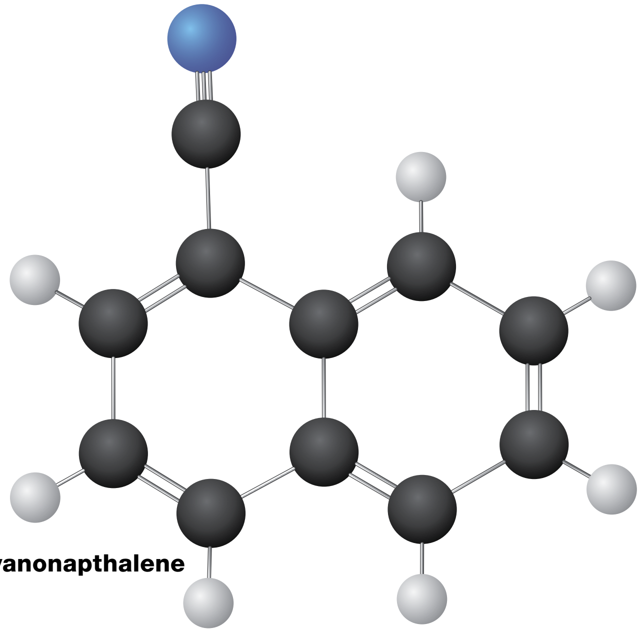
◀▼▶ **CARBON CHEMISTRY** Astronomers have found a variety of carbon-based molecules in the dark cloud TMC-1, four of which appear here: benzonitrile (C_6H_5CN), propargyl cyanide ($HCCCH_2CN$), cyanonaphtalene ($C_{10}H_7CN$), and indene (C_9H_8).



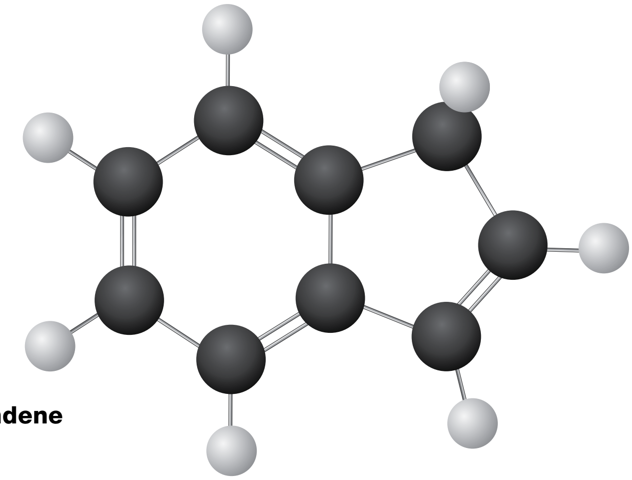
Propargyl cyanide



PAHS GALORE TMC-1, in which astronomers have found gadzooks of hydrocarbons, lies in the dark cloud Barnard 22, the section of the Taurus Molecular Cloud Complex shown here. TMC-1 is part of the second filament from the top, moving counterclockwise.



Cyanonapthalene



Indene

Answering these questions could provide compelling details about why different star-forming regions have different starting materials. It could even lead to predictions about the future chemical composition of a region's planetary systems.

Studies like this also give astrochemists quantitative data about which kinds of carbon- and oxygen-containing compounds are present — key ingredients for life as we know it. Other chemical clues can be teased out, too, like the ratio of carbon to oxygen in the cloud (which influences the kinds of reactions that can occur).

In short, the more that astrochemists figure out about the chemical composition of an area of space, the more they understand the chemistry that happened there in the past — and that can happen there in the future.

Finding PAHs in Unexpected Places

In another study, members of McGuire's lab found a different kind of carbon molecule in an area of space that up until very recently had seemed far too cold to provide the energy necessary for these molecules to form.

The molecule, 1-cyanoprene ($C_{17}H_9N$), is a modified version of a very stable carbon compound called pyrene ($C_{16}H_{10}$). Pyrene is a member of the class of molecules known as *polycyclic aromatic hydrocarbons*, or PAHs (pronounced "pahz"). Made of fused rings of carbon, they're often a product of combustion reactions and rather smelly, giving space the distinctive, slightly smoky scent reported by astronauts once they climb back inside their craft and remove their helmets.

PAHs are also remarkably stable, thanks to the arrangement of shared electrons around the carbon atoms that make up their rings. If you've ever looked at a nebula through a telescope, you've stared right into a cloud full of PAHs. And if you've bitten into a hamburger with grill marks, you've eaten them, too.

PAHs are found all over space, usually indirectly: Astronomers think that up to one-quarter of all the carbon in our galaxy's interstellar medium is incorporated into PAHs, mostly in higher-temperature areas around star nurseries. The molecules form in the extended atmospheres of aging stars, then are ejected into interstellar space. Large PAHs (those with at least 35 carbon atoms) can survive the harsh ultraviolet radiation they encounter there. Small PAHs, however, were long thought to be destroyed. Finding smaller PAHs like 1-cyanoprene in cold molecular clouds would upend those assumptions.

And that's exactly what happened.

First, in 2021, McGuire and others identified small, two-ring PAHs in TMC-1, a cold molecular cloud in the constellation Taurus: two versions of naphthalene ($C_{10}H_8$, more commonly known as the chemical that gives mothballs their odor). The same year, additional research groups found the two-ring PAH known as indene (C_9H_8) in the same location. A fourth two-ring PAH, 2-cyanoindene, was reported in TMC-1 in 2022 by McGuire's group along with collaborators from the Harvard-Smithsonian Center for Astrophysics (CfA).

And then in 2024, the same MIT-CfA team, led by postdoctoral researcher Gabi Wenzel in McGuire's lab, reported they had found 1-cyanoprene in TMC-1, a version of pyrene that can be found with rotational spectroscopy.

Using a measurement known as *column density* (a way to standardize the amount of a gaseous compound by comparing it to the amount of a known gas in the same area, such as molecular hydrogen), the team calculated that pyrene alone made up around 0.1% of all of the carbon found in TMC-1, and accounted for up to 1% of all PAHs among the many billions of atoms and molecules in that dense cloud.

That might not sound like much, but given the many millions of compounds the cloud's atoms could create, that one of every 100 PAHs is this one specific molecule blew the astronomers' minds.

MOLECULES FOUND IN TMC-1: BEATRIZ INGLESSIS / *S&T*, SOURCE: ZACH FRIED / MIT; TMC-1: SEAN WALKER / *S&T*

Using data previously gathered from TMC-1, the researchers calculated that the abundance of pyrene there suggested that even larger PAHs could exist as a sort of carbon "sink" in cold molecular clouds.

But researchers still don't know how they emerged — only that the traditional formation pathways for PAHs should theoretically require far more energy than a cold molecular cloud can provide.

"Over time, the interstellar medium is continually building up heavier elements like carbon, oxygen, silicon, and nitrogen," explains astrophysicist Karin Sandstrom (University of California, San Diego). "But the fact that [these scientists] find so much 1-cyanoprene in these interstellar clouds means that the chemistry is actually happening in the dense cloud itself."

Proposing Pyrene's Celestial Fate

If 1-cyanoprene (and by extension, pyrene) is being formed in prestellar clouds, what happens to it after that?

In 2023, PAHs emerged in a very different location. Laboratory experiments on samples taken from the asteroid 162173 Ryugu by the Hayabusa 2 spacecraft revealed the four-ringed PAH pyrene with a distinctive chemical signature: The molecule contained a form of carbon that indicated the molecule must have formed in a cold environment, such as a dark molecular cloud where star formation hadn't turned on yet.

Comets and asteroids typically hold the elements and molecules that were floating around in the planet-forming disk, with minimal alteration. These compounds, in turn, came from the gas cloud that collapsed to create the solar system.

McGuire's group compared the amount of pyrene found in TMC-1 to the amount found in the Ryugu sample. The team concluded that the estimated abundances of pyrene in TMC-1 and Ryugu were consistent with what they would expect to find in an asteroid that descended from that cold cloud of molecules.

Ryugu confirms that pyrene has at least one formation pathway that does not involve high-temperature combustion reactions. The evidence so far suggests that the molecule can not only form in large amounts in these clouds, but can also survive all the way from the cloud's development as a stellar nursery to the formation of planets and other solar system objects. We can trace the original source of our solar system's pyrene — and thus some of its carbon, one of the elements necessary for life on Earth — to the molecular cloud that created our planetary system.

The implications are slowly rewriting our understanding of carbon chemistry in space. From the darkest and coldest regions of the universe, chemistry that we don't yet understand appears to deliver carbon to comets and asteroids in a form that can survive the violent forces of star formation. In turn, those objects could deliver carbon to newly forming planets — even ours.

The Chemistry of Life?

For McGuire, the Holy Grail of astrochemistry is finding carbon-based biologically relevant molecules like amino acids and nucleic acids (DNA and RNA) in interstellar space. Scientists have already found the simplest amino acid, glycine, in two comets in the solar system: Comet Wild 2 and Comet 67P/Churyumov-Gerasimenko. The Ryugu sample held uracil, a key building block of RNA. And in early 2025, data from the asteroid Bennu revealed the presence of all five DNA and RNA building blocks, along with 14 of the 20 amino acids needed for the protein synthesis that makes life on Earth possible.

If these molecules were made in the ISM, they could be carried to other solar systems and could even become the precursors of life on other planets. It's a huge, heady question for a field that is already bursting with new discoveries. Is there a common recipe that could give rise to the conditions needed for carbon-based living organisms like us to emerge elsewhere in the universe? That's a mystery that will take much more research to unravel.

For now, McGuire is content to study how chemistry helps tell the story of star cycles: from cold clouds to star birth to solar systems, star death, supernovas, and back to cold clouds, again and again.

"We're filling in self-contained loops in the history of the universe and the galaxy," McGuire says. "We are piecing together the role of chemistry at each different stage in that process."

The full extent of the stellar cookbook may remain a mystery for some time, but molecule by molecule, astrochemists are revealing its secrets. And contrary to the musings of a poet at the dawn of the Space Age, the universe appears to be full of enough of those molecules to keep us busy studying them for a very long time indeed.

■ **NICOLE BOECK** (née Nazzaro) is a biochemist and science writer living in Edmonds, Washington. Her favorite carbon-based molecule is theobromine ($C_7H_8N_4O_2$), the compound that makes chocolate taste like chocolate.

Not (Quite) Life Itself

Nucleobases are molecules that serve as the building blocks of DNA and RNA. DNA, the double-stranded helix, is made of long strands of the nucleobases adenine, guanine, cytosine, and thymine and holds all of our genetic information. RNA, used for many purposes including transcribing genetic information for specific genes, replaces thymine with uracil. While these five nucleobases are not "alive" themselves, without them there would be no life on Earth.

BEATRIZ INGLESSIS / S&T

SKY AT A GLANCE
July 2025

3 EARTH is at aphelion, farthest from the Sun for the year (some 3.4% farther than it was at perihelion in January).

3 EVENING: Face southwest to see the Moon, one day past first quarter, about 2½° lower left of Virgo's brightest star, Spica.

7 EVENING: In the south, the waxing gibbous Moon hangs around 4½° lower left of Antares, Scorpius's smoldering heart.

12 MORNING: Look low in the east-northeast to see Venus rising in tandem with Aldebaran 3½° below. Turn to page 46 for more on this and other events listed here.

15 EVENING: The waning gibbous Moon rises in the east, with Saturn a bit more than 2° below it. Follow the pair as it climbs high in the south before sunrise.

20 MORNING: Face east-northeast to see the waning crescent Moon rise above the horizon with the Pleiades in tow. About 1½° separates the Moon from the brightest Pleiad, Alcyone. See page 48 for details.

23 DAWN: Early risers are greeted with the delightful sight of a thin sliver of lunar crescent some 5° left of Jupiter low above the east-northeastern horizon. Venus, the Morning Star, blazes to the pair's upper right.

26 DUSK: The two-day-old Moon follows Leo's lucida, Regulus, by a bit less than 2° as the pair sets in the west-northwest.

28 DUSK: Look low in the west after sunset to see the waxing crescent Moon around 4° left of Mars. Catch this sight before the duo sinks out of view.

29–30 ALL NIGHT: The Southern Delta Aquariid meteor shower peaks, favoring viewers at southerly latitudes. The waxing crescent Moon shouldn't spoil the show. Go to page 50.

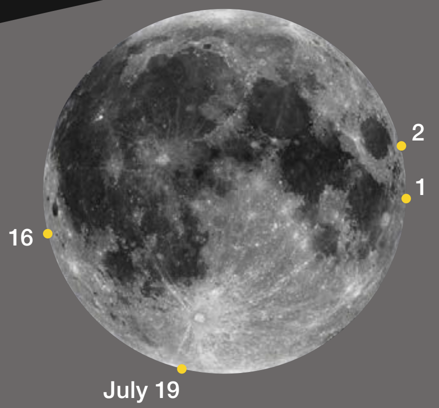
30 EVENING: Face southwest to see the Moon, two days shy of first quarter, back in Virgo where it shines a bit more than 2° lower right of Spica.
—DIANA HANNIKAINEN

◀ The emission nebula M17, also known as the Swan or the Omega Nebula, is a naked-eye target under dark skies. It's also a great object to show through a telescope at outreach events. For more targets and tips for outreach, turn to page 22.
RON BRECHER

JULY 2025 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		

FIRST QUARTER
July 2
19:30 UT

FULL MOON
July 10
20:37 UT

LAST QUARTER
July 18
00:38 UT

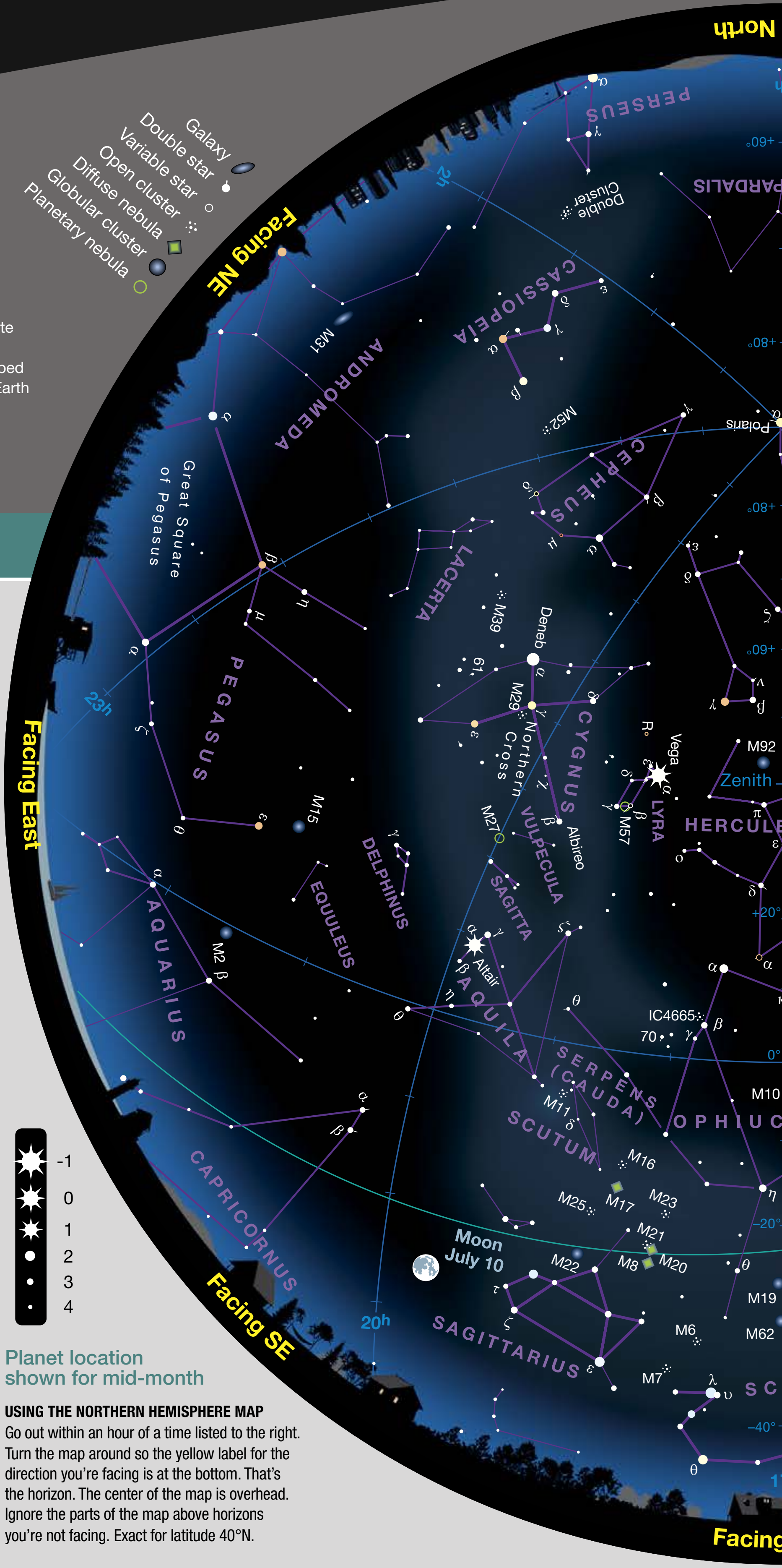
NEW MOON
July 24
19:11 UT

DISTANCES

Apogee	July 5, 2^h UT
404,624 km	Diameter 29′ 32″
Perigee	July 20, 14^h UT
368,042 km	Diameter 32′ 28″

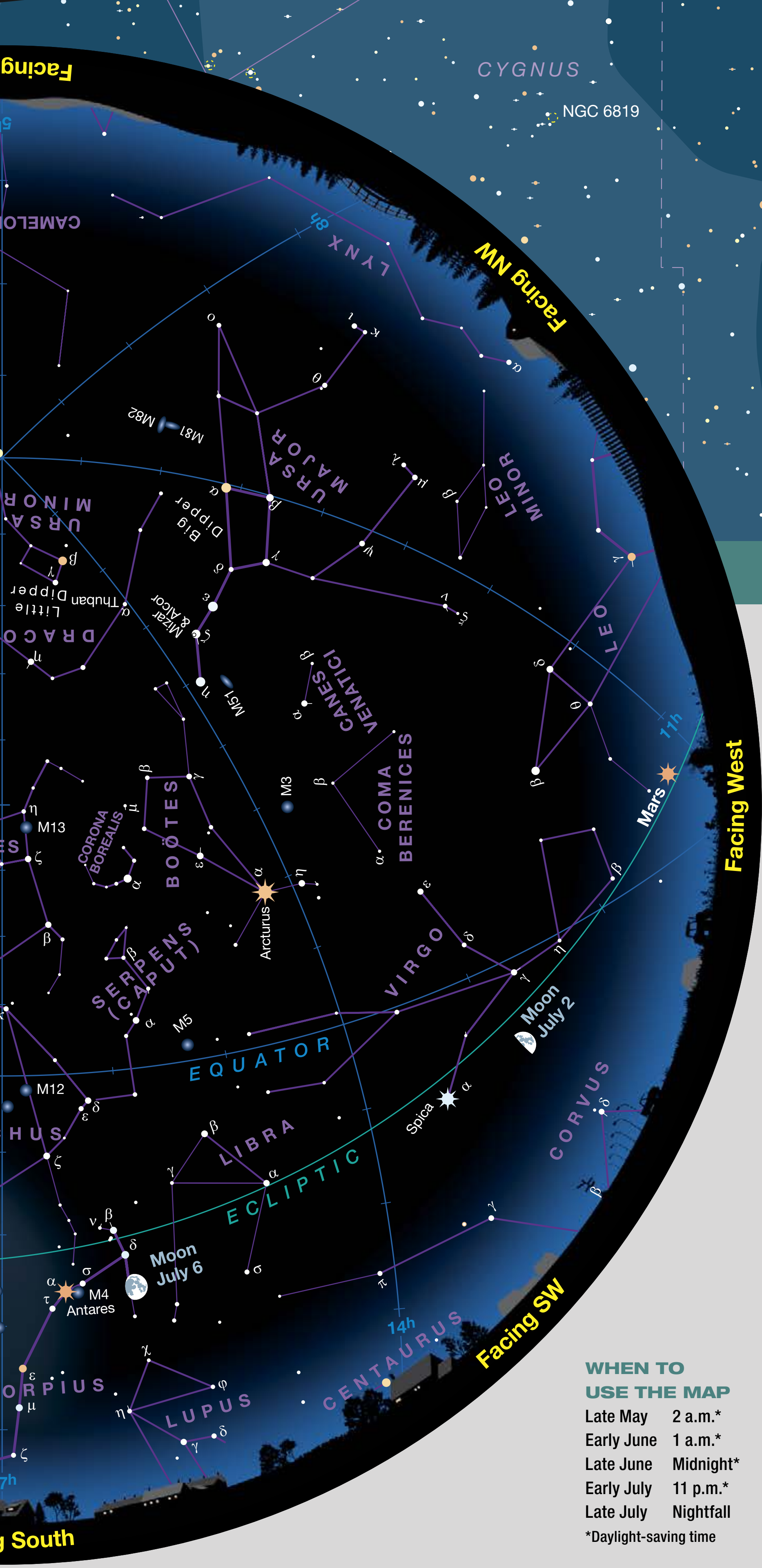
FAVORABLE LIBRATIONS

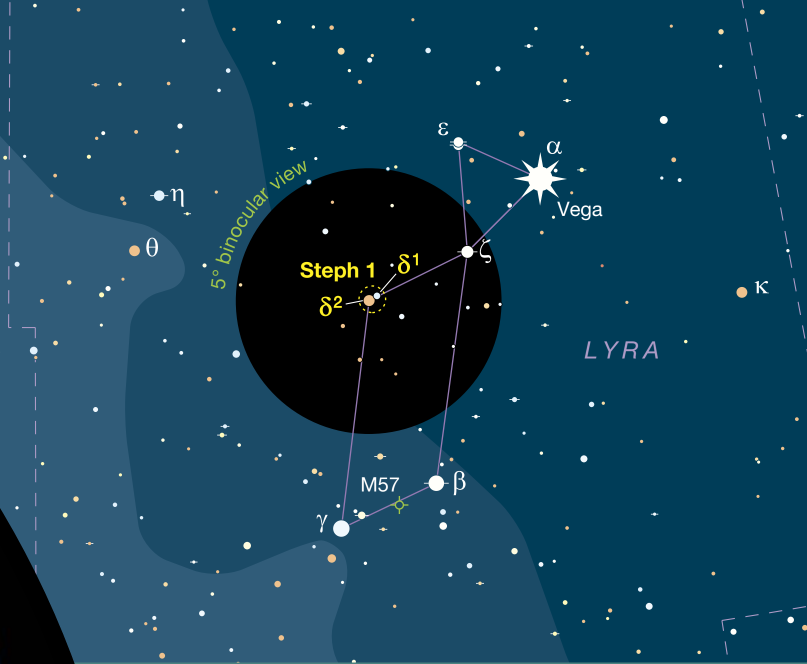
- Mare Smythii July 1
- Mare Marginis July 2
- Lallemand Crater July 16
- Drygalski Crater July 19



Planet location shown for mid-month

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





WHEN TO USE THE MAP

Late May	2 a.m.*
Early June	1 a.m.*
Late June	Midnight*
Early July	11 p.m.*
Late July	Nightfall

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Overlooked Lyra Sights

I can't be sure how many times I've swept the constellation Lyra, the Lyre, with binoculars. It could be more than a thousand. But how many times have I deliberately slowed down to take a good look at anything besides Epsilon (ε) Lyrae, the famous Double Double, and M57, the Ring Nebula? Not often.

Much to my chagrin, I'd been stargazing for more than a decade before I recognized the existence of the open cluster **Stephenson 1**, also known as the Delta Lyrae Cluster. Heck, I'd rarely paid attention to Delta itself, which is a real shame. **Delta (δ) Lyrae** is a lovely color-contrast optical double for binocular observers marking the northeast corner of the Lyra parallelogram. The brighter of the two stars is 4.3-magnitude Delta^2 Lyrae, a cool red giant. How cool? With an estimated temperature of 3400 kelvin, Delta^2 is roughly 2400K cooler than the Sun. Its neighbor, Delta^1 Lyrae shines at magnitude 5.6 and is a young, hot, *B*-type star nearly 15,000K hotter than the Sun. The two Deltas are too far apart to be physically connected, and they're moving in different directions. So, their apparent proximity is simply a pretty line-of-sight cosmic coincidence.

Now what about Stephenson 1? Under clear skies you may spot a clutch of 7th- to 9th-magnitude stars surrounding Delta Lyrae and spanning perhaps 20′. It's a rather sparse cluster, but one that I really enjoy in binoculars. Rather than pouring on the aperture and magnification for maximum resolution, I like to use 7× or even 5× binos to concentrate the cluster's light into a gauzy glow around the Delta duo. Try it in a scope and binoculars and see which view you prefer.

■ **MATT WEDEL** enjoys tracking down the often-overlooked sky targets — especially ones he's overlooked himself.

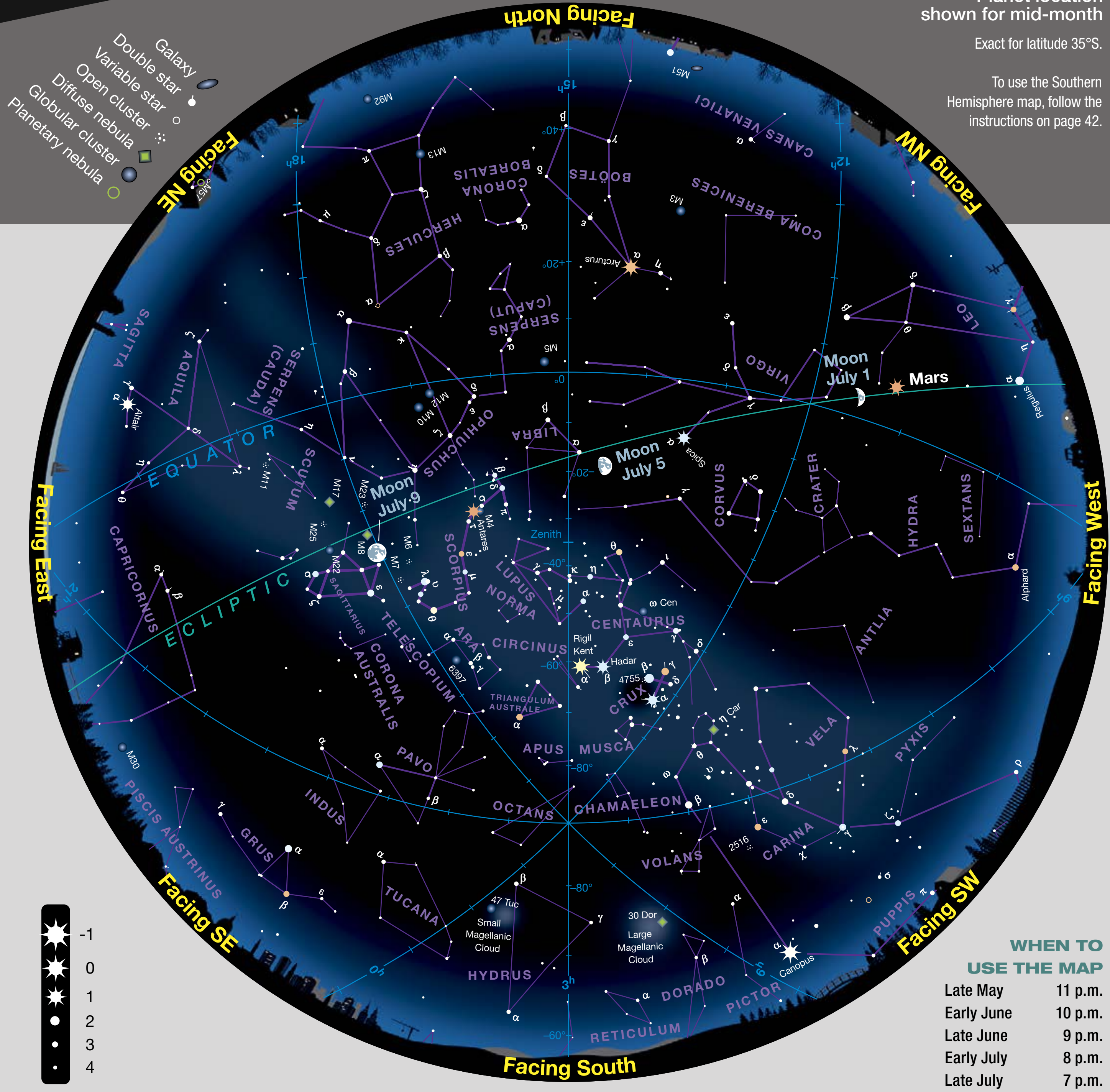
Southern Hemisphere Sky Chart

by Jonathan Nally

Planet location shown for mid-month

Exact for latitude 35°S.

To use the Southern Hemisphere map, follow the instructions on page 42.



WHEN TO USE THE MAP

Late May	11 p.m.
Early June	10 p.m.
Late June	9 p.m.
Early July	8 p.m.
Late July	7 p.m.

THERE ARE NO PRIZES for guessing the geometric shape made by the three main stars in the constellation **Triangulum Australe**. The brightest of the trio, Alpha (α) Trianguli Australis, is a 1.9-magnitude orange supergiant located about 390 light-years away. With a diameter more than 140 times that of the Sun and a luminosity some 5,500 times greater, it's a beast of a star. Beta (β), however, is a bit more ordinary. This 2.9-magnitude star is about twice the size of the Sun, though almost 10 times brighter. Lying just 40 light-years from Earth, Beta is much closer than Alpha. The third member of the trio is Gamma (γ) — a white-hot star 190 light-years away that, like Beta, shines at magnitude 2.9. It matches Beta's apparent brightness by having a greater luminosity — burning about 250 times brighter than the Sun. ■

Stories in the Stars
by Stephen James O'Meara

Three Testy Globulars

This month, see if you can spy three of our galaxy's senior citizens without optical aid.

▲The easiest naked-eye globular for Northern Hemisphere observers is M13, in Hercules. It's not only relatively bright, its location is easy to find. The cluster lies along the western edge of the constellation's Keystone asterism, between the stars Eta (η) and Zeta (ζ) Herculis. If you succeed with M13, try your luck with M5 in Serpens Caput and M4 in Scorpius.

AKIRA FUJII

Warm July evenings in the Northern Hemisphere can bring comfort to stargazers, especially those who like to lie under a dark sky and simply look up at the stars in wonder. The summer night sky is also dappled with globular star clusters — massive star cities containing tens of thousands to a million or more stars that are nearly as old as the universe itself. You might enjoy challenging yourself to see how many globulars you can spy without optical aid. To get you started, here is a target list of three. But be warned: Some of these may test your visual mettle.

The three clusters appear on the center star chart on pages 42–43. Dedicate a clear, moonless night for your search under the darkest skies available. It helps to be relaxed — try sitting in a chair. You can use binoculars to locate the clusters first, then try to see them with just your eyes. Take a few deep breaths before you start your naked-eye search. Next, breathe normally. All three clusters are dim naked-eye objects, so use *averted vision* — look slightly to the side of where you think the target is located, so that its faint light falls on the night-sensitive part of your retinas. Don't stare at any one location for too long, or you will fatigue your eyes. Rest between searches. These are some of the techniques many observers employ in order to see faint objects.

First, try for M13, the Great Globular Cluster in Hercules. You'll find it on the center star chart immediately southwest of the *zenith* — the point directly overhead. Note that the cluster lies along a line between the roughly 3rd-magnitude stars Eta (η) and Zeta (ζ) Herculis, about one-third of the way from the former to the latter. At a distance of 23,000 light-years, M13 shines only at magnitude 5.8. But that light is spread across 20′ of sky. So you won't be looking for a stellar object but rather a tiny patch of dim, fuzzy light.

Our next target, M5 in the head of Serpens, the Serpent, lies about 40° southwest of M13, just north of the blue line marking the location of the celestial equator on our center star chart. While M5 is some 1,500 light-years more distant than M13, it outshines that popular cluster by 0.2 magnitude. It is, however, more challenging to see for two reasons. First, M5 is about 7½° southwest of 2.6-magnitude Alpha (α) Serpentis and is much lower in the sky than M13. Second, the cluster lies only about 20′ northwest of 5th-magnitude 5 Serpentis (not shown on our star chart, but essentially right next to M5). Although M13 and M5 are similar in apparent size (around 20′), you may find that M5, which has an especially dense core, appears more starlike than M13.

Our final and most challenging target, M4 in Scorpius, the Scorpion, is comparably bright. It's the closest globular star cluster visible to unaided eyes. But while M4 is only 7,200 light-years distant, its 100,000 or so suns are loosely concentrated and spread across an area of sky nearly three times larger than that of M13 or M5. Worse, M4 is even lower in the sky and lies only about 1° west of 1st-magnitude Alpha Scorpii (Antares), whose glare all but ruins the naked-eye view of the cluster. Try blocking the bright light of the star with the edge of a roof or some other terrestrial obstruction and look for a ghostly diffusion of misty light just brighter than the sky background.

If you succeed with any of these ancient denizens of the night sky, you will have your own stories to share with other observers who also enjoy fun visual challenges.

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

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

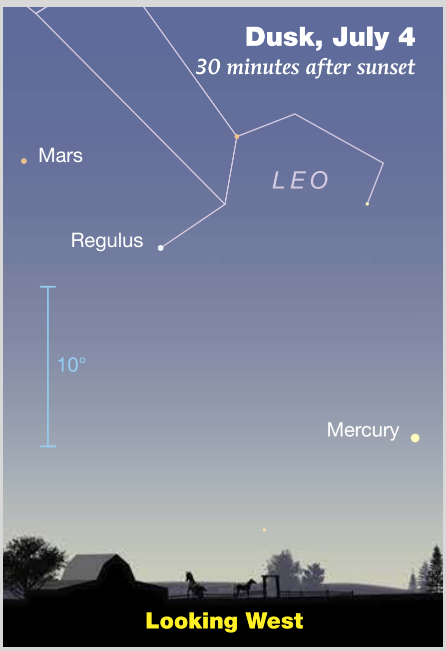
Plenty of Morning Fun

Venus, Jupiter, and the crescent Moon adorn the dawn sky.

THURSDAY, JULY 3

This evening **Mercury** shines at magnitude +0.4 and is at greatest elongation, 26° east of the Sun. (It actually reaches that point at 1 a.m. EDT on July 4th, after it has set.) On paper, that sounds great — the innermost planet is positioned far from the Sun's overwhelming glare. Indeed, it's the farthest Mercury ventures from the Sun at dusk this year, and only 1° shy of the 2025 maximum, which occurred at dawn in April. But there's a "but." As the diagram presented in the March issue (page 46) clearly shows, the angle the ecliptic makes to the horizon at this time of year is quite shallow as seen from mid-northern latitudes. That's why Mercury's altitude for this apparition maxed out a week ago, on June 26th. Even so, the planet has lost only 1° of altitude since then and is still a reasonably easy catch if you have an unobstructed west-northwestern horizon. Mercury's final evening apparition for the year happens in October, though it's much less favorable.

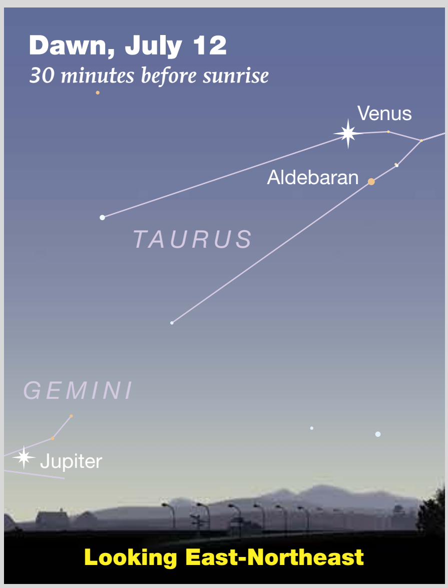
▼▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway.



SATURDAY, JULY 12

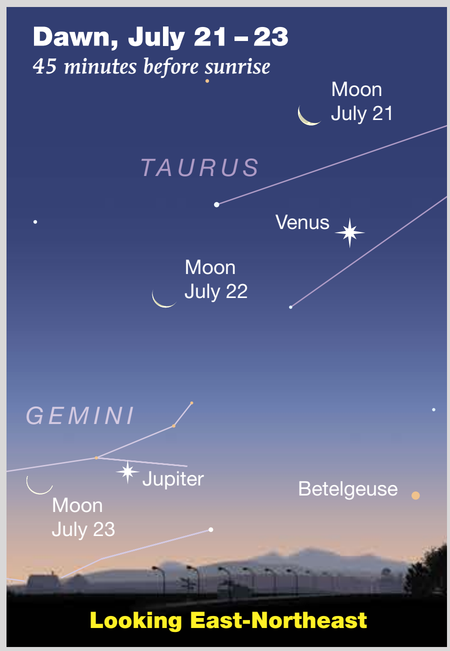
This morning **Venus** scores a bull's eye! The bull in question is, of course, Taurus. The celestial bovine's face is formed by the ragged V-shape of the Hyades star cluster, with Aldebaran (not a true cluster member) serving as a golden-orange left eye. Normally Taurus's face lacks a bright right eye — and that's where Venus comes in. When twilight begins to light the morning sky, look to the east to catch an attractive, albeit temporary, alteration to the Bull's face as the Morning Star gives it a lovely symmetry. Just one day later, Venus has shifted far enough to make the arrangement look a bit wonky.

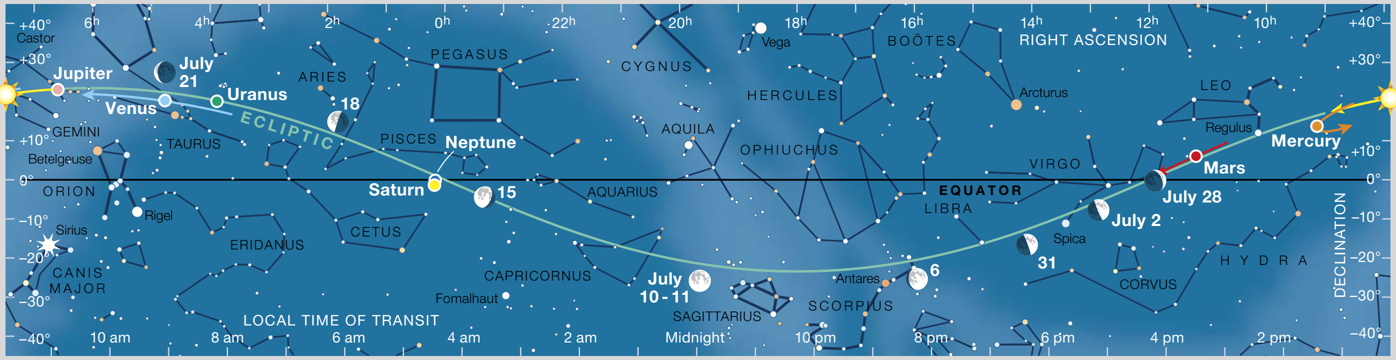
The brilliant planet is nearing the mid-point of a lengthy apparition that continues through to the end of the year. As Venus pairs up with Aldebaran, it gleams at magnitude –4.1, a full 100× brighter than the star. On this morning, the duo are separated by 3.5° but are slightly closer at dawn on the 13th, with only 3.2° between them.



TUESDAY, JULY 15

Tonight, as the evening of the 15th transitions into the morning of the 16th, turn toward the eastern horizon to watch the 70%-illuminated, waning gibbous **Moon** (two days before last quarter) rising with **Saturn** trailing closely behind. They're about 2.5° apart.





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

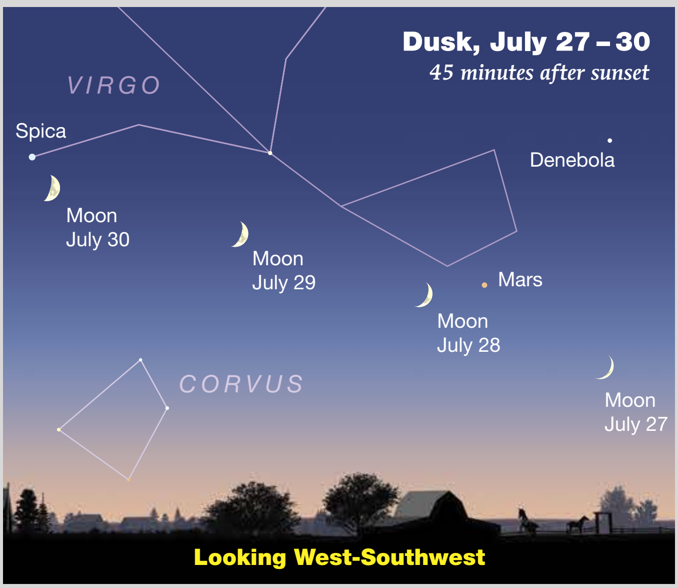
The gap shrinks slightly to a minimum of 2.3° just before 2:30 a.m. EDT, after which the Moon drifts past the Ringed Planet. This is Luna's closest encounter with a planet this month, so it's worth staying up for. Saturn shines at magnitude +0.9, which makes it the brightest dot of light in this rather sparse patch of sky. Its nearest competitor is 1.2-magnitude Fomalhaut, more than 30° below and right of Saturn.

SUNDAY, JULY 20

This morning the waning crescent **Moon** plows right through the heart of the **Pleiades** cluster in Taurus. This will be a fine sight in binoculars or a small telescope, but even those choosing to view without optics can enjoy the show. Turn to page 48 for details.

MONDAY, JULY 21

If it seems like a lot of the action this month takes place in the hours after midnight, that's because it does. Only fast-moving Mercury and a faded Mars hold down the dusk fort — the rest of the naked-eye planets are clustered in the morning sky, and now the **Moon** joins the cast. As twilight's glow begins to light the sky, look eastward to see the 14%-illuminated lunar crescent perched a bit less than 7½° above **Venus**. Both reside in northern Taurus and are attractively arrayed as part of an extended, sideways V that includes Aldebaran and the Hyades. Although this is the widest dawn pairing between the Moon and Venus in 2025 (just wait until September when we get the closest!) it's a lovely sight *any* time these two meet.



TUESDAY, JULY 22

What could possibly be more visually arresting than the **Moon** next to **Venus**? How about a thumbnail-thin crescent lit by earthshine and positioned between Venus and **Jupiter** — the two brightest planets. (And before you dash off an email to our letters department, I concede that during close oppositions, Mars can briefly outshine Jupiter.) This morning's Moon is just 7% illuminated and sits about 11° left of Venus and 11° upper right of Jupiter. The trio form a striking, squashed triangle angled above the eastern horizon. Jupiter shines at magnitude –1.9 and is just now beginning a new apparition following its June 24th conjunction with the Sun. Now at magnitude –4.0, Venus is 7× brighter than Jupiter. On the following morning (the 23rd), look for an even thinner crescent Moon (2.5% illuminated) perched above the east-northeastern horizon and 5° to Jupiter's left.

MONDAY, JULY 28

Returning to the evening sky once more, we close off the month with the **Moon** meeting up with **Mars**. The Red Planet is parked about 3¾° right of the waxing lunar crescent. Unfortunately, Mars is late in its apparition and only glows at magnitude 1.6 — a far cry from its January peak of magnitude –1.4. The Moon has a second notable encounter two nights later (on the 30th) when it approaches 1st-magnitude **Spica**, in Virgo. The pair hover above the southwestern horizon as twilight dims, and the separation between them narrows to about 1½° as they set in the late evening.

■ Consulting Editor **GARY SERONIK** keeps an eye on the sky from his home in British Columbia's Okanagan Valley.

Two Fine Lunar Occultations

The Moon passes in front of Pi Scorpii and the Pleiades.

◀ The Pleiades star Merope hovers at the Moon's dark limb moments before being occulted on April 11, 2024, as photographed from Gandhinagar, India, by Pruthu Vanara. In this month's occultation event, stars will disappear at the waning crescent Moon's bright limb and reappear on its dark limb.

On the night of July 6th, much of North America will witness a rare occultation of Pi (π) Scorpii. The 2.9-magnitude star is bottommost of the prominent stellar trio that outlines the head of Scorpius, the Scorpion. The event is unusual because Pi is located well off the beaten track of the *ecliptic*, the path followed by the Sun, Moon, and planets across the celestial sphere. But during the current major lunar standstill (*S&T:* Apr. 2025, p. 49), the Moon routinely dips below the southernmost point of the ecliptic in its monthly cycle. As a result, occultation opportunities expand to include stars that don't normally lie along its path. Pi Scorpii, at a declination of –26.1°, is one of them.

Across the eastern U.S., observers can watch the dark limb of the waxing gibbous Moon (87% illuminated) cover the star on July 7th at around 1 a.m. EDT. Farther west the occultation takes place earlier on the evening of July 6th. From Denver, Colorado, for example, the event begins just before 10 p.m. MDT, while it starts before sundown for observers on the West Coast. The star reappears on the Moon's bright limb several minutes to more than an hour later, depending upon your location.

You'll find a map and list of disappearance and reappearance times for many cities at the International Occultation Timing Association's (IOTA) web page: **https://is.gd/2025pisco**.

This enjoyable slice of Pi serves as a warm-up for the highly anticipated occultation of the Pleiades on July 20th. During the early morning hours, the 24%-illuminated waning crescent Moon blots out many of the brightest cluster members during its hours-long traverse of the famed Taurus cluster. Even more exciting, each Pleiad pops back into view in dramatic fashion on the Moon's dark limb. Such reappearances are thrilling to watch, especially when earthshine clearly illuminates the nighttime side of the Moon.

Due to lunar parallax, the Moon crosses the cluster on slightly different tracks depending on your location. The time of night also affects how many stars you'll see occulted. Those in the western U.S. and Canada see the Moon cover more stars than observers in the east where the Sun rises before the Moon has crossed most of the cluster.

◀ In the best Pleiades occultation of 2025, a thick lunar crescent covers many of the cluster's bright stars during the early morning hours of July 20th. Even a small telescope will provide excellent views of the event. The simulation presented here shows the occultation as seen from Salt Lake City, Utah, moments before 3.7-magnitude Electra is eclipsed.

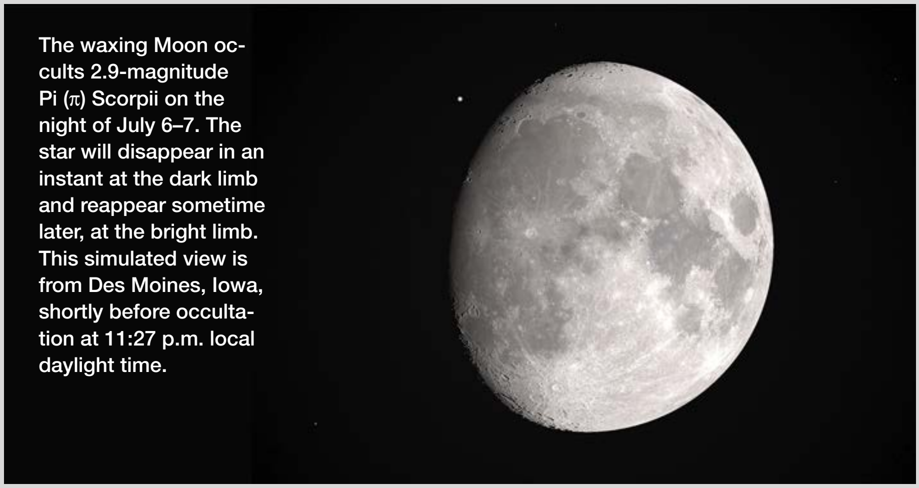
PLEIADES OCCULTATION: *STELLARIUM*

From Philadelphia, Pennsylvania, the Moon's leading bright limb occults three of the brightest Pleiads in morning twilight: Electra (17 Tauri, magnitude 3.7), Maia (20 Tauri, 3.9) and Taygeta (19 Tauri, 4.3), in that order. Only Electra reappears on the dark limb shortly before sunrise.

Farther west in St. Louis, Missouri, Electra, Maia, Merope (23 Tauri, magnitude 4.2) and Alcyone (η Tauri, 2.9) disappear in a dark sky and flash back into view before sunrise. In Salt Lake City, Utah, the Moon completes its journey across the cluster before the start of morning twilight, hiding and uncovering Electra, Merope, Alcyone, Pleione (28 Tauri, magnitude 5.1), and Atlas (27 Tauri, 3.6).

If you're on the West Coast, observing the event requires a little advanced planning. Seek out a location with an unobstructed eastern horizon because the occultation will already be underway as the Moon rises. Most of the bright-limb disappearances occur at low altitude. Fortunately, by the time the cluster stars begin to reappear, the Moon is much better placed.

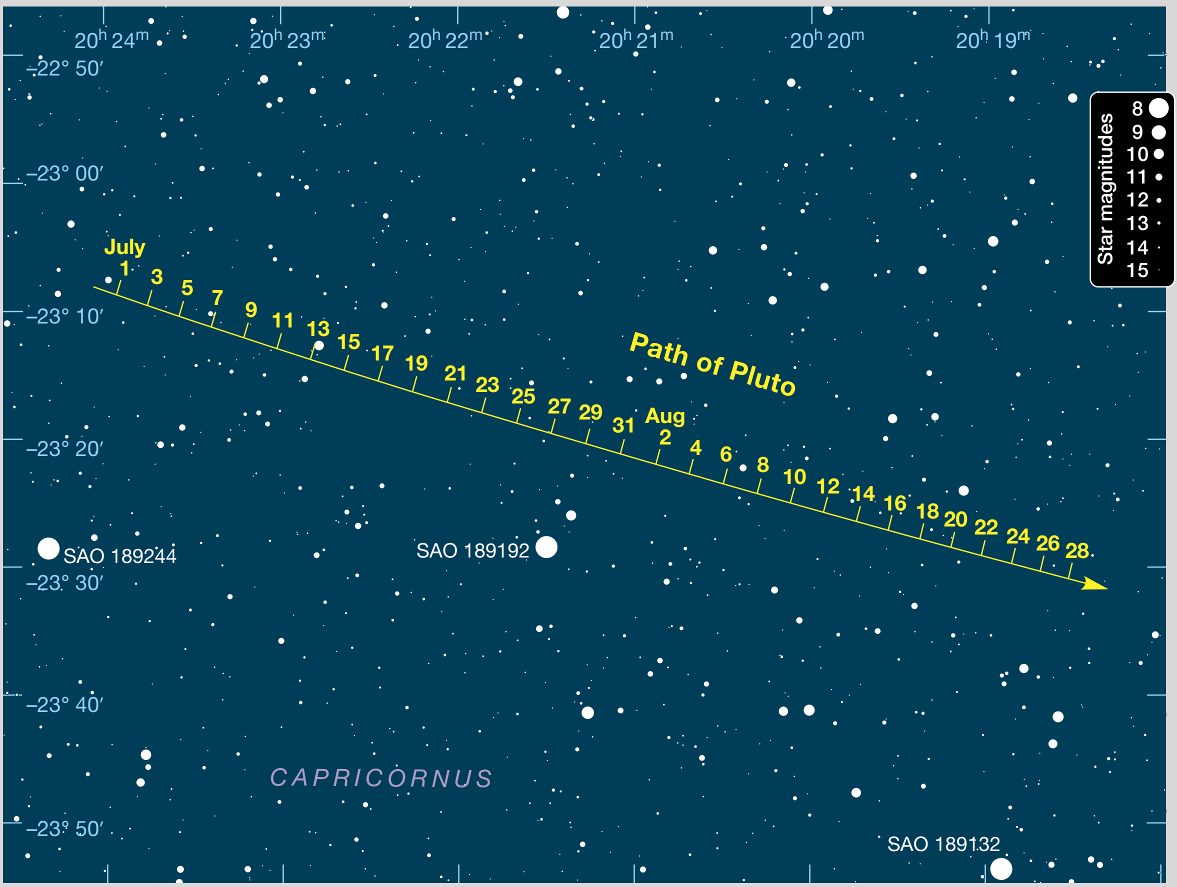
For detailed information, including maps and times for several of the brightest Pleiades, go to **https://is.gd/iotapleiades** and click on the links for the July 20th events.



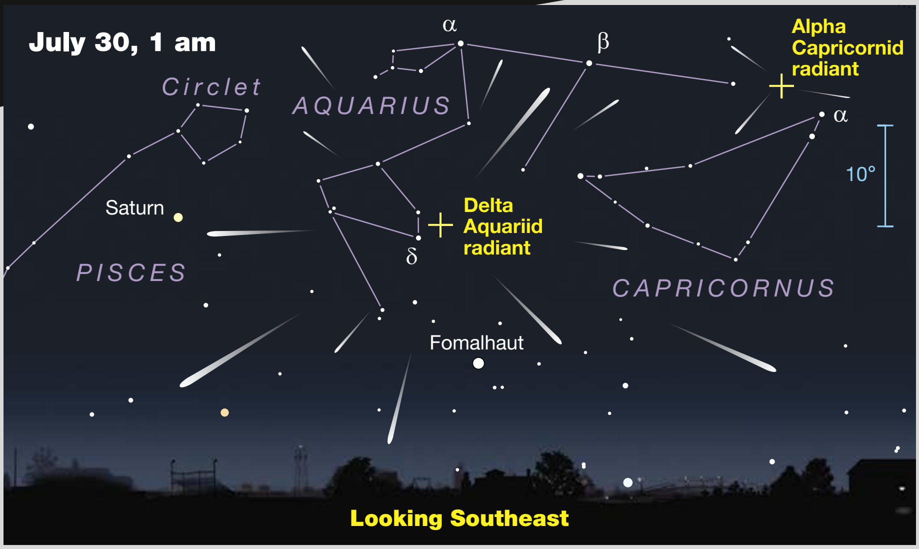
The waxing Moon occults 2.9-magnitude Pi (π) Scorpii on the night of July 6–7. The star will disappear in an instant at the dark limb and reappear sometime later, at the bright limb. This simulated view is from Des Moines, Iowa, shortly before occultation at 11:27 p.m. local daylight time.

Pluto at Opposition

THE DISTANT DWARF planet Pluto has no bright neighbors this summer as it plies the stellar barrens of western Capricornus about 4° southeast of the 8.6-magnitude globular cluster M75. At the time of opposition on July 25th, the remote world shines at magnitude 14.4, making it a target for 10-inch or larger telescopes. Seek Pluto when it's highest in the sky, around 1 a.m. local daylight time in late July. Unfortunately, its declination varies little for the next decade as its steeply inclined orbit carries it farther and farther south of the ecliptic.



PI SCORPII OCCULTATION: STELLARIUM



The Southern Delta Aquariids and Alpha Capricornids Burn

KEEP ADDING TINY twigs to a fledgling fire, and it will eventually bloom into a blaze of heat and light. On the night of July 29–30, two modest meteor showers combine to spark a lively night of meteor-watching. The primary player is the annual Southern Delta Aquariid shower, which peaks at around 25 meteors per hour. Members spurt from the radiant located just east of the star Skat, or Delta (δ) Aquarii.

Given the shower's relatively southern declination, observers in the tropics have the best view. From a latitude of 40° north, the radiant culminates at an altitude of around 35° at around 3:00 a.m. local daylight time. The shower is rich in fainter meteors and best observed from a dark sky between midnight and 4 a.m. Fortunately, the waxing crescent Moon will be out of the picture when activity is strongest. The Southern Delta Aquariids zip across the heavens at the modest speed of 40 kilometers per second (90,000 mph) and generally don't leave persistent trains.

The shower originates from something known as the 96P/Machholz Complex — a mixed bag of eight meteor showers, two comet groups, and the asteroid 2003 EH1. Comet 96P orbits the Sun every 5.3 years and last reached perihelion in 2023. Particles ejected

▲ Both the Southern Delta Aquariids and Alpha Capricornid meteor showers complement each other as they reach maximum on the same night, July 29-30. Their radiants lie in the same general region of the sky, but each shower displays its own characteristic meteors.

from the comet's nucleus between 20,000 and 10,000 BC ultimately gave rise to the Southern Delta Aquariids, making each luminous streak you see a timeline to the remote past.

Let's add a few more twigs to the fire: The Alpha Capricornids peak at the same time as the Southern Delta Aquariids, but at a modest rate of just 5 meteors per hour. However, what they lack in quantity they make up for in quality — the Alpha Capricornids are known for producing slow-moving fireballs. The radiant is also a little higher for mid-northern latitudes, located about 3½° northeast of Alpha (α) Capricorni. The shower is the spawn of Comet 169P/NEAT, which next comes to perihelion in September 2026.

In addition to these two displays, late July is also when the first Perseids make their appearance as the shower ramps up to its August 12th maximum. Add in an average of five or six sporadics per hour, and there should be enough meteors to kindle a modest blaze of activity in the predawn sky.

Action at Jupiter

AND SO IT BEGINS once again. This month Jupiter climbs out of the dawn solar glare to start a new apparition after a brief absence. The planet was in conjunction with the Sun on June 24th and should be visible to the naked eye starting around July 9th when it gleams at magnitude –1.9 and rises roughly 45 minutes ahead of the Sun.

This apparition is especially favorable for Northern Hemisphere observers. The giant planet spends most of its time traversing Gemini before crossing into neighboring Cancer on June 22, 2026. Due to the 13-month span between Jupiter oppositions, 2025 is a year without one — it doesn't reach opposition again until January 10, 2026.

There will be the usual number of enjoyable naked-eye conjunctions involving Jupiter this apparition, but by far the most exciting will be when it has a close pairing with brilliant Venus on the morning of August 12th (stay tuned for more). Appropriately enough, this Jupiter season concludes with a second Venus meeting — this time at dusk on July 9, 2026. Twenty days later, on July 29th, Jupiter is in conjuction with the Sun and the cycle begins anew.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for when Jupiter is at its highest.

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

July 1: 7:30, 17:26; **2:** 3:22, 13:17, 23:13; **3:** 9:09, 19:05; **4:** 5:01, 14:57; **5:** 0:52, 10:48, 20:44; **6:** 6:40, 16:36; **7:** 2:31, 12:27, 22:23; **8:** 8:19, 18:15; **9:** 4:11, 14:06; **10**: 0:02, 9:58, 19:54; **11**:

5:50, 15:46; **12**: 1:41, 11:37, 21:33; **13**: 7:29, 17:25; **14**: 3:20, 13:16, 23:12; **15**: 9:08, 19:04; **16**: 5:00, 14:55; **17**: 0:51, 10:47, 20:43; **18**: 6:39, 16:34; **19**: 2:30, 12:26, 22:22; **20**: 8:18, 18:14; **21**: 4:09, 14:05; **22**: 0:01, 9:57, 19:53; **23**: 5:48, 15:44; **24**: 1:40, 11:36, 21:32; **25**: 7:27, 17:23; **26**: 3:19, 13:15, 23:11; **27**: 9:06, 19:02; **28**: 4:58, 14:54; **29**: 0:50, 10:45, 20:41; **30**: 6:37, 16:33; **31**: 2:29, 12:25, 22:20

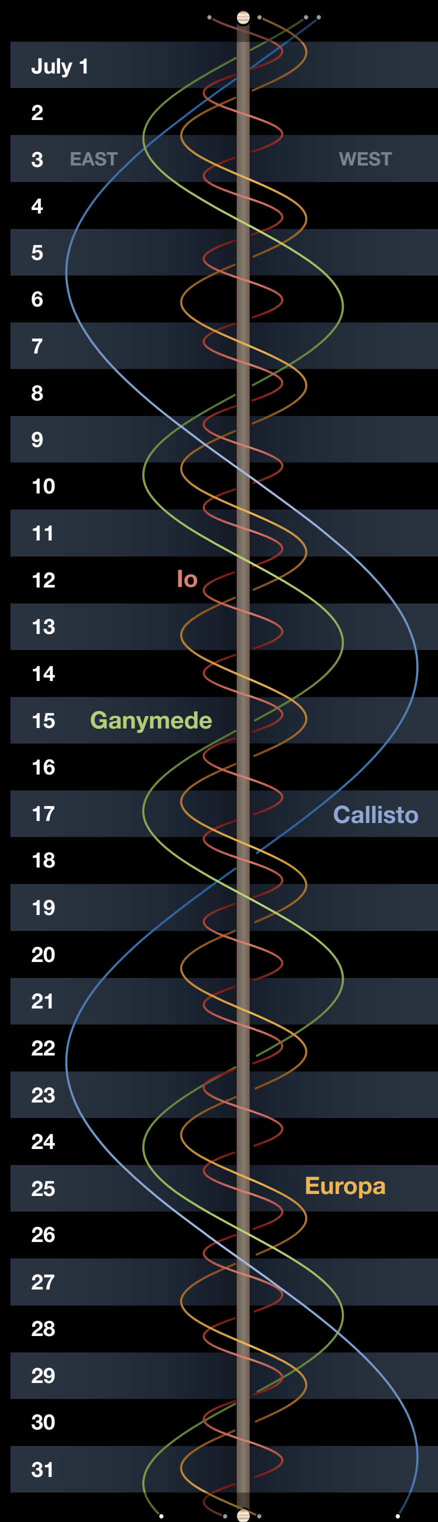
These times assume that the spot will be centered at System II longitude 78° on July 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 78° and $1\frac{2}{3}$ minutes later for each degree more than 78°.

Phenomena of Jupiter's Moons, July 2025

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

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.

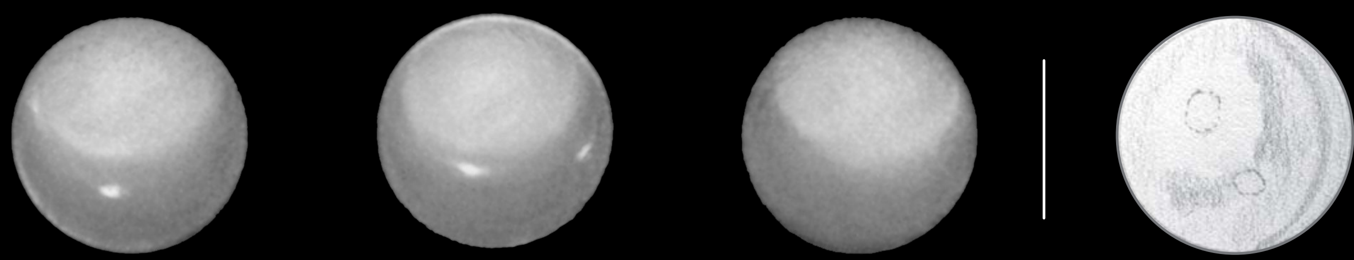
Jupiter's Moons



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.

Two Remarkable Visual Discoveries

The human eye is a force to be reckoned with.



▲ The three infrared-light images of Uranus at left taken by the Hubble Space Telescope on August 14, 1994, captured a pair of bright clouds as well as the high-altitude haze that forms a bright "cap" over the planet's south pole. The similarity of these images to O'Meara's 1981 sketch at right is striking.

NASA / JPL / SPACE SCIENCE INSTITUTE

When the twin Voyager spacecraft flew past Saturn in 1981, they returned images that verified the existence of the ghostly "spokes" in Saturn's B ring that Contributing Editor Stephen James O'Meara had reported five years earlier (see our May issue, page 52). Voyager 2 was outbound to its 1986 encounter with Uranus when Bradford Smith, the leader of the Voyager imaging team, challenged O'Meara to try to determine the Uranian rotation period.

The ice giant is so remote that its apparent diameter never exceeds 3.7 arcseconds — that's about 7% the size of Jupiter and 18% as large as Saturn at opposition. The planet's low apparent surface brightness poses an even greater handicap for observers.

Unable to follow the motion of any well-defined markings, astronomers attempting to determine the rate of Uranus's axial rotation employed spectrographs to measure the Doppler shifts in sunlight reflected from the planet's approaching and receding limbs. The accuracy of this technique is extremely sensitive to guiding errors and atmospheric turbulence. In the case of Uranus, it's further complicated by the fact that the planet's rotational axis is inclined by a whopping 98° to the plane of its orbit. Uranus rolls along on its side almost pole-first while making its 84-year-long circuit of the Sun, so it's hardly surprising that the rotation periods determined spectrographically were wildly discordant, ranging from between 10.8 and 24 hours.

For several months after O'Meara accepted Smith's challenge, he was unable to make out more than the limb darkening of the planet's bland disk using Harvard College Observatory's venerable 9-inch Alvan Clark & Sons refractor. To his surprise, a pair of white spots appeared on the night of July 22, 1981. One was stationary, marking the position of the planet's south pole, while the other was located closer to the limb.

These spots remained visible for several weeks. The motion of the one nearest to the planet's equator suggested a rotation period of 16.4 hours. A third bright but short-lived spot observed on two nights in late August the same year had a 16.0-hour period.

O'Meara's discovery was announced early in 1984 in International Astronomical Union Circular 3912. The temperate-latitude clouds captured in contrast-enhanced images during the Voyager 2 flyby two years later were found to circle the planet within minutes of the periods that O'Meara had reported. In visible light, features recorded by Voyager 2's cameras amidst the hydrocarbon hazes of Uranus's deep, frigid atmosphere contrasted so poorly with their surroundings it seemed utterly implausible that any visual observer could have seen so much as a hint of them.

▶ On March 1, 1903, Percival Lowell jotted a note in his observing log about the feature he dubbed Ascraeus Lucus. His description matches perfectly with this Mars Express image of Ascraeus Mons, the second largest volcano on Mars, at upper left.

In retrospect, Uranus seems to have been unusually quiescent during the 1986 Voyager 2 flyby. Ground-based telescopes imaging in near-infrared wavelengths have recorded very faint belts and zones as well as a few bright spots in recent years. The prominent, persistent spots that O'Meara witnessed appear to be a rare phenomenon, so luck surely played a role in this last great planetary discovery by a visual observer. In the decades following his 1981 observations, O'Meara has never seen another well-defined feature on Uranus even though he has studied the planet with far more powerful telescopes.

Lowell's Discovery

Some 80 years before O'Meara's discoveries, one of the greatest feats of visual planetary observing wasn't made by a great observer. Percival Lowell is deservedly notorious for his intricate maps of Mars cobwebbed with "little gossamer filaments" (see page 12). He fervently believed they were a network of canals constructed by a struggling Martian race to convey the seasonal meltwater from the polar caps to the ochre deserts near the planet's equator. In addition to covering Mars with illusory lines, Lowell's depictions of Mercury and even the cloudscapes of Venus and Saturn also feature spurious linear markings.

Despite the scorn and derision heaped on Lowell's work, his illusion-prone eye did make one truly remarkable observation of Mars. On the night of March 1, 1903, he was examining the 12.6 arcsecond Martian disc through his 24-inch Clark refractor when his eye was drawn to an isolated dark spot that he christened Ascraeus Lucus. Appearing only about 1 arcsecond in diameter, it was a typical example of the oases that Lowell imagined to be groves of vegetation surrounding pumping stations or cities.

In his 1906 book, *Mars and its Canals*, Lowell recounted "a most curious observation":

> *Usually the oases are of solid tone throughout; equally sombre from centre to circumference. But in this case such uniform complexion found exception exception. . . . the Ascraeus Lucus came out strangely differentiated, a dark rim inclosing a less dark kernel. The sight was odd enough to command comment in the shape of a sketch which accompanied the note, and the further remark that other spots had similarly that year affected the like look.*

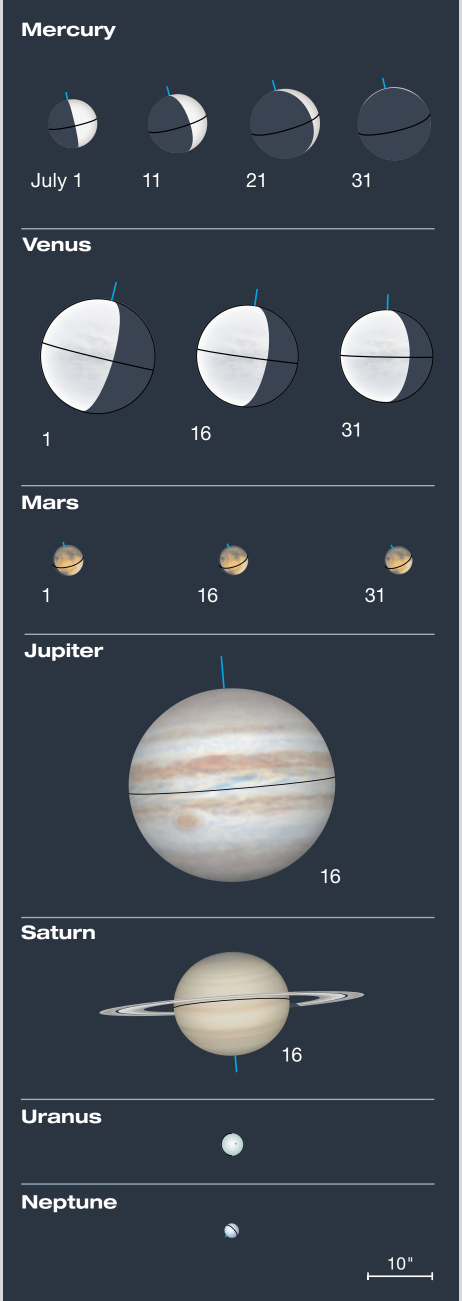
In this instance there can be no disputing the uncanny accuracy of what Lowell described, though it was an uncomprehending glimpse. In 1972 the Mariner 9 spacecraft revealed Ascraeus Mons as the northernmost and tallest of three enormous shield volcanoes collectively known as the Tharsis Montes. All three appear as oases on Lowell's Mars maps.

In high-resolution images taken by orbiting spacecraft, Ascraeus Mons appears as an annulus. In fact, all the Tharsis shield volcanoes display a brighter center around their frosty summits surrounded by a ring of darker basalt lava on their flanks. It's amazing that Lowell managed to resolve this aspect when he scrutinized such a tiny dot on the Martian disk.

Thanks to sensitive video cameras and image-processing software, backyard astronomers routinely capture images of the planets that rival many taken by spacecraft. While marveling at their results, I'm always mindful that the human eye has achieved feats of resolution that are every bit as impressive. Long vigils at the eyepiece patiently waiting for atmospheric turbulence to subside are rewarded with the fleeting moments of extreme clarity that Lowell called "revelation peeps." Once experienced, they make visual observers forgo sleep and brave many a cold night.

■ Contributing Editor **TOM DOBBINS** is coauthor of *Epic Moon, A History of Lunar Exploration in the Age of the Telescope*, available at **shopatsky.com**.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk until the 11th • **Venus** visible at dawn all month • **Mars** visible at dusk and sets before midnight • **Jupiter** visible at dawn starting on the 9th • **Saturn** rises around midnight and visible to dawn.



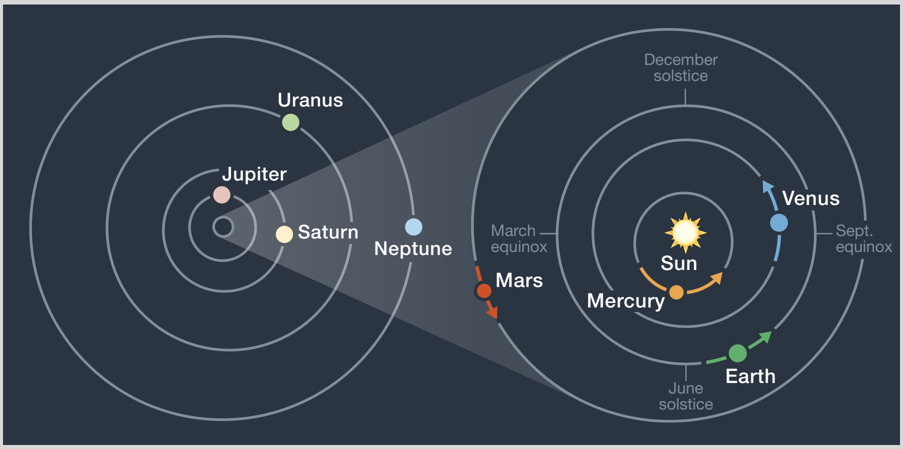
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

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

July Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$6^h 39.5^m$	+23° 07′	—	–26.8	31′ 28″	—	1.017
	31	$8^h 40.5^m$	+18° 20′	—	–26.8	31′ 31″	—	1.015
Mercury	1	$8^h 29.0^m$	+19° 38′	26° Ev	+0.2	7.6″	46%	0.884
	11	$9^h 01.0^m$	+15° 26′	25° Ev	+0.9	9.2″	29%	0.732
	21	$9^h 04.9^m$	+12° 43′	17° Ev	+2.3	10.8″	12%	0.621
	31	$8^h 41.9^m$	+13° 07′	5° Ev	+5.3	11.4″	1%	0.591
Venus	1	$3^h 35.9^m$	+16° 37′	43° Mo	–4.2	17.8″	64%	0.937
	11	$4^h 21.1^m$	+19° 04′	42° Mo	–4.1	16.5″	68%	1.013
	21	$5^h 08.5^m$	+20° 52′	40° Mo	–4.0	15.4″	71%	1.086
	31	$5^h 57.7^m$	+21° 52′	38° Mo	–4.0	14.4″	75%	1.156
Mars	1	$10^h 38.0^m$	+9° 44′	58° Ev	+1.5	4.9″	92%	1.925
	16	$11^h 10.6^m$	+6° 11′	53° Ev	+1.5	4.6″	93%	2.024
	31	$11^h 43.9^m$	+2° 26′	48° Ev	+1.6	4.4″	94%	2.113
Jupiter	1	$6^h 19.4^m$	+23° 14′	5° Mo	–1.9	32.0″	100%	6.158
	31	$6^h 48.4^m$	+22° 53′	27° Mo	–1.9	32.6″	100%	6.044
Saturn	1	$0^h 08.9^m$	–1° 28′	98° Mo	+1.0	17.7″	100%	9.387
	31	$0^h 08.6^m$	–1° 39′	126° Mo	+0.8	18.6″	100%	8.929
Uranus	16	$3^h 51.5^m$	+19° 57′	53° Mo	+5.8	3.5″	100%	20.109
Neptune	16	$0^h 08.7^m$	–0° 31′	112° Mo	+7.9	2.3″	100%	29.500

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



A Star-Studded Shoulder

Northeastern Ophiuchus has plenty to offer backyard observers plagued with light pollution.

As readers of this column know, I enjoy scoping relatively small sections of sky and reporting on what I find. My suburban nights are badly light-polluted, especially to the south, so I have to pick my spots carefully. Clusters and double stars are good — nebulae and galaxies, not so much.

One evening last summer I focused on an area approximately 5° square, located in the eastern shoulder of Ophiuchus, the Serpent Bearer. The region is dominated by 2.8-magnitude Cebalrai, also known as Beta (β) Ophiuchi, a star easily sighted in finderscopes or red-dot finders. The patch of sky lies a tad north of the celestial equator — in my case, barely above a light dome ballooning from the city center a few miles south of me. Despite the light, I got to work setting up a 4¼-inch f/6 Newtonian reflector, an 8-inch f/6 Dobsonian, and tripod-mounted 10×50 binoculars.

Big Bright Cluster

I began my Ophiuchus adventure by aiming my binoculars at Beta. Right away, I noticed the sprawling open cluster **IC 4665** just 1¼° northeast of the star. And no wonder; IC 4665 sports a diameter of around 70′ (estimates vary, depending on the source) and a total visual magnitude of 4.2. Number 4665 in the Index Catalogue is built for binoculars.

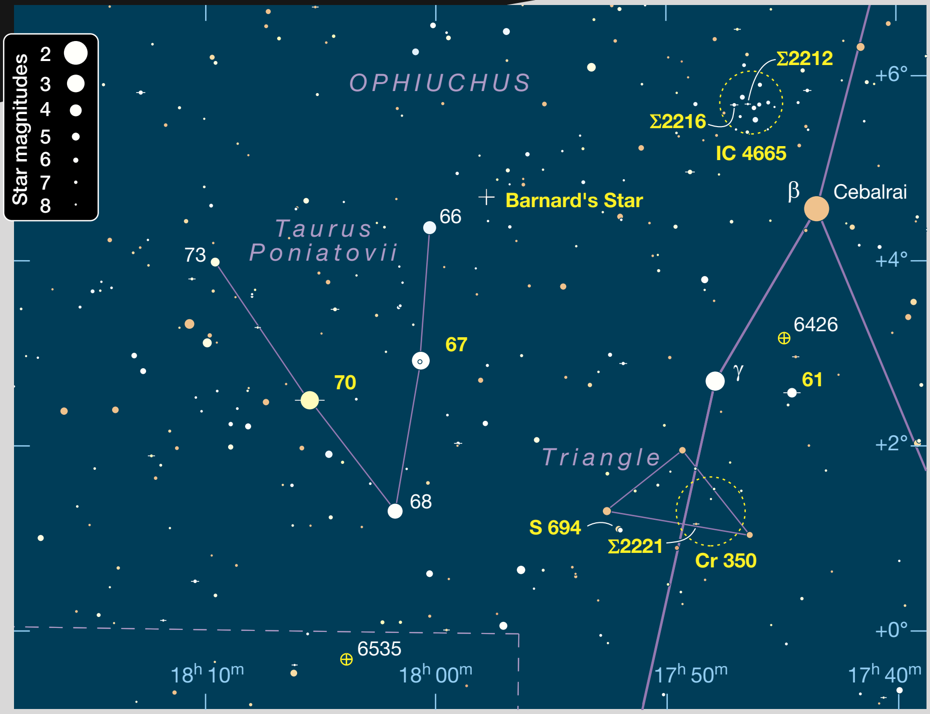
In my 10×50s, I counted 11 stars from magnitude 6.8 down to 8.8 (the city limit for my binos) in a very loose clump about 40′ across. Nine additional stars, mostly 8th magnitude, were visible outside the main clump, five of which formed a ragged north-south row along the extreme western side of the cluster. The combination of clump and row gave me the impression, correctly or not, that IC 4665 consists of two separate populations.

My 4¼-inch telescope armed with a wide-angle eyepiece generating 22× framed the whole thing nicely. I tallied two dozen stars down to magnitude 10.5, including three more (for a total of eight) in the ragged row. Bumping up to 54× revealed the double star **Σ2216** in the eastern portion of IC 4665. The unbalanced tandem consists of an 8.0-magnitude primary and a 10.1-magnitude secondary 27.3″ apart. Something else caught my eye several arcminutes southeastward, on the edge of the clump — a reddish ember (8.4-magnitude HD 161820) in the otherwise blue-white family.

Turning to my 8-inch reflector, I inserted the same wide-angle eyepiece to produce 41×. As with the smaller scope, IC 4665 was beautifully framed. The previously mentioned Σ2216 resolved instantly. And upping the magnification to 135× yielded a close binary, **Σ2212**, situated near the middle of the cluster. The 9.5- and 9.6-magnitude siblings, just 3.3″ of space between them, lined up nearly north-south. The specks were extremely tight at 135× but

ALAN DYER

▲ **A SHOULDER TO LEAN ON** Ophiuchus is an impressively large constellation. Covering almost 1,000 square degrees of sky, the Serpent Bearer ranks 11th in size among the 88 official star groups. This photo shows the constellations's northeastern shoulder, anchored by 2.8-magnitude Beta (β) Ophiuchi. Fine double stars and several star clusters reside in the region.



◀ **SHOULDER AND BULL** The broad eastern shoulder of Ophiuchus features several deep-sky targets and the V-shaped mini-constellation dubbed Taurus Poniatovii.

split cleanly at 174×. Who'd ever think of observing IC 4665 at high magnification? I'm glad I did!

Little Faint Cluster

After that unexpectedly pleasing scrutiny of IC 4665, I reapplied 22× on the 4¼-inch and returned to Beta. I then aimed southeastward slightly more than 2° to arrive at 3.8-magnitude Gamma (γ) Ophiuchi. Finally, less than 1° west-southwest of Gamma, the 4¼-inch swept up a striking double: **61 Ophiuchi**. With its 6.1- and 6.5-magnitude elements nicely spaced 20.8″ apart, Super 61 (as I call it) is a perfect pairing for small scopes.

On to tougher territory. From Gamma, I headed southward to a 1½°-wide triangular asterism, its three corners marked by stars of magnitudes 5.9, 6.5, and 6.6. Near the western edge of the triangle resides an inconspicuous cluster identified as **Collinder 350**. Officially, Cr 350 has a diameter of 40′ plus an encouraging total visual magnitude of 6.1; however, those values are misleading. The cluster contains only about 20 stars, none brighter than 8th magnitude. My 4¼-inch reflector at low magnification detected 10 members, sprinkled across half a degree of sky. I picked up a similar number northwest of the cluster boundary, a bit outside the triangle. My 8-inch at 41× registered at least three dozen stars, members or not, strewn throughout a circular area roughly 1° in diameter.

Tucked inside the southeastern boundary of Cr 350 is a faint, uneven binary called **Σ2221**. Comprising a 9.0-magnitude primary and an 11.1-magnitude secondary 19.5″ eastward, Σ2221 challenged my backyard telescopes. In my observing notes I wrote that the double was "dim but doable in the 4¼-inch at 93× — easier in the 8-inch." Happily, the wonderful double **South 694** (S 694) awaited me ¼° southeast of the triangle's easternmost star. Featuring 6.7- and 7.3-magnitude components 79.3″ apart, S 694 was friendly to the binos and colorful in my scopes. The brighter star shines lemon yellow, while the other gleams blue-white. In contrast to that painted pair, the 5.9-magnitude triangle star burns strongly orange.

Shoulder Sights

Object	Type	Mag	Size/Sep	RA	Dec.
IC 4665	Open cluster	4.2	70′	17^h 46.2^m	+05° 43′
Σ2216	Double star	8.0, 10.1	27.3″	17^h 47.0^m	+05° 42′
Σ2212	Double star	9.5, 9.6	3.3″	17^h 46.4^m	+05° 42′
61 Ophiuchi	Double star	6.1, 6.5	20.8″	17^h 44.6^m	+02° 35′
Cr 350	Open cluster	6.1	40′	17^h 48.1^m	+01° 21′
Σ2221	Double star	9.0, 11.1	19.5″	17^h 48.7^m	+01° 10′
S 694	Double star	6.7, 7.3	79.3″	17^h 52.1^m	+01° 07′
Cr 359	Open cluster	3.0	240′	18^h 01.1^m	+02° 54′
67 Ophiuchi	Double star	4.0, 8.1	54.7″	18^h 00.6^m	+02° 56′
70 Ophiuchi	Double star	4.2, 6.2	6.7″	18^h 05.5^m	+02° 30′
Barnard's Star	Red dwarf	9.5	—	17^h 57.8^m	+04° 46′

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.

Ersatz Cluster

A few degrees east of Gamma, the 4th-magnitude Flamsteed stars 67, 68, and 70 Ophiuchi outline a triangle 1° wide by 1½° tall. The eye-catching trio dominates **Cr 359** (also known as Melotte 186), which was originally considered a vast, sparsely populated open cluster, but is actually a chance alignment of unrelated suns. Two other obvious points in Cr 359 are 4.6-magnitude 66 Ophiuchi and 6.0-magnitude 73 Ophiuchi, which stand less than 2° north of the bright triangle. The result-

CLUSTER BRIGHT Large and loosely arranged, IC 4665 is an ideal target for binoculars. Only about 55 million years old, this young cluster contains about 20 relatively bright stars and hundreds of fainter members. IC 4665 is unusual in that it lies 15° west of the galactic equator, well beyond the most cluster-rich areas of the Milky Way. Based on data acquired by the Gaia spacecraft, IC 4665 is approximately 1,100 light-years from Earth.

ALAN DYER

ing V-shaped Collinder quintet stretches about 3°, top to bottom.

This five-star V has a history. In her engaging book *Celestial Sampler*, former *S&T* columnist Sue French explained how the grouping briefly became the constellation Taurus Poniatovii, Poniatowski's Bull: "It was created in 1777 by the Abbé Martin Poczobutt, director of the Royal Observatory of Vilna in honor of King Stanislaw Poniatowski of Poland." Sue commented that the regal collection was symbolized by only a handful of stars but, "its likeness to the V-shaped Hyades group forming the face of the winter constellation Taurus inspired Poczobutt to place this bull in the summer sky." As I studied Taurus Poniatovii last summer, I couldn't help chuckling at what had transpired nearly 250 years earlier. Poczobut's bullish reassignment of the stars east of Gamma left Ophiuchus with a separated shoulder. (See also *S&T:* Aug. 2022, p. 20.)

Cr 359, the faux open cluster enveloping Poniatowski's Bull, was surprisingly attractive in my binos. I counted 20 stars shining prominently between 4th- and 7th-magnitude, plus at least a dozen fainter ones scattered across 4° of sky — hardly awesome, yet modestly pretty. In addition, the Flamsteed triangle mentioned earlier provided two more telescopic doubles. Low power in my 4¼-inch showed that 4.0-magnitude **67 Ophiuchi** has an 8.1-magnitude companion 54.7″ away. And at 72×, yellowish **70 Ophiuchi** resolved into 4.2- and 6.2-magnitude components 6.7″ apart. A lovely set!

Neighborhood Speedster

For my final stop, I aimed the 8-inch reflector at 66 Ophiuchi, then inched slowly 44′ northwestward to a solitary 9.5-magnitude red dwarf. Admittedly, there isn't much to see — only a dim, somewhat orangey spark. But it's a very special spark. Christened **Barnard's Star** in honor of American astronomer E. E. Barnard, the warm-hued dwarf possesses the highest proper motion of any known star. Barnard's measurements in 1916 alerted astronomers to the fact that the celestial speedster is motoring northward in excess of ¼° per century. Barnard's Star exhibits this impressive motion partly because it's a galactic neighbor — not quite 6 light-years from Earth. (Turn to page 63 of the May 2024 issue for a finderchart.)

My Beta-to-Barnard tour of Ophiuchus was fun, and I managed it without the aid of a finderscope. Observers working with red-dot (or similar) non-optical finders can, as I did, locate Beta first, then hop through the region telescopically by employing a low-power, wide-angle eyepiece. The targets are certainly worth a look, as they're largely immune to light pollution. Set your sights on the Serpent Bearer's separated shoulder and see if you agree.

■ Contributing Editor **KEN HEWITT-WHITE** has never suffered a separated shoulder but has a chronic case of *lumen nervosa* — a fear of light pollution.

Step Up Your Outreach

SHARE THE UNIVERSE: *A Guide to Outreach Astronomy*

Richard Stember
Springer, 2024
154 pages, ISBN 13-9783031534942
$50.00, hardcover

ASTRONOMY CLUBS take outreach seriously and recognize it to be absolutely essential to furthering the hobby. In addition, most astronomers find engaging with the public to be fun and rewarding. Until *Share the Universe*, I don't think there has been as comprehensive a resource that introduces amateurs to the fundamentals of informal education.

Richard Stember is an amateur astronomer who has conducted outreach for decades. He tells us in the preface that inspiration came to him when he and his 11-year-old son attended an astronomy event at his son's school. Stember was inspired to purchase a telescope, join a club, and begin his long-standing vocation of communicating science to the general public. He even went on to form a nonprofit dedicated to astronomy outreach.

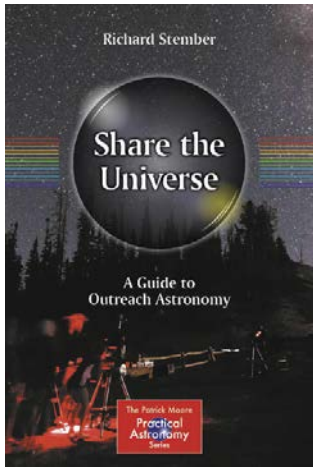
> You're likely to find an activity or two that you haven't tried before and some clever ideas.

For those new to the practice, this guide will provide inspiration and encouragement along with a wealth of information and advice. Much of the book is a nuts-and-bolts how-to for planning and conducting an outreach session. Everything is comprehensively covered, ranging from what to consider when scheduling an event and how to pick a suitable site, right down to the basics of how to help someone approach a telescope and put their eye to an eyepiece.

In the chapter, "Knowing Your Audience," Stember hints at the wider role amateur astronomers can perform as they engage with the public. A section on scientific practice describes the practical realities and the misperceptions that the general public are likely to have regarding science. For instance, he explains that the concept of a "theory" has a very different connotation in colloquial use than it does in scientific circles where it refers to a body of knowledge and working models that explain established facts rather than guesses or suppositions. Outreach astronomers, he suggests, have an excellent opportunity to make such distinctions clear to the public.

Before starting out, it's important to understand what aspects of astronomy your audience might be familiar with and what common misconceptions you are apt to encounter. Sometimes religious or cultural differences can add challenges, as can physical impairments. Stember touches on all of these potential obstacles and more. This chapter should be required reading, especially for anyone new to doing outreach.

Share the Universe is not just for the novice, however. In it, the author discusses the science of informal education and describes the differences between the *captive* audience that formal educators encounter and the *non-captive* ones that attend public events. He goes on to introduce the notion of *informal interpretation* and opines on the role of the outreach astronomer as an educator. Many techniques and concepts that have proven effective in formal education can be adapted to informal situations. Stember provides some examples of professional informal educators (such as museum and park guides) as role models.



One of the last chapters outlines some hands-on activities that potential outreachers might find useful. If you're like me, you're always looking for ways to make your outreach events fun and interesting, especially for young audiences. You're likely to find an activity or two that you haven't tried before and some clever ideas to improve the ones you have. This chapter is worth a read even for those with extensive experience and well-established programs.

The idea of formalizing outreach may not appeal to every astronomer. Some may find that Stember's approach tends to overly complicate an activity that they do just for fun. However, I think that everyone who interacts with the public will find value in this book. I've led hundreds of successful outreach events over the past 30 years and yet *Share the Universe* provided me with some new perspectives. This thoughtfully written volume should deliver insights and inspiration to outreach astronomers of every ilk and every level.

■ Contributing Editor **TED FORTE** is the director of the Patterson Observatory in Sierra Vista, Arizona, and serves as the outreach coordinator for the Huachuca Astronomy Club.

 by Peter Bresseler

Get Lucky in the Deep Sky

Here's a great way to record high-resolution photos of bright targets beyond our solar system.

One of the goals of a deep-sky astrophotographer is to resolve the smallest details their scope is capable of producing. Typically, imagers do this by assembling a system that matches their pixel scale (how much sky is recorded on a single pixel) to the resolution their site normally allows, practicing careful polar alignment and autoguiding, and perhaps enlisting help from additional devices like active optics that compensate for image motion multiple times each second. But there is another, easier way to achieve extremely high-resolution images. It's called *lucky imaging.*

Lucky imaging is a method where you record many short exposures of your target and combine only the sharpest ones. The result is a picture with far higher resolution than is possible when recording individual long exposures. This method has been the standard approach to recording the most detailed pictures of the Sun, Moon, and planets since the turn of the century. It also avoids losing a long exposure to trails from passing aircraft or satellites — you simply exclude frames with trails from your composite.

▲ **RESOLVED PLANETARY** High-resolution images of bright targets, particularly planetary nebulae like NGC 2392, are easy to capture using the lucky imaging technique. The author combined 7,200 individual 1-second exposures recorded through his Celestron C14 and ZWO ASI294MC PRO camera to produced this remarkable result.

The technique works best on bright deep-sky targets. With it you can capture fine structures within many planetary nebulae, resolve stars within the cores of dense globular clusters, or discern fine details within H II regions in nearby galaxies. With the right combination of telescope, camera, and imaging technique, you can take stunning images that approach the resolution limit of your telescope. Here's how it works.

Resolving Power and Pixel Scale

Getting the most out of your telescope requires understanding its full capabilities. The maximum resolution of a telescope is determined by the *Rayleigh criterion* (sometimes referred to as the diffraction limit), which states that the minimum resolvable feature is limited by diffraction to the ratio of the wavelength of the light to the aperture diameter. Visible light spans wavelengths from about 400 to 700 nanometers. Using the midpoint of that range, 550 nm, the Rayleigh criterion is simplified using this formula:

$$\theta = \frac{138}{D} \,,$$

where D is the telescope aperture in millimeters and θ is the resolution in arcseconds.

Telescope manufacturers often provide the theoretical resolution limits of their instruments. For example, under ideal conditions, a Celestron C14 with an aperture of 356 millimeters has the ability to resolve double stars separated by 0.39″ (138 / 356 = 0.39). Resolving power increases with aperture, so larger scopes can resolve even smaller features.

The next thing to consider is how a camera's sensor converts an analog signal (a celestial scene of varying brightness) to digital data (a grid of numbers representing the brightness in each pixel). The *Nyquist sampling theorem* says that a structure must be scanned at *twice* the resolution limit in order to ensure that the digital image reproduces the finest details faithfully. This means that the pixel size of your camera should be half the diffraction limit of your telescope.

With my C14 of diffraction limit θ, the pixel scale p in arcseconds is calculated as follows:

$$p = \frac{\theta}{2} = \frac{0.39''}{2} = 0.195''.$$

Therefore, to utilize the full potential of a C14, the pixel scale should be around 0.195″ per pixel.

At first glance it seems paradoxical: Why use a sampling of 0.195″ per pixel if the telescope can only resolve 0.39″? The answer lies in the way diffraction at the telescope aperture creates images at the focal plane. The image of a star is not a point but a *point spread function* with a bright central peak encircled by a pattern of faint rings separated by dark gaps — a so-called Airy disk. The Rayleigh criterion is calculated using the radius of the dark gap between the central peak and the first ring, but the central peak is sharper than that, so in principal the image contains still finer detail.

▶ SIMPLIFIED IMAGING TRAIN Lucky imaging relies on short exposures of 1 second or less. This means that autoguiding isn't required. The only equipment needed is a moderately large aperture telescope, a sturdy tracking mount, and a camera capable of producing a pixel scale approximately twice the telescope's resolving power, which is usually determined by the seeing conditions.

A quick way to calculate the optimum pixel scale, p, of any telescope-camera combination is to use this equation:

$$p = 206.265 \times \frac{P}{F}\,.$$

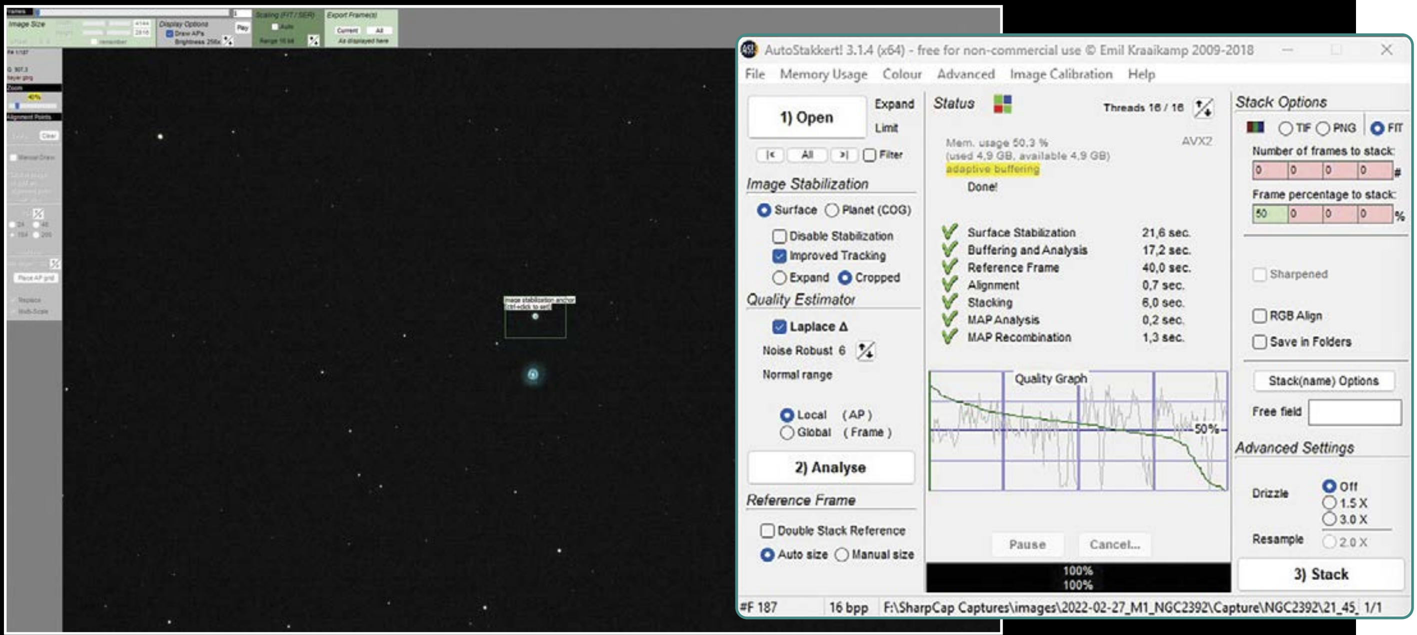
Here P is the size of the pixels in your camera in microns (µm, or millionths of a meter), F is the focal length of your telescope in millimeters, and p is in arcseconds.

When pairing the C14 with my ZWO ASI294MC camera having 4.63 µm pixels, the system's pixel scale is 0.24″. This is slightly larger than the optimum size of 0.195″ and doesn't quite achieve the full Nyquist resolution, though it is still useful for lucky imaging in all but perfect conditions.

Matching the Seeing Conditions

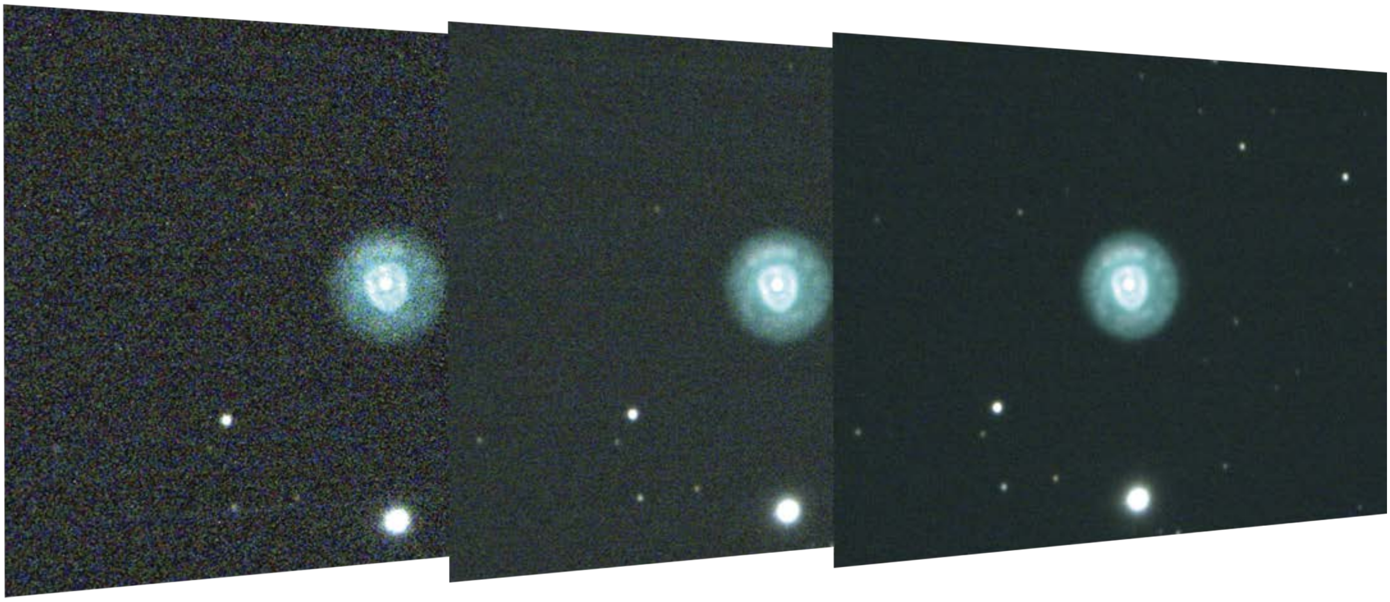
Of course, the scintillation of the atmosphere, also known as seeing, is a ground-based telescope's biggest limiting factor.

ABOVE THE NOISE Key to the lucky imaging technique is to record short exposures that are brief enough to capture moments of steady seeing while also acquiring enough signal in your target to be above the readout noise in each image. This single frame shows NGC 2392 captured with *SharpCap* camera control software.

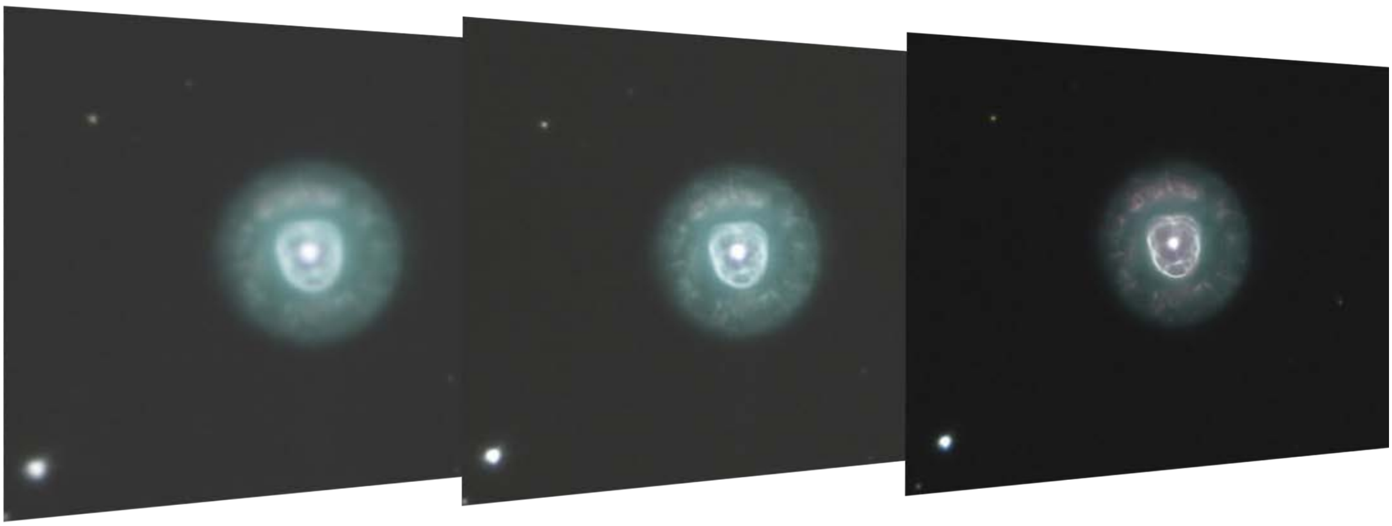


THE PLANETARY APPROACH *Autostakkert! 4* lets you combine hundreds or thousands of exposures. To combine deep-sky images in the program, first navigate to the folder containing your images by clicking the ***1) Open*** button. Next, be sure to select ***Surface*** in the Image Stabilization section at top left. Calibration frames are imported using the Image Calibration pulldown menu along the top. After tapping the ***2) Analyse*** button, the program examines all the images and produces the Quality Graph seen at the lower center of the window. Images to the right of the point where the green line drops below the midpoint should be rejected by changing the ***Frame percentage to stack*** number to a corresponding number in the Stack Options section at upper right. In this case, roughly 50% of the frames will be stacked.

TARGETED STACKING Once sorting is completed, select your target object or a star in its immediate vicinity, then click ***3) Stack*** in the control window. The time it takes to stack your images will depend on several factors including the size of your sensor, how many frames you are stacking, and the speed of your computer's processor.



▲ **STACKING IMPROVEMENT** Combining many frames increases the signal-to-noise-ratio of your final image. The frame at left shows a single 1-second exposure, while adding 10 images *(center)* and 90 *(right)* drastically reduces the noise in the image while improving the signal of the nebula. Achieving a high SNR permits additional stretching and other processing while still keeping the noise at a tolerable level.



▲ **DECONVOLVED RECOVERY** After stacking is finished, the result is a high-signal image like the result at left. The image is then processed like most any deep-sky image. Because so many frames are stacked, the picture holds up well when applying sharpening (middle) or deconvolution to restore the intricate loops within NGC 2392 as seen at right.

At an image scale of 0.24″ my C14 and ZWO camera scans at a much finer resolution than the seeing usually allows. If the seeing is around 2″, all structures smaller than this limit appear blurred. Nevertheless, the image still contains fine brightness gradients. To optimally reproduce these details, the pixel resolution should be about half of the seeing, or 1″.

At 0.24″ per pixel in 2″ seeing, a star's Airy disk spreads over 64 pixels rather than the four specified by the Nyquist theorem. Distributing light over such a large number of pixels means that less light is recorded per pixel. This leads to a reduction in the *signal-to-noise ratio* (SNR), the ratio of the detected light intensity and the detector's readout noise. In general, a higher SNR means better image quality. Because of the reduced SNR, the too-small pixels don't recover any image structure finer than the Nyquist limit.

There are two ways to optimize the SNR under poor seeing conditions: Either increase the effective pixel size by binning, or shorten the telescope's focal length using a focal reducer. With binning, several pixels combine to act as one larger, more sensitive pixel. Binning four pixels (2 × 2) increases the pixel scale to 0.48″, while binning 4 × 4 brings it to 0.96″. Alternatively, adding a Celestron 0.7× focal reducer shortens the focal length to 2,745 mm and produces 0.34″ per pixel on my ZWO camera. The trick is to find the optimum balance between detail and image noise. Try both approaches and see which works best.

▲ **STRONG COMPARISON** The details recorded in the author's result of NGC 7662, the Blue Snowball Nebula in Andromeda (left), compares well with those captured with the Hubble Space Telescope (right).

Capture Technique

The best approach to lucky deep-sky imaging is to use a camera capable of extremely high frame rates, such as those produced by Player One Astronomy, QHY, or ZWO. The goal is to "freeze" the atmospheric fluctuations that otherwise blur astronomical images. While you can use an uncooled camera, the results are often better with a cooled version, particularly when shooting on warm summer nights. But with a mount that is properly polar aligned, the exposures are so short that autoguiding is unnecessary, which greatly simplifies your imaging setup. All you need is the telescope, a good tracking mount, the camera, and your control computer.

You can use either a color camera or a monochrome version. Keep in mind that if your goal is color images, you'll need to record at least three times the amount of data through individual red, green, and blue filters.

The basic procedure is straightforward. I use the freeware *SharpCap* (**www.sharpcap.co.uk**) to control my camera, though another good option is *FireCapture* (**www.firecapture.de**). Both are free and offer extensive controls for both deep-sky and planetary imaging. In *SharpCap* I first adjust the gain, which is a signal amplification setting comparable to the ISO value of a DSLR or mirrorless camera.

In the case of the ZWO ASI294MC Pro, my imaging camera, the gain varies between 0 and 400. However, increasing the gain reduces the camera's full-well capacity (maximum number of electrons a pixel can hold).

Setting the gain to zero yields the highest full-well capacity, but read noise is also high and not ideal for the task at hand. If I set the gain to the maximum value of 400, the readout noise is pleasingly low, but the full-well capacity is low. For lucky imaging, it's important to find a balance between high gain, low readout noise, and a reasonable full-well capacitance.

While there is no "set and forget" value that works in all conditions, ZWO recommends a gain between 100 and 150. With my ASI294MC, a gain of 120 works for most of my imaging needs.

Next, I'll set the exposure. Exposure time is based on the brightness of the object and the seeing conditions. You can gauge the seeing by watching a star near the subject you're targeting to monitor changes in its size and shape. In moments of good seeing it appears small and round, while in poorer moments it looks larger and more distorted.

In my experience an exposure time of 1 to 2 seconds has proven useful with my f/11 scope; telescopes with faster focal ratios like f/5 can utilize even shorter exposures of a half second or less as long as they produce an acceptable SNR.

HIDDEN IN THE GLARE Lucky imaging is also useful for revealing nebulosity close to bright stars. This image reveals the nebula IC 349 next to Merope in M45, the Pleiades. Typically this little knot of glowing gas is hidden by its proximity to the 4th-magnitude star. The author captured the image with thousands of short exposures recorded with his C14 and ZWO ASI294MC PRO camera.

HUBBLE IMAGE: NASA / ESA / A. HAJIAN (U. OF WATERLOO)

The better the SNR, the more clearly the object stands out from the background. This is achieved by stacking many short-exposure images to form a composite image. The SNR of an image increases in proportion to the square root of the exposure time or, equivalently, by the square root of the number of frames you stack. For example, 100 individual images increase the signal by 100, while the noise only increases by the square root of 100, or 10. Thus stacking 100 frames improves the SNR by 10×. A very large number of individual exposures are required to achieve a sufficiently high SNR. In lucky imaging, it isn't uncommon to stack 5,000 or more frames to produce an image.

In order to achieve that high SNR with short exposures, you should target bright, compact objects such as planetary nebulae, globular clusters, and some bright H II regions in nearby galaxies.

I typically set my camera to shoot 600 one-second FITS frames and repeat the process at least three times to ensure I have enough good frames to produce a composite image with an acceptable SNR.

Stacking the Results

Once you've recorded your frames, it's time to stack the best images. A lucky imaging session typically produces dozens of gigabytes of data. Although computer storage space is not an issue these days, the flood of data from thousands of individual images requires a special approach.

Each of the 16-bit FITS images recorded with my ASI294MC are 23 MB apiece. With 1,800 individual frames thats more than 40 GB! Classic deep-sky image-processing programs such as *PixInsight* aren't designed to deal with huge numbers of individual images. Fortunately, there is a good alternative that will at least stack the result for subsequent processing. I use the freeware *Autostakkert! 4* (**autostakkert.com**), a fast and free program written by Belgian imager Emil Kraaikamp for stacking lunar and planetary images; it also efficiently selects sharp deep-sky images. An overview of the program appeared in *Sky & Telescope*'s September 2016 issue, page 68.

Using *Autostakkert* to sort and stack images is easy. After starting the program, click the ***1) Open*** button and navigate to the folder containing all the images. Add your calibration frames (darks and flats) in the Image Calibration section at the top. Then select the color conversion setting in the "Colour" pulldown menu — ***Auto Detect*** often works well, though you may need to experiment to find the best match for your particular camera model.

Next, select ***Surface*** in the Image Stabilization section, then select a star to use as an image stabilization anchor; this same star will also be used to evaluate each image to be stacked. Click the ***2) Analyse button***, and the images will then be evaluated and automatically sorted in quality order from best to worst starting at the left of the "Quality Graph." This can take several minutes or longer, depending on the size of the images and the speed of your computer's processor.

▲ **EXTRAGALACTIC STAR FORMATION** As long as your target is bright enough, it can benefit from lucky imaging. This detailed result shows NGC 604, a starbirth region in spiral galaxy M33 in Triangulum, captured with the author's C14 and ZWO camera.

After the analysis, choose a percentage of frames to include in the ***Stack Options*** section. Select FIT as your output file format, then refer to the Quality Graph for guidance on how many frames to combine — typically, the point where the green line drops down sharply is where the worst images reside. When you've determined how many images to stack, input the value in the "Frame percentage to stack" area, click the ***3) Stack*** button. In several minutes, the process is complete.

Autostakkert! is exclusively a stacking program, so the composites it produces are best stretched and sharpened (or deconvolved) in other image-processing software such as *PixInsight* or *MaxIm DL* the same way you'd process any other deep-sky photo.

Conclusion

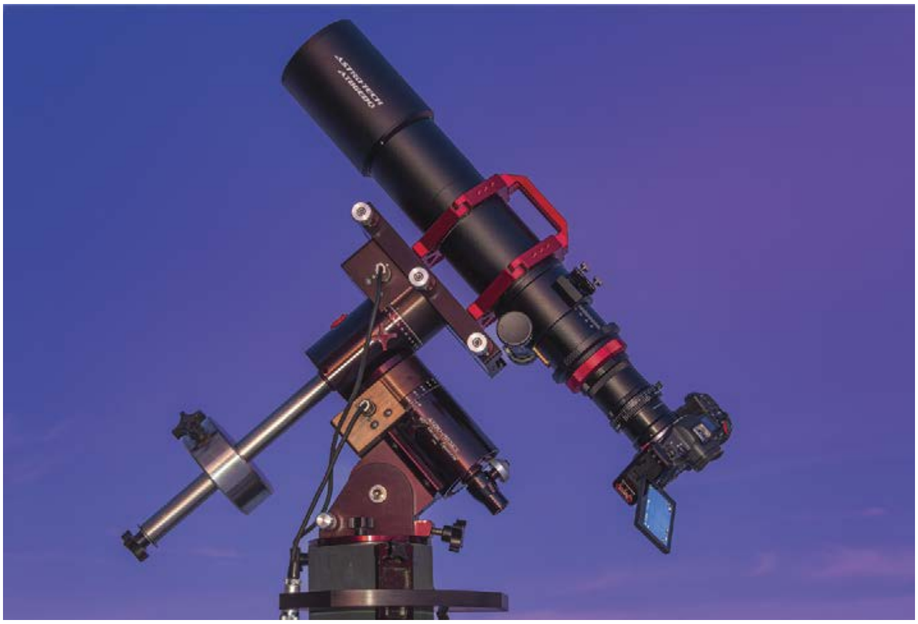
Lucky imaging is an effective method for producing high-resolution pictures of the brightest deep-sky objects. Using a long-focal-length telescope and a camera with small pixels with this technique resolves finer structures than often is possible with long exposures and autoguiding, especially under good seeing conditions.

While it cannot completely mitigate the effects of poor seeing, lucky imaging offers a great opportunity for imagers to record excellent detail in certain deep-sky objects, even under strong light pollution. And with the increasing sensitivity of the latest generation of CMOS cameras, even fainter targets can benefit from this novel technique.

■ **PETER BRESSELER** is a lifelong astronomy enthusiast who has discovered several galactic nebulae. Visit his website at **pixlimit.com**.

Astro-Tech's AT86EDQ f/7 Quad Refractor

Meet a small refractor that can just about do it all.



◀ The Astro-Tech AT86EDQ is suitable for use with any small equatorial mount, though the author did his testing with his venerable Astro-Physics AP400. The telescope is shown with the Askar Backfocus Adjuster used in some of the testing.

Astro-Tech 86EDQ

U.S. Price: $1,299 (as of early April 2025)
Optional ATEDQR 0.8× Reducer: $229.95
astronomics.com

What We Like

Excellent sharpness both visually and photographically

Superb focuser and fittings

What We Don't Like

Focuser does not rotate

Camera rotator lacks index markings

Difficult to thread filters into adapter

OKLAHOMA-BASED Astronomics has been busy in recent years. Through its house brand, Astro-Tech, the company has introduced several series of apochromatic refractors, each distinguished by its lens configuration and the type of glass employed.

The ED series is the entry level having doublet objectives but with some models using premium Ohara FPL-53 glass for one element. The EDL series offers large-aperture doublets, having one element made with Hoya's premium FCD-100 glass (an optical equivalent of FPL-53). The EDT refractors employ a triplet-lens design with a single element of Chinese FK-61 glass, similar to the better-known FPL-51 from Ohara in Japan, a step down from FPL-53. At the top of the line is Astro-Tech's premium EDX series triplet objective with one element of the highest grade FCD-100 glass.

In 2023 I tested the carbon-fiber tube version of the 90-mm EDX, the AT90CFT (*S&T:* Nov. 2023 p. 66) and found it superb both visually and photographically.

The EDQ Series

While all of Astro-Tech's previous refractors can be used photographically, they require the addition of an optional field-flattener lens to get the maximum corrected field. The new EDQ series does not.

As per the "Q" in the name, they are all four-element (i.e., quadruplet) using a single flattener lens made of ED glass mounted at the rear of the tube, in addition to the front triplet objective with one ED element of unspecified glass type.

The EDQ line includes 86-mm, 106-mm, and 126-mm models, all f/7 designs, but they can be converted to f/5.6 with the addition of the optional ATEDQR 0.8× reducer lens unique to the EDQ series.

I tested the first and smallest in the series, the AT86EDQ f/7 Quad Refractor with the optional reducer on loan from the manufacturer.

Mechanical Features

The focuser and fittings of the AT86EDQ are similar to those of the 90CFT I tested previously, suggesting they come from the same factory. The scope's tube has a handsome, anodized, matte-black finish which tends to emphasize fingerprints. Other components are anodized in glossy red. The felt-lined tube rings clamp on with large knobs that are easy to grip even when wearing gloves. The focuser itself doesn't rotate, so loosening the tube rings is necessary to turn the

ALL IMAGES ARE COURTESY OF THE AUTHOR

entire tube should you wish to orient the focus knobs at a different angle.

However, the focuser does have a solid camera-angle adjuster equipped with a large, glove-friendly locking knob. This rotator proved smooth and accurate and didn't introduce any focus shift or tilt when turned to any angle. Though intended for use with a camera, it also worked well for turning a star diagonal to a convenient viewing angle. Its only deficiency is the lack of a degree scale around its circumference to help setting a camera to the same orientation for multi-night shoots, or to frame segments of a mosaic accurately.

The large, 81-mm (3.2-inch) diameter rack-and-pinion focuser has a generous 85 mm of travel and locks down solidly. Even unlocked I found it didn't slide out of focus or slip when aimed straight up while carrying the load of a large 2-inch eyepiece and diagonal.

Unlike the rotator, the focuser includes index marks — handy for presetting focus. The unit's 10:1 dual-speed adjustment proved smooth and precise, with no wobble when unlocked, nor image shift when tightened. It has tension adjustment screws, but I never needed to touch them. While it can accommodate electronic motors, I did all my testing by manually focusing the AT86EDQ; the high quality of the focuser made that easy and accurate.

The scope's dew shield extends 95 mm from its retracted position, affording good protection on damp or frosty nights. While there's no locking mechanism, I never found it necessary; it always stayed put even when the scope was aimed high.

The faces of the tube rings are tapped with sets of M6 bolt holes for attaching other accessories. The flat surface of the top handle also has two M6 threaded holes, as well as a single ¼-20 hole.

The focuser has a single Synta-style finder bracket shoe, with bolt positions for adding one more. I feel at least two mounting shoes should be standard issue these days for mounting a guidescope and perhaps a control computer.

The focuser's camera rotator has female M69 threads on the camera side and accommodates a step-down ring with M63 female threads. That adapter, while narrow, is ribbed for a better grip — a helpful feature as it needs to be removed when using the reducer. While I never had it seize up, it can twist on quite tightly.

The included 2-inch visual back threads into the M69-to-M63 adapter ring. Out of the box, the AT86EDQ visual back is already installed and locked onto the focuser with three tiny 1.5-mm hex screws. Unfortunately, they had been tightened so firmly at the factory the screws gouged the adapter ring. Even with them removed the visual back was still stuck and took considerable force to twist off. (I encountered the same issue with the AT90CFT scope).

A set of camera adapter rings also comes with the AT86EDQ, and they, too, thread into the M69-to-M63 ring. That set of rings offers both M54 and M48 threads, two common sizes for cameras and T-rings. While the final M48 ring can accept 48-mm filters, threading one into the recessed fitting proved difficult.

Using the optional 0.8× reducer requires removing the M69-to-M63 step-down ring, as the large reducer has its own M69 male threads and screws directly onto the focuser.

While the reducer was said to come with its own adapter(s) to present M48 male threads to the camera, my sample

◀ The AT86EDQ weighs 5.2 kg (11.4 lbs) and is 46 cm (18 inches) long with the dew shield and focuser retracted. The dew shield can extend 95 mm to ward off moisture, while the focuser has 85 mm of travel to accommodate most eyepieces and cameras.

▲ *Left:* The telescope has only a single Synta-standard mounting shoe for accessories. The rings and top handle are tapped with M6 bolt holes to attach others. The red ring is the camera angle adjuster, fitted with a large lock knob. *Right:* The rack-and-pinion focuser has a large lock knob and accepts motorized accessories. The 24-cm-long Vixen dovetail bar has a slot and bolt holes for shifting the scope's position to balance a camera rig.

▲ The 2-inch visual back and its 1¼-inch insert use brass compression rings to hold eyepieces. A set of camera adapters is also standard. The adapters and the visual back thread onto the focuser's M69-to-M63 step-down ring.

▲ The optional 0.8× focal reducer has a 60-mm diameter lens and threads directly onto the focuser. It needs the step-down rings from the main adapter set to work with M54 or M48 camera nosepieces or T-rings.

▲ The triplet objective lens and internal flattener are thoroughly multi-coated. The blackened tube interior has five knife-edge baffles, and the focuser includes multiple ribs for additional stray-light suppression.

didn't. To use it I borrowed the M63-to-M48 rings from the scope's adapter set to complete the configuration needed to shoot at f/5.6.

If all that sounds a bit confusing, it was in practice, too, on a couple of nights when I tried to change shooting modes, only to find myself at a loss as to which adapters went where.

Optical Quality

With any telescope I test I like to have at least one purely visual night with it. This allows me to star-test the instrument and enjoy the simple pleasure of just observing, unencumbered by cameras, cables, and computers.

I observed with the scope on January 25, 2025, the evening of the internet-sensation "planetary alignment!" It was a chance to view three of the planets during a rare winter night of good seeing. Once the scope had settled down to the cold night air, planetary disks snapped into sharp focus. That "snap" is the first sign of good optics.

At 150×, using an Astro-Tech 4mm 82° UWA eyepiece, the North Polar Cap and Syrtis Major were clearly visible on Mars. Jupiter's dark belts showed hints of fine structure, and the Galilean moons were tight points of light. Venus presented a clean white crescent phase with no false color except for what the atmosphere contributed. There was no blue or magenta halo from chromatic aberration in the optics. While refractor purists might have some concern about the anonymity of the ED glass employed in the objective lens, it performed as well as any premium glass I've tested.

Pairing the scope with an Astro-Tech 20mm 100° XWA eyepiece yielded wonderful wide-field views of open clusters along the Milky Way, with stars sharp to the edges of the field. The Orion Nebula was superb, with the 3.3° field of the XWA framing all the nearby nebulosity and clusters.

On the rigorous star test at high power, Capella (viewed at 200× with a Tele Vue 3 to 6mm Nagler Zoom) looked textbook-perfect in focus, with a well-defined central Airy disk surrounded by a clean first diffraction ring coming and going and little in the way of extraneous fuzz or glow. Rigel clearly

▲ At its native f/7 (left) the EDQ has a focal length of 602 mm, yielding a field of 3.4° by 2.3° on a full-frame sensor such as the Canon R5 used for these test images. At f/5.6 (right) adding the 0.8× reducer widens the field to 4.2° by 2.8° at a focal length of 480 mm. Both images are stacks totaling about 50 minutes of exposures.

▲ At its native f/7 (on the left) the AT86EDQ presented sharp stars to the corners of the image with virtually no aberrations. At f/5.6 with the optional reducer (on the right), stars showed minor elongation and flaring at the extreme corners from residual tangential astigmatism. These are from single frames used in the final Orion images.

showed its 7th-magnitude companion 9.4″ from the brilliant primary star. Castor was cleanly split into its slightly unequal components 5.6″ apart.

Racking through focus on bright stars revealed extra-focal patterns that looked colorless and nearly identical inside and outside of focus. Very few scopes present perfect patterns in this sensitive test. The EDQ exhibited what looked like about ⅛-wave of spherical aberration from under-correction (judged against the diagrams in Richard Suiter's book, *Star Testing Astronomical Telescopes*). A telescope is considered diffraction limited if its optics are at least ¼ wave.

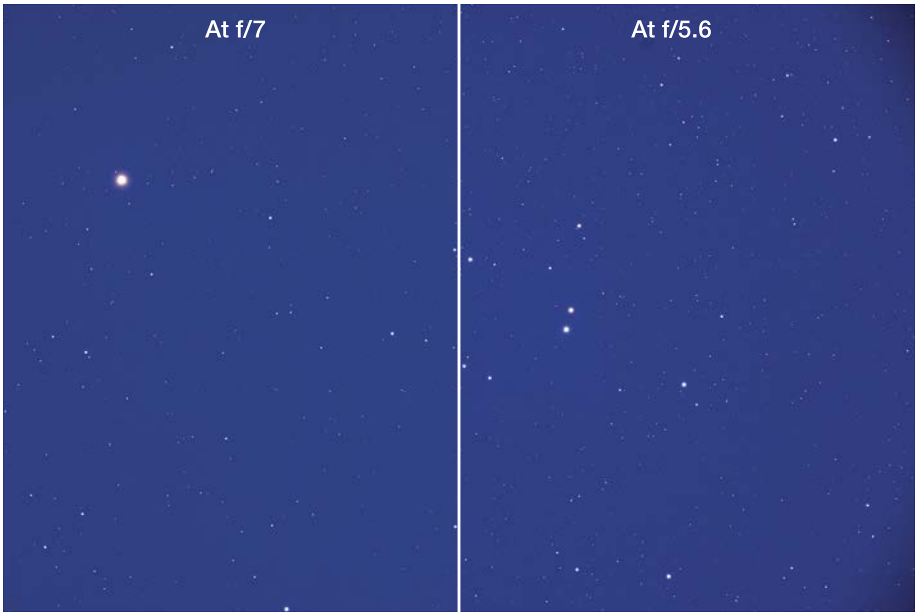
Thus, the AT86EDQ handily passed the star test, by a margin that matched or exceeded any telescope I've reviewed in recent years.

Imaging Performance

I shot test images with a Canon R5, a full-frame 45-megapixel camera with 4.4-micron pixels that should reveal even minor aberrations. At its native f/7 focal ratio, the AT86EDQ performed very well with no sign of astigmatism or color flaring in the corners of the frame. The internal flattener lens was doing its job.

The optional 0.8× reducer at $230 is just that, a reducer only, as the field is already flat. At pixel-peeping levels of enlargement, stars at the extreme corners showed slight elongation and flaring but you'd be hard pressed to see that under most circumstances. At f/5.6, the reducer offers the advantage of almost a full-stop faster photographic speed and a wider field of view, making it a good option for increasing the versatility of the AT86EDQ.

The quad optical design appears to be forgiving of backfocus (the distance from the optics to the sensor). One night I substituted the included



▲ In twilight test shots of the Hyades, field illumination at f/7 (on the left) was excellent, showing only gradual light fall-off across the outer half of a full-frame sensor. At f/5.6 (right) the reducer exhibited noticeable darkening at the corners.

16-mm-thick adapter ring for Askar's Backfocus Adjuster, also 16 mm thick, but that enables shifting the spacing by 2 mm in either direction. At either f/7 or f/5.6 I could see no significant ill effect from having the spacing too short or too long.

Only when spaced 2 mm from the recommended backfocus position could I see a slight bloating and elongation of stars at the corners. But only at f/7 — odd, as I thought the reducer would have been more sensitive to backfocus. Included with the telescope are 0.5-mm-thick and 1-mm-thick shims for adding spacing if needed to get your camera perfectly positioned. I didn't find them necessary.

I also recorded images during twilight to evaluate the scope's field illumination and fall-off. At f/7 the vignetting was minimal and gradual on a full-frame sensor, with no more than about a 10% drop-off at the corners. As often happens with reducer lenses, the vignetting with the 0.8× reducer at f/5.6 was more pronounced, producing noticeably dark corners with a 30% to 40% drop in brightness and a sharp decline. This is correctable with calibration or processing.

In all, the AT86EDQ worked so well that on a run of clear nights in January 2025, it was my telescope of choice for reshooting many of the Messier star clusters in the winter and spring sky — targets I hadn't photographed in a decade or more. A telescope passes muster when I decide to actually use it and not just test it.

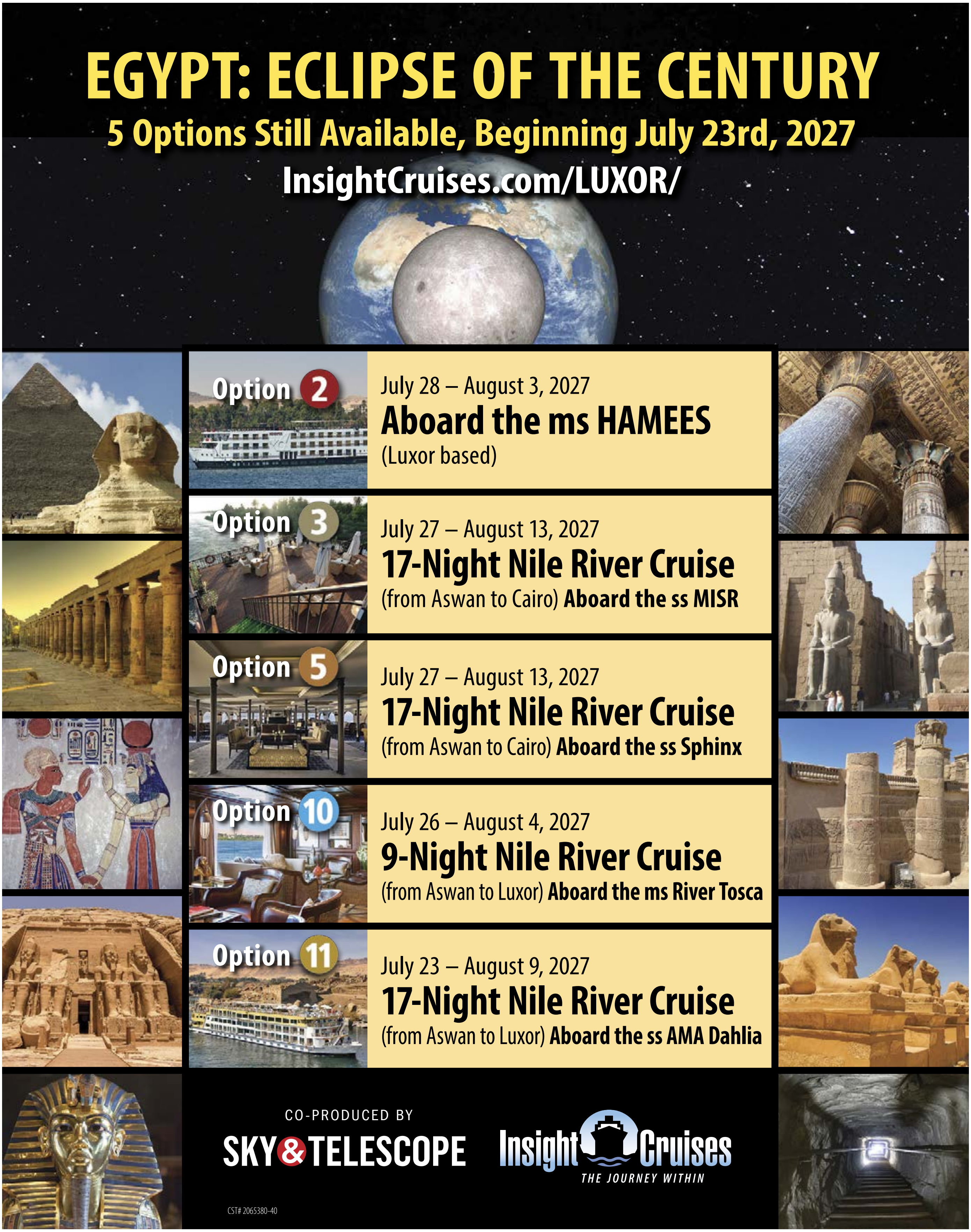
Recommendations

If you could take only one telescope to an island paradise, what would it be? The AT86EDQ would be one of my picks for a desert-island telescope. It can do it all. The scope offers enough aperture for pleasing views of the planets and bright deep-sky objects, while being small enough for grab-and-go observing. For astrophotography, it has a long enough focal length to work well on small, bright deep-sky targets, yet at the same time has enough speed and a wide enough field of view to capture large, faint targets.

I certainly enjoyed my nights out with the Astro-Tech AT86EDQ and can recommend it to beginners and advanced users alike.

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

▲ As shown at left, the AT86EDQ at f/7 with the standard camera adapters nicely frames large star clusters such as M38 in Auriga. The picture at right used the 0.8× reducer, which widens the field to also include M36 at bottom left. Both are stacks of about 90 minutes of exposures with a Canon R5.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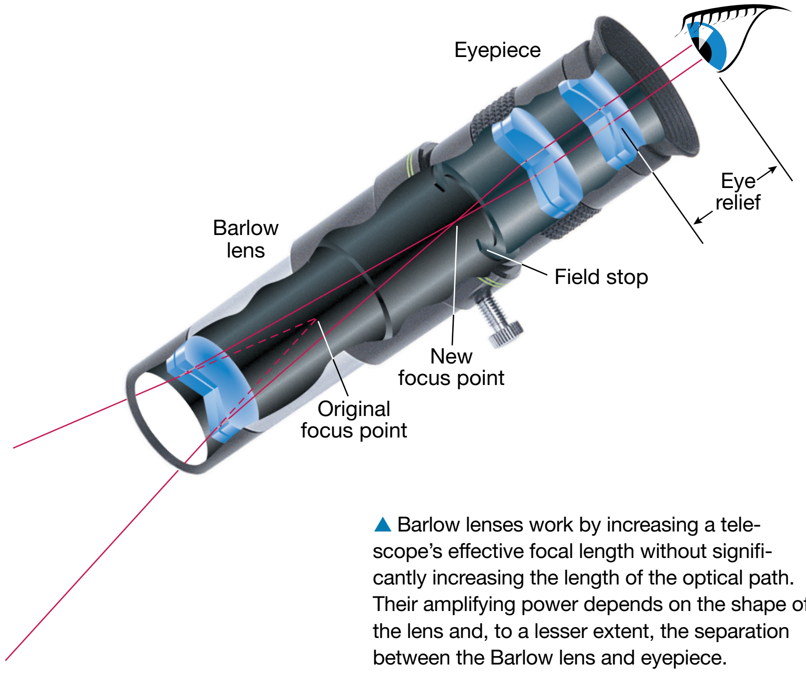
What Is a Barlow Lens?



▲ Barlow lenses work by increasing a telescope's effective focal length without significantly increasing the length of the optical path. Their amplifying power depends on the shape of the lens and, to a lesser extent, the separation between the Barlow lens and eyepiece.

AT THE MOST BASIC LEVEL, a telescope requires two things to show us distant objects. These are an *objective* (the main lens or mirror) to gather light, and an *eyepiece* to bring that light into focus. Eyepieces (sometimes called oculars) come in a variety of focal lengths, which changes the magnification of the targeted subject — a longer focal length produces less magnification than a shorter one. So if you want a good range of magnifications to employ with your scope, you'll need a bunch of eyepieces, right? Not really. That's where a Barlow lens (or just "Barlow") comes into consideration.

This simple device was invented by English physicist Peter Barlow in 1834. It consists of a tube containing a negative (concave) lens that diverges the light cone passing through it, effectively increasing the focal length of the objective and the magnification it produces. Barlow lenses are placed in a telescope's focusing tube, and an eyepiece is inserted behind it. The view is then magnified more than using the eyepiece alone. Also, using a Barlow generally improves the off-axis sharpness of the eyepiece — dramatically so if your telescope's objective has a short focal ratio (such as f/5).

For example, let's say you have a 20-mm eyepiece. Adding a 2× Barlow makes this eyepiece perform as if it had a focal length of 10 mm, thus doubling the magnification. But more than that, adding the Barlow increases the ocular's *eye relief* (the farthest distance your eye can be from the eyepiece and still see the entire field of view). This is a real boon when you're using short-focal-length eyepieces, which tend to offer reduced eye relief. But using a Barlow with some long-focal-length oculars places the exit pupil position well beyond the designer's intended position, compromising the view.

Barlows come in a variety of magnifications, typically 2× or 3×, though other values (and even models offering variable magnification) aren't unusual. With some planning, adding a Barlow to your collection effectively doubles how many eyepieces you have. The trick is to plan which focal lengths you own so that their magnification isn't repeated.

Let's say you own three eyepieces with focal lengths of 5 mm, 10 mm, and 20 mm. Adding a 2× Barlow makes the 20-mm eyepiece perform like the 10-mm used alone (though with a wider field and more eye relief), and the 10-mm eyepiece will perform like your 5-mm. Not particularly helpful! However, suppose you replace the 10-mm eyepiece with another whose focal length isn't in the mix, say, 13 mm. Then you'll have a good range of non-repeating magnifications. Another solution is to look for a Barlow with magnifying power that doesn't cause a repeat, such as a 2.25× model.

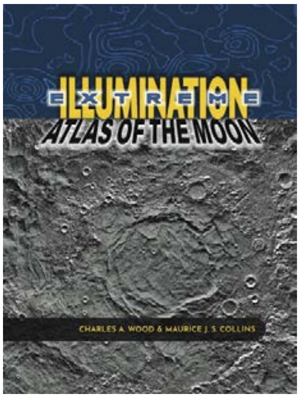
In addition, the magnifying power of a Barlow is affected by the distance between its lens and the eyepiece. Placing a Barlow at the front of a star diagonal strongly increases the Barlow's magnifying power compared to placing it behind the diagonal.

Most every eyepiece manufacturer also offers good-quality Barlows or similar accessories. For example, devices produced by Tele Vue and Explore Scientific (called Powermates and Focal Extenders, respectfully) perform like a Barlow but are designed with additional elements that preserve the eye relief of the inserted eyepiece. Changing the distance between these lenses and the eyepiece doesn't vary the magnification as it does with a standard Barlow (with the exception of the 5× models).

Finally, does your telescope have a 2-inch-diameter focuser? If so, you might be tempted to buy a 2-inch Barlow (instead of one with a 1¼-inch barrel). However, this bigger Barlow might be overkill if you're using only 1¼-inch eyepieces to observe visually. Instead, the larger diameter offers the most benefit if you're using your telescope for astrophotography.

A Barlow lens or focal-extender is an excellent accessory that can virtually double the number of eyepieces in your collection at a fraction of the expense of several additional oculars. ■

GREGG DINDERMAN / S&T



▲ ILLUMINATION ATLAS

S&T Contributing Editor Charles A. Wood teams up with Maurice J. S. Collins to publish *Extreme Illumination Atlas of the Moon* ($60). This unique atlas examines the lunar surface using NASA's Lunar Reconnaissance Orbiter's digital elevation measurements to envision the topography of the Moon's surface illuminated from low angles. With it, Wood and Collins present our nearest neighbor with uniform, raking light from multiple directions. Following the introduction, the atlas presents 12 pages of hemispherical maps, each with the direction of illumination noted and a smaller plot of the lunar basins located in each region. An additional 90 plates focus on each basin in detail, again using multiple lighting angles. A closing section highlights other features worthy of closer scrutiny. 8½-by-11 inches, hardcover, 182 pages. ISBN 9798323588909.

Extreme Illumination Atlas of the Moon
Available through Amazon
https://is.gd/illuminationatlas

▲ BACKYARD DOME

British observatory manufacturers Pulsar Observatories, in partnership with Explore Scientific, now offers a complete observatory dome kit for North American amateurs. The Pulsar 2.7m Full Height Observatory Dome Kit ($12,000) contains all the parts to assemble a 2.7-meter (8.9-foot) glass-reinforced-plastic telescope dome. The sectional structure is 2.7 m tall when fully assembled and has a 0.7-m slit and 1.7-m wall panels that are easy to assemble. Its door is approximately 1.2-by-0.7 m and includes a high-quality locking system. The building can comfortably house telescopes of apertures up to 16 inches. The kit includes both the automation-ready Pulsar remote shutter drive and Pulsar dome drive, as well as an induction charger for power storage. Price includes shipping in the lower 48 states.

Pulsar Observatories
Available in North America from **Explore Scientific**
1010 S. 48th St., Springdale, AR 72762
866-252-3811; explorescientific.com

◀ UPDATE YOUR BISQUE MOUNT

Robotic mount manufacturer Software Bisque now offers upgrades for older Paramounts. The MKS 6000 Upgrade (starting at $1,825) lets users step up to the latest electronics in their existing Paramount MYT, MX+, MX Classic, ME Classic, and ME II models with either motor-based or on-axis encoders. The upgrade kit includes built-in Ethernet and Wi-Fi along with USB Type C communication ports, as well as improved through-the-mount power solutions to accommodate higher amperages. Users can install the kit themselves, or ship their mount to the Bisque factory at additional cost. Owners can also opt to receive a new shipping box and packing material for your equatorial head for the trip to the factory.

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A Cherried-Out Refractor

An old tree becomes a beautiful telescope.

▲ Jim Vach's beautiful refractor is made from a Surplus Shed 80-mm lens and the trunk of a cherry tree he planted 24 years ago. The padauk veneer at left will eventually become the dew shield.

TWENTY-FOUR YEARS AGO, Wisconsin ATM Jim Vach planted a cherry tree. It was a good producer for many years, but it eventually fell victim to a fungus. So Jim bought some new root stock, grafted a piece of the old tree onto the new stock, and cut down the diseased tree to prevent the fungus from spreading.

About that same time, he bought an 80-mm f/5 doublet objective lens from Surplus Shed (**surplusshed.com**). Jim is a woodworker, so combining the two seemed like an obvious next step.

Before the physical work started, however, Jim needed to know just how long to make the scope body. That led to a series of emails between us about finding the exact focal length of a lens, the length of the focuser, the light path of a diagonal, etc. Those emails eventually became the basis for my article on building refractors in the November 2024 issue (page 60).

Once Jim knew how long the tube needed to be, he took a section of the trunk about 15 inches long and sawed it down to a rectangle about 12 inches long and 4½ inches squarish, just small enough to fit into his lathe. He sank a heavy bolt or screw into one end to fit into the chuck and drilled the other end for the live center which he mounted in the tailstock. That let him spin the log and round it into a smooth cylinder.

Once it was roughed to a diameter of 4¼ inches, he filled the big cracks with a mixture of sawdust and superglue, then filled the hairline cracks with straight superglue to bind them together and prevent further cracking. He then turned it on down to $4\frac{3}{16}$ inches. Next he applied a rich walnut stain that would hide the crack and split repairs.

At this point the first big obstacle arose: The log couldn't be hollowed out in one piece, at least not on Jim's lathe. He'd have to cut it into two shorter sections and join them with a cylindrical mortise-and-tenon joint. A little more math led him to cut the log into sections that were 5 inches long and slightly more than 4 inches, which he figured would allow for the joint, the socket for the objective lens, the focuser, and star diagonal while still leaving room for error.

▲ *Left:* Jim started with a 15-inch piece of the cherry tree's trunk. *Middle:* he bored out the log on a lathe. *Right:* The telescope tube had to be worked on in two pieces for stability on the lathe. Jim made a cylindrical mortise-and-tenon joint to fasten the two sections together.

JAMES VACH (4)

The next steps were "facing" the ends to ensure that they were perfectly perpendicular to the axis of rotation, then hollowing out the cylinders. That couldn't be done with a center support on the working end, so Jim had to grip the cylinders in the chuck on one end and hope it would hold tight. He then carefully carved out the insides, boring the larger section to a diameter of 90 mm and the smaller section to 82 mm, the size of the rack-and-pinion focuser. Both pieces were bored from both ends, meeting inside.

He made a plug to fit snugly inside the larger tube so the jaws of the chuck wouldn't crush it while he bored out the socket for the lens cell. He mounted the cell backward (after flipping the lens around) in order to provide more support for the wood and better attachment options. Then he flipped the tube around and cut the matching socket and tenon where the two tube sections would be joined. Of this process, Jim wrote, "Nothing hard . . . just soooo many chances for something to go terribly wrong."

But things went beautifully right! Nothing broke, nothing flew across the shop, and the two pieces fit like magic when he slid them together. A little glue, and they were mated for life. Five coats of clear, glossy polyurethane spar varnish later, the tube was finished, and the scope was ready for assembly.

Jim lined the tube with black flocked paper to eliminate reflections. He mounted the focuser and a solid aluminum dovetail that also added strength to the tube to discourage warpage. A sewer pipe end cap painted black made a perfect lens cover, and another cap with the end cut out will anchor a dew shield made of beautiful padauk veneer, which is still under construction at the time of this writing.

The entire OTA weighs only 1 kilogram (2¼ pounds). It's the perfect grab-and-go telescope, when it's not sitting proudly on display as a work of art in its own right.

■ Contributing Editor **JERRY OLTION** has made one pretty telescope, but nothing like this.

TWILIGHT COMET
César Briceño
Comet ATLAS (C/2024 G3) impressed observers with several long, broad dust tails as it cut through southern skies earlier this year. Several artificial satellites are visible as streaks right alongside the comet as seen above Andacollo, Chile, on January 24th.
DETAILS: *Canon EOS RP and 85-mm lens. Total exposure: 30 seconds at f/2.8, ISO 1600.*

◁ TOTALITY'S END

Eric Africa

The eclipsed Moon above West Chester, Ohio, sported bands of white, orange, and red during totality on March 14th. This color-and-darkness gradient hints at the shape of Earth's shadow with the lightest area being closest to the edge of the umbral shadow and the darkest area near its center.

DETAILS: *Astro-Physics 92-mm Stowaway APO refractor and Canon EOS Rebel T6i camera. Stack of multiple exposures of a few seconds at ISO 400.*

▽ ECLIPSE TIMELINE

Philippe Moussette

This composite image recorded from Quebec City, Quebec, combines exposures of the Moon at seven intervals throughout the eclipse of March 14th. Note the color gradient slowly changing orientation as the Moon plunged through Earth's shadow.

DETAILS: *Canon EOS R3 camera and Canon RF 600-mm lens. Composite of several exposures each less than a second at f/4, ISO 200-800.*

▷ SPECKLED CRATERS

Ulli Lotzmann

The highlands around the center of the lunar nearside hold a diverse collection of impact craters. The largest of these features are Ptolemaeus (upper left), Alphonsus (center left), Arzachel (bottom left), and Albategnius at center.

DETAILS: *CFF Telescopes 16-inch Classic Cassegrain and ZWO ASI 678MM camera. Composite of multiple exposures through longpass filter.*

▽ SMOKY GALAXIES

Dave Doctor

Reddish dust lanes and star-forming regions swirl through the arms of M51, a grand-design spiral galaxy. Gravitational interactions between M51 and the dwarf galaxy NGC 5195 have left immense clouds of unresolved stars in their wake as the smaller galaxy passes behind the spiral.

DETAILS: *Orion Optics AG14 Newtonian astrograph and QHY QHY268M camera. Total exposure: 23 hours through LRGB filters.*

DUSTY CORONA AUSTRALIS

Fernando Menezes

The Corona Australis Molecular Cloud is a large swath of dust and gas lit by several bright stars including Alpha (bottom), Gamma (center left), and Epsilon (top) Coronae Australis. The two bluish reflection nebulae at top are NGC 6726-7 and IC 4812, with globular cluster NGC 6723 just above the pair.

DETAILS: *Sky-Watcher Esprit 150ED refractor and ZWO ASI6200MC Pro camera. Mosaic of six frames each a stack of 100-200 exposures.*

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Ad Index

Event Calendar

Here's the info you'll need to "save the date" for some of the top astronomical events in the coming months.

June 13–15
SOLAR ECLIPSE CONFERENCE
Leuven, Belgium
www.sec2025.be

June 19–22
CHERRY SPRINGS STAR PARTY
Coudersport, PA
cherrysprings.org

June 21–28
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GrandCanyonStarParty

June 24–29
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

June 25–28
ASTROCON
Bryce Canyon National Park, UT
https://is.gd/astrocon2025

June 25–29
GOLDEN STATE STAR PARTY
Adin, CA
goldenstatestarparty.org

June 25–29
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 25–29
YORK COUNTY STAR PARTY
Susquehannock State Park, PA
yorkcountystarparty.org

June 26–28
BRYCE CANYON ASTRO FESTIVAL
Bryce Canyon National Park, UT
https://is.gd/brca_astrofest

July 20–25
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

July 22–26
WASHINGTON STATE STAR PARTY
Waterville, WA
tmspa.com

July 24–27
STELLAFANE CONVENTION
Springfield, VT
stellafane.org/convention

August 16–24
MT. KOBAU STAR PARTY
Osoyoos, BC
mksp.ca

August 20–24
SASKATCHEWAN STAR PARTY
Maple Creek, SK
sssp.saskatoon.rasc.ca

August 20–25
NORTHERN NIGHTS STAR FESTIVAL
Palisade, MN
mnastro.org/events/northern-nights

August 22–24
NOVA EAST
Smileys Provincial Park, NS
novaeast.rasc.ca

• For a more complete listing, visit https://is.gd/star_parties.

Fun with Photons

The author uses light-travel times from celestial objects to enliven his community engagement.

▲ Children at an astronomy outreach event marvel at how long it takes the light to travel from stars and planets to their eyes. You, too, can explore a variety of engaging ways to keep your audience's attention.

ANYONE WHO HAS engaged in astronomy outreach has probably found that while the general public is interested in the subject, relatively few individuals dive deeply into night-sky adventures. Even fewer keep records of their observations or build their own telescopes. All the more important, then, to help young people capture an early interest in astronomy that can then develop for the rest of their lives.

Years ago, a wonderful third-grade teacher asked me to help her with a lesson in astronomy. I had the privilege of giving a classroom presentation, followed by an actual hands-on star party at which I and fellow Royal Astronomical Society of Canada members set up telescopes. The students, along with their siblings and parents as well as their teachers, got to experience the wonders of the night sky first-hand.

> Contemplating photons' travel time from celestial object to eyepiece is a fun way to share astronomy.

But my first challenge was to engage the 9-to-10-year-olds' latent interest in astronomy during the classroom session. I started by asking the students to turn toward their classmates who were seated by the windows: "We're looking *out* at Fred and Margaret over there aren't we?" The students agreed, nodding "yes."

I wanted them to dive into this deeper. So, I continued, "However, think about it this way. An unbelievable number of photons of light continually buzz in the interior of the Sun, and when some of them — a lot of them, in fact — reach its surface, they escape into space. Some of those photons are headed in our direction and take about 8 minutes to get here at the speed of light. Now, they're traveling through the window into our classroom and bouncing off Fred and Margaret over there, and then they come into our eyes so we can 'see' our classmates. So, those photons that were part of the Sun have actually become part of us, making each one of us a real part of the universe." From there, the students' imagination did the rest.

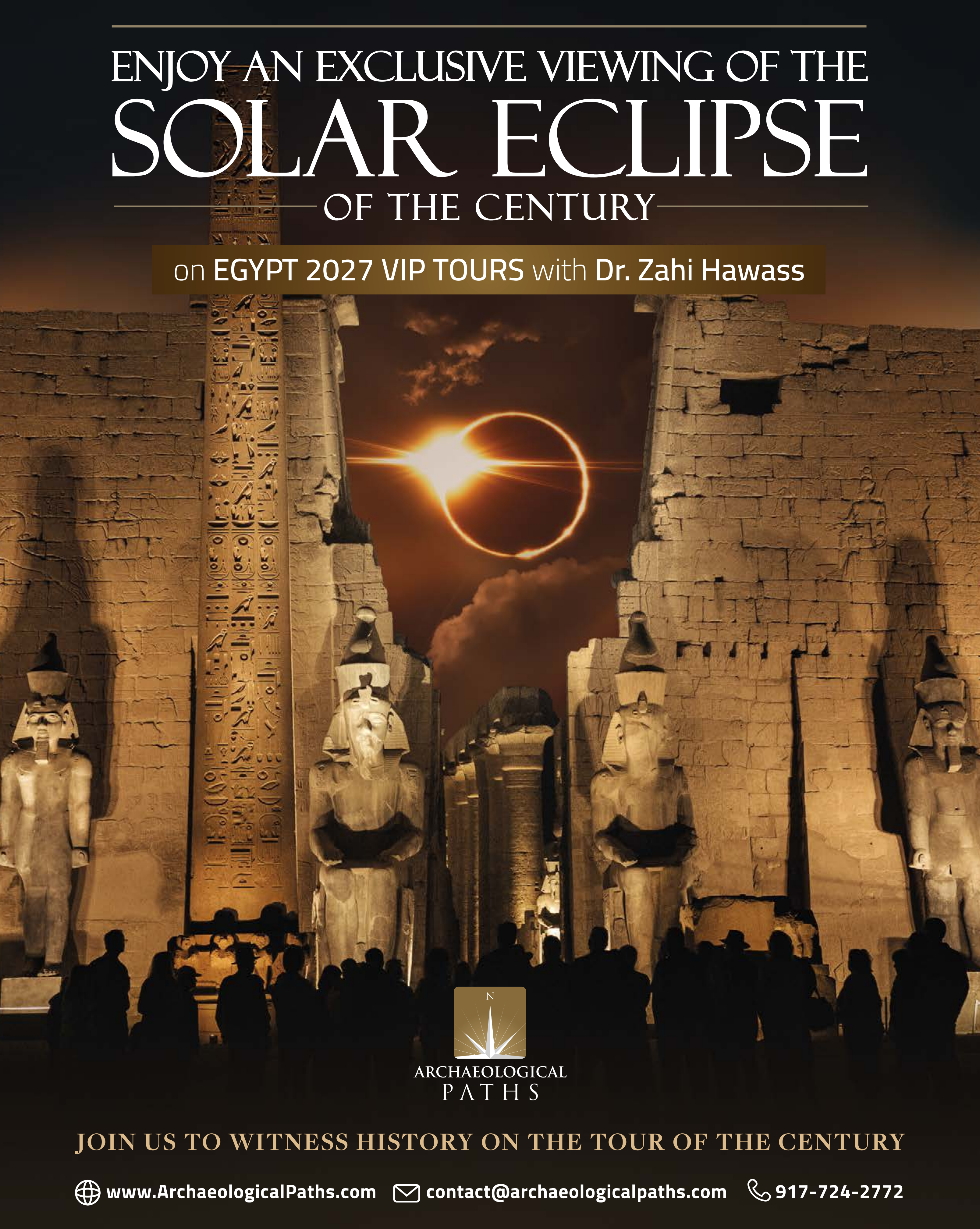
I knew we were going to be able to observe Uranus during the star party. I thought it would be exciting to explore ahead of time what would be happening when we looked at the planet through a telescope. This prompted me to explain that the photons had a much longer way to travel from the Sun all the way out to Uranus than they did to reach Earth . . . almost 3 billion kilometers in all. "Our photons will take two hours and 40 minutes to travel from the Sun out to Uranus, reflect off its surface, then they spend another two and a half hours hurtling toward Earth at the speed of light. They then travel down the tube of the telescope, bounce off the mirrors, and make their way through the eyepiece and into our eyes."

This, of course, led to classroom discussions of other, even more mind-boggling observing experiences as we explored the stories of other photons that our eyes would be welcoming. We started with Virgo's brightest star, Spica. Its light would have left the binary-star system while the Boston Tea Party was taking place, more than 250 years ago! And the photons from the red supergiant Antares, in Scorpius, would have left before Christopher Columbus embarked on his historic voyage across the Atlantic!

I was lucky to have the opportunity to repeat the experience for several years afterwards. It was a fun way to learn how to make the enjoyment of astronomy a personal, hands-on experience — not just for the kids but for the presenter and the other club members operating their telescopes, too!

And that's what astronomy is all about, Charlie Brown.

■ **DAVE GAMBLE** has been fascinated by astronomy since its current photons left Regulus. He enjoys everything astronomy-related, from imaging to building telescopes as well as observing.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