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SKY & TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY
AUGUST 2025

SPOTLIGHT ON JUPITER

STORMS, MOONS, AND A DANCE WITH VENUS

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SKY&TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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ON THE COVER

Hubble image of Jupiter and its spots, Aug. 25, 2020

PHOTO: NASA / ESA / STSCL / A. SIMON (GSFC) / D M. H. WONG (UC BERKELEY) / OPAL TEAM

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Jupiter's Turn to Shine

IN LAST MONTH'S COLUMN, I touched upon the importance of outreach and the value of the inspirational factor of astronomy. This month, I find myself with more to say on the matter — and brace yourselves, for I'm sure this won't be my last foray into the subject.

Astronomy aficionados come from all walks of life, but we often have a shared experience that unites us: At some point, a life-changing moment drew us into the wonderful world of astronomy. More often than not, it's our first glimpse of something through a telescope. Many of us have a vivid recollection of seeing that something through the eyepiece for the very first time and recognizing it from so many coffee-table books or issues of *Sky & Telescope*. And we've all had the same reaction: That thing *looked 3D*!

▲ Jupiter is in the spotlight this month.

The "aha-moment" object could have been Saturn, as it has been for so many (including me!), or the Moon's craters. But for others, the pivotal moment in their astronomical journey was seeing Jupiter's bands and the Galilean moons "up close" for the first time. We're tapping into that aha-moment this month, with big Jove as the star of this issue.

The term "Galilean moons" invokes Galileo Galilei, of course, who saw the planet's four largest satellites circling Jupiter in 1610. But you might be surprised to learn who bestowed their individual names by which we know them today. (Certainly Galileo would be.) That's all outlined for you in the article by Contributing Editor William Sheehan starting on page 20.

It's impossible to think of Jupiter without conjuring up that sloshy, stormy swirl that we know as Jupiter's Great Red Spot. How can it have lasted for so long? Why is it shrinking? (Yes, it's shrinking.) Will it — to our collective horror — vanish completely? Read all about this in Amy Simon's article on page 14.

Beginning on page 46, Consulting Editor Gary Seronik and Contributing Editor Bob King comprehensively cover the close conjunction of Jupiter and Venus on the morning of August 12th. The conjunction might end up being a consolation prize (but what a prize it will be) for a disappointing Perseid meteor shower this year. But don't let the latter deter you — the sight of the two bright planets less than a degree apart will surely work as a wow factor for inspiring friends and family.

To help us pull all this marvelous content together, we're welcoming Edwin Aguirre back into the folds of the *Sky & Telescope* family. (Although, once you're here, you never really leave.) He joins us as Associate Editor, and we couldn't be more thrilled. Longtime readers might recognize his name, for Edwin was an editor here from the mid-1990s through the mid-2000s. Welcome back, Edwin!

Diana

Editor in Chief

SEAN WALKER

Editorial Correspondence
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Subscription Rates:
U.S. and possessions: $59.46 per year
Canada: $75.38 (including GST)
All other countries: $91.29, by expedited delivery
All prices are in U.S. dollars.

Customer Service: Magazine customer service and change-of-address notices: skyandtelescope@omeda.com
Phone toll-free U.S. and Canada: 800-253-0245
Outside the U.S. and Canada: 847-559-7369
Mailing address: *Sky & Telescope* Magazine, P.O. Box 219, Lincolnshire, IL 60069-9806, USA

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Remembering the Boks

◀ Bruce Weaver, an alumnus of the University of Arizona, fondly recalls Bart Bok's lectures on Galactic Structure and Dynamics.

I enjoyed reading Klaus Brasch's "Bart and Priscilla Bok: A Galactic Love Story" (*S&T:* Mar. 2025, p. 28). Bart and Priscilla were strong supporters of the Monterey Institute for Research in Astronomy (MIRA) from its very foundation in the early 1970s. At Priscilla's suggestion, the Boks donated their entire personal library of astronomical journals, stretching unbroken from the 1940s to Bart's death. These became the nucleus of MIRA's Priscilla Fairfield Bok Library.

We honored our relationship with the Boks in a special memorial edition of the *MIRA Newsletter* (**https://is.gd/PFBok**), which included "A Brief Memorandum About the Life and Career of Priscilla Fairfield Bok, 1896–1975" by Bart Bok. Bart includes a picture of himself seated on the memorial bench that he established at the Arizona-Sonora Desert Museum in Tucson in Priscilla's name.

The bench was considered lost for a while, but my wife and I rediscovered it in the aviary. The bench is decorated with impressions of galaxies, but the plaque, on the side of a support, is difficult to locate. Next time you visit the museum, you might rest a bit on the bench and contemplate their "Galactic Love Story."

Wm. Bruce Weaver
MIRA Director
Marina, California

The March 2025 issue's article on Priscilla and Bart Bok was a blast from the past. As a University of Arizona undergraduate majoring in astronomy in 1973, I had the pleasure of knowing Bart Bok. I cherish the memory of the time he yelled at me to keep the classical music down in the Raymond E. White, Jr. telescope dome, as I wiled away the nights on the 21-inch scope instead of going to class.

I later changed my major to geology, because it involved less math and better pay. Thank you for the trip down memory lane.

Charles D. Sheldon
O'Fallon, Missouri

Klaus Brasch's fine article accurately reflects Bart and Priscilla Boks' lives and astronomical contributions. However, there is an apparent error that should be corrected.

Bart did not continue to advocate for construction of the 2.1-meter (84-inch) Kitt Peak National Observatory telescope after his arrival in Tucson, Arizona, in 1966. It was fully operational by September 1964, a few months after I joined the observatory's staff as a new PhD.

Stephen P. Maran
Chevy Chase, Maryland

The Sun Sets on NEOWISE

It was a pleasure to read Amy Mainzer's "Farewell to NEOWISE" (*S&T:* Apr. 2025, p. 12). Mainzer's public outreach efforts are widely appreciated: "No way! A dog star? You can't be serious" (from the *Ready Jet Go!* kids TV series). The Wide-field Infrared Survey Explorer and its reincarnation NEOWISE, clearly encompassed a broad array of research interests, spanning from an infrared sky survey to asteroids.

Apparently, mission and mission-extension funding for the discovery and study of potentially hazardous asteroids is not a high priority for NASA, and this lack of commitment seems to have presented recurring challenges for the NEOWISE mission. Going forward, one may only hope future research efforts are not stymied by the current draconian climate of budget-cutting emanating from the nation's capital.

Raymond G. Gregory
Sarasota, Florida

Your April issue was excellent — with the two articles "Farewell to NEOWISE" and "Black Holes from the Dawn of Time" (*S&T:* Apr. 2025, p. 34) being particularly noteworthy. The author of the latter article, Camille Carlisle, continues to be an exceptional writer for your magazine. Both articles were written in such a way as to be readily understandable by someone who's not a scientist — a real achievement considering the complexity of the topics discussed.

Chris Skillern
San Diego, California

Alphabet Soup

Great article by Camille Carlisle, but PBH? In a world of MACHOs and WIMPs, is it any wonder that we haven't found any primordial black holes? If you were called a PBH, would you want to be found? Perhaps, we would have better luck if we called them something more interesting like "baby universe gravitational singularities" (BUGS).

Sandy Steier
Monsey, New York

Rising Raisins

I enjoyed the "Seeing Red" letters by Einar A. Berger and Richard High as well as Monica Young's replies (*S&T:* Mar. 2025, p. 6). Indeed, raisins in dough provide an instructive analogy. It remains puzzling to me, though: Why don't the raisins expand, too?

As Charles Misner, Kip Thorne, and John Wheeler note on page 719 of *Gravitation*, the student first accepts expansion, then asks: What about the expansion of the Sun-Earth distance, of a meter stick, of an atom? They explain that expansion only occurs on distance scales where the universe is homogeneous, like between clusters of galaxies. Why this is true eludes me. Though, I confess I haven't diligently tried to understand the prerequisite general relativity.

Bob Wieting
Simi Valley, California

Monica Young replies: *The statement "space expands" seems like it ought to apply to all space, including the space between atoms or planets or stars. However, at smaller scales, there is enough mass (gravity) to prevent expansion. Even on the scales of galaxies, there's enough gas and dark matter in addition to the stars to prevent expansion. It's on larger scales — or in emptier regions of space known as cosmic voids — that expansion occurs.*

Radio Telescopes at Home

I was pleased to read "The Itty Bitty Radio Telescope" by Jerry Oltion (*S&T:* Mar. 2025, p. 72). Since I live in an urban area, it's difficult for me to observe the Milky Way with my eyes, and stargazing has been challenging. However, with this radio telescope, I should be able to experience the presence of the Milky Way by detecting the radio waves emitted by hydrogen.

I'm in the process of gathering the equipment needed to receive 2.4-GHz radio waves. I'm so excited to begin!

Kanto Miyazaki
Nishitokyo, Japan

Eros Encounter

Roger Sinnott's "Winking Star" (*S&T:* Mar. 2025, p. 7) brought back memories for me. In England, the meeting of Eros and Kappa Geminorum was a close flyby rather than an occultation. I observed it with the rest of the Oxford University Astronomical Society at St Catherine's College through an 8-inch reflector. A few years ago, I wrote a short piece in a newsletter about how I became interested in astronomy and mentioned this flyby. Christopher Taylor of the Hanwell Community Observatory in Oxfordshire immediately realized that we must have seen it together, as we both mentioned it in our observing logs. He passed away in December 2024, a sad loss to both astronomy and the history of astronomy.

Peter Morris
Upminster, England

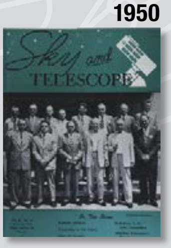
FOR THE RECORD

- Atoms don't have rotational or vibrational states, so they can't store energy that way — only molecules do and can, contrary to page 37 of the August 2024 issue.
- The high-resolution view of galaxy cluster Abell 426 on page 33 of the May issue is 31½ arcminutes across, not arcseconds.
- The weight of iOptron's HAE16C Hybrid Mount listed on page 68 of the May issue is incorrect. The equatorial head weighs 2.6 kg (5.7 lbs).

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

August 1950

Dustfree Galaxies "Some years ago it was found that galaxies occurring in dense clusters were systematically different in nature from isolated galaxies. If the latter are shaped like flat disks, as is our own Milky Way, they almost always contain gases and tiny solid particles drifting about between the stars. [But] practically none of the flattened galaxies observed [in dense clusters] have any appreciable amount of interstellar matter, no obscuring clouds are seen, and the very luminous relatively 'young' stars do not exist.

"Dr. Lyman Spitzer, Jr., [and] Dr. Walter Baade . . . suggest that this lack of interstellar matter in cluster galaxies is a direct result of collisions between galaxies. . . . Galaxies like our own, which are not in compact clusters, have had few, if any, collisions and have been able to retain their interstellar matter."

August 1975

Sun's Shape "At the University of Arizona, Henry A. Hill [and collaborators] recently announced very precise measurements of the shape of the sun [and conclude] it is indistinguishable from a sphere. . . . This finding contradicts the result announced in 1967 by R. H. Dicke and H. M. Goldenberg at Princeton University, which indicated a slight but definite oblateness . . .

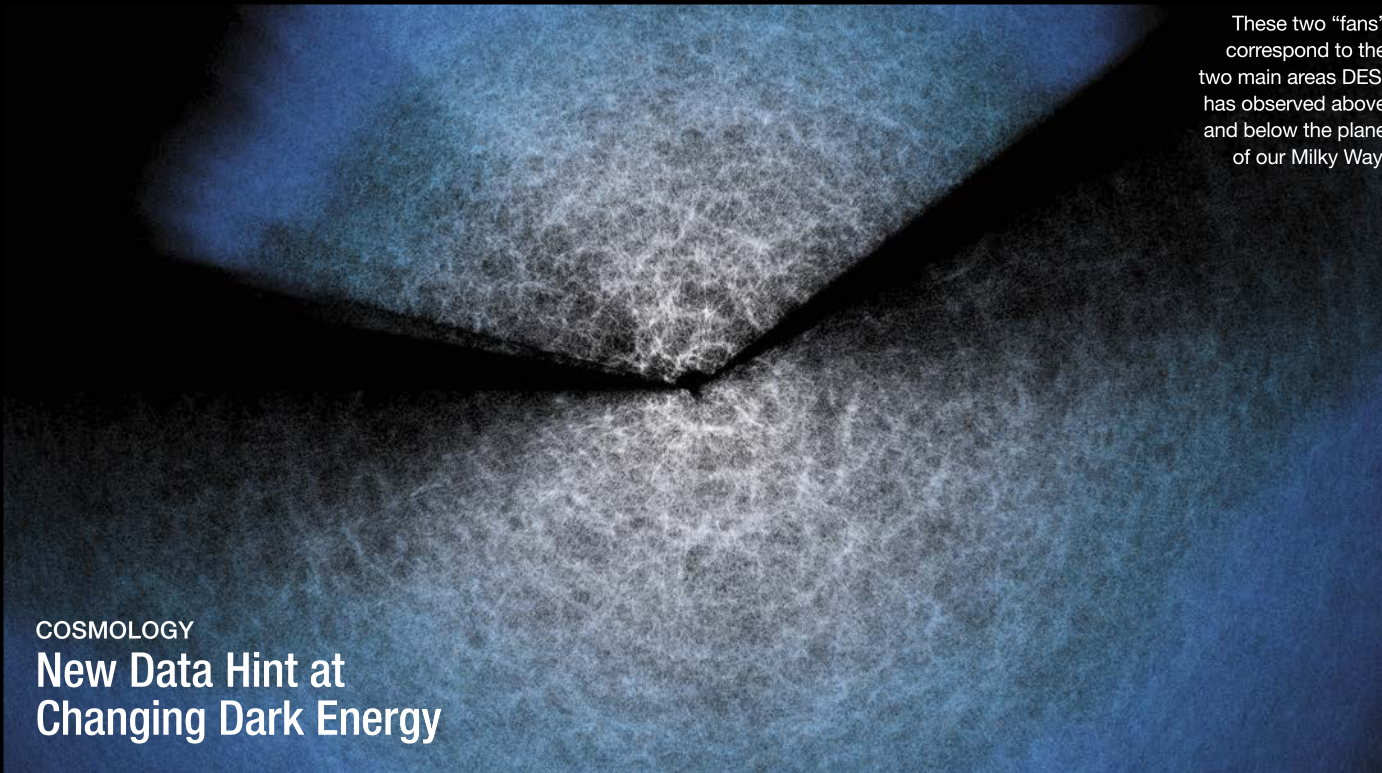
"Small though this discrepancy may appear, it is of fundamental importance. If Hill is correct that the sun is round, then Einstein's 1915 theory of general relativity is intact and does not require replacement by an alternative theory proposed by Dicke and C. Brans in 1961."

Spacecraft in 2004 and 2011 found that the Sun's equatorial radius is only 0.008 arcsecond greater than the polar, far less than Brans-Dicke predicted. Studies continue to attempt to explain this value, given the Sun's rotation rate and internal mass distribution.

August 2000

Lost and Found "Minor planet 719 Albert, discovered in 1911 and then not seen for 89 years, has just turned up as a 22nd-magnitude speck of light in western Virgo. Jeffrey A. Larsen and colleagues, using the 0.9-meter Spacewatch telescope at Kitt Peak, Arizona, found the slowly moving object on CCD images . . . But the first person to recognize it as a long-lost echo from astronomical history was Gareth A. Williams [of the] Minor Planet Center in Cambridge, Massachusetts.

"[Williams] came within one minute of issuing a routine electronic circular for the new object he called 2000 JW_8. Then he proofread the orbital elements he'd just calculated. 'This looks a little like Albert,' he muttered aloud. 'This looks a *lot* like Albert!' He quickly made a definitive linkage, scrapped the preliminary circular, and ran across the hall to show the results to the center's director, Brian G. Marsden. They announced Albert's recovery on IAU *Circular* 7420 that evening."



These two "fans" correspond to the two main areas DESI has observed above and below the plane of our Milky Way.

COSMOLOGY

New Data Hint at Changing Dark Energy

THE LARGEST 3D MAP of the universe yet shows hints that dark energy might be weakening over cosmic time. If true, it means that our most trusted cosmological model — in which dark energy is constant — might be wrong.

Dark energy is the reason the universe's expansion rate is currently accelerating. In the early universe, when everything huddled close together, gravity dominated over dark energy. But as space expanded, the gravitational attraction between galaxies (and their halos of dark matter) waned with their growing separation, while a constant dark energy would always have exerted the same repulsive force. Around 5 billion years ago, the pull of gravity dipped below the might of dark energy, and the expansion of the universe began to accelerate away.

Now, new data from the Dark Energy Spectroscopic Instrument (DESI) suggests the acceleration itself may be slowing. Located at the Kitt Peak National Observatory in Arizona, DESI is a powerful instrument capable of observing 5,000 galaxies simultaneously. Astronomers on the DESI team have analyzed three years of observations with more than 14 million galaxies and quasars, posting results on the astronomy arXiv preprint server.

On its own, the new DESI data are consistent with our standard cosmological models. Add in other observations, though, such as of the cosmic microwave background, gravitational lensing, and distant supernovae, and the neatest way to tie it all together is to invoke a weakening dark energy.

"What we are seeing is deeply intriguing," says DESI co-spokesperson Alexie Leauthaud-Harnett (University of California, Santa Cruz). "It is exciting to think that we may be on the cusp of a major discovery about dark energy and the fundamental nature of our universe."

This isn't the first hint from DESI that our leading cosmological model has issues. The project's first results already showed subtle hints of mutable dark energy in 2024. And results presented at the American Physical Society's Global Physics Summit in California from the similarly named but independent Dark Energy Survey (DES) likewise point to a repulsive force that changes over time.

However, it's still far from an open-and-shut case. "The significance of the claim that dark energy is dynamic is still low," says Andy Taylor (University of Edinburgh, UK), who wasn't involved in the research. "It is still possible the disagreement is a statistical fluke, or there may still be some bias in the data causing the results."

That said, if future data firm up these findings, it would be a remarkable breakthrough. "It would be a hugely significant result, worthy of a Nobel prize on its own," Taylor says.

"Whatever the nature of dark energy is, it will shape the future of our universe," says DESI Director Michael Levi (Lawrence Berkeley National Lab). If dark energy were constant, it's possible that runaway expansion would eventually tear all structure in the universe apart in a "Big Rip." But in light of these new results, that fate seems less likely.

"It's pretty remarkable," Levi adds, "that we can look up at the sky with our telescopes and try to answer one of the biggest questions that humanity has ever asked."

■ **COLIN STUART**

DESI COLLABORATION / DOE / KPNO / NOIRLAB / NSF / AURA / R. PROCTOR

SCIENCE POLICY

NASA Cuts Loom Large, Alarm Scientists

PRESIDENT TRUMP released a budget blueprint on May 2nd, calling for deep cuts to NASA and the National Science Foundation as well as other science-funding institutions.

The White House budget request slashes the NASA Science Mission Directorate funding by 47%, cutting astrophysics funding from $1.5 billion to just $500 million. That includes axing the Nancy Grace Roman Space Telescope, the DAVINCI mission to Venus, and the Mars Sample Return mission. The budget request also retires the Space Launch System mega-booster and the Orion crew capsule after the Artemis 3 mission to the Moon, and it does away with the Gateway lunar space station entirely.

Reaction from the space science community was swift.

The American Astronomical Society (AAS) has "grave concerns" about the deep cuts to science funding. "These cuts would damage a broad range of research areas that will not be supported by the private sector," the AAS said in a statement. "This will derail not only cutting-edge scientific advances, but also the training of the nation's future STEM [science, technology, engineering, and mathematics] workforce. These proposed cuts will result in the loss of American leadership in science."

The budget request will undergo changes as Congress reacts. Judy Chu of California, whose district includes the Jet Propulsion Laboratory and Caltech, was "horrified" that the Mars Sample Return would be axed. "I can't be clear enough: This decision would devastate our region, our workforce, and our future scientific discoveries," Chu says.

Nominated NASA Administrator and billionaire CEO Jared Isaacman has opposed severe cuts to the agency in past comments, but his position awaits Senate confirmation, which could take anywhere from days to months.

Scientists, meanwhile, are considering their options. "Even if President Trump decided to turn it around tomorrow, a tremendous amount of damage has been done," says Bruce Jakosky (University of Colorado, Boulder). "People are leaving, and other countries are starting to poach our scientists. If people leave, it's going to take at least a generation to get that experience back."

A full White House budget request is expected in May; once that's revealed, Congress will deal with the details. For now, the outcome for NASA is still to be determined.

■ **LEONARD DAVID**

Updates at https://is.gd/NASAbudget.

EXOPLANETS

Hints of Life on a Potential Ocean Planet

ASTRONOMERS MIGHT HAVE detected hints of life on a faraway planet — but they need more data to say for sure.

Using the James Webb Space Telescope (JWST), Nikku Madhusudhan (University of Cambridge, UK) and colleagues found hints of the molecules dimethyl sulfide and dimethyl disulfide in the atmosphere of exoplanet K2-18b, 124 light-years away in Leo. On Earth marine algae produce these molecules, and they could serve as biosignatures on other planets.

At around 2½ times Earth's girth and more than 8 times its mass, K2-18b could be a *hycean world* (a portmanteau of "hydrogen" and "ocean"), sustaining a planet-wide ocean beneath a thin atmosphere rich in molecular hydrogen. Alternatively, K2-18b could be a lifeless, gas-rich planet.

"In general, we have to be extremely cautious when claiming possible hints of life," says Víctor Rivilla (Center of Astrobiology, Spain), who wasn't involved in the study. Rivilla is among scientists who have found dimethyl sulfide in places without life, such as on comets or in interstellar gas clouds. "Such a huge and exciting result," he adds, "will surely need much more robust evidence."

Astronomers can observe molecules in an exoplanet's upper atmosphere by the light they absorb when the planet passes in front of its parent star. In 2023, Madhusudhan led JWST observations of K2-18b's atmosphere, detecting several carbon-bearing molecules, such as carbon dioxide, methane, and a whisper of dimethyl sulfide.

Now, the team has again turned JWST toward the world, finding stronger hints of dimethyl sulfide and a similarly significant detection of dimethyl disulfide. The findings appear in the April 20th *Astrophysical Journal Letters*.

However, the results haven't yet reached the level of statistical confidence that astronomers generally prefer. Further observations could not only confirm the signals are real, but also determine whether the molecules they represent could be made in abiotic ways.

To find another world with life would be a profound reckoning for humanity — but one that will have to wait for follow-up data and rigorous vetting.

■ **ARIELLE FROMMER**

Illustration of a hycean world

A. SMITH, N. MADHUSUDHAN (UNIVERSITY OF CAMBRIDGE)

BLACK HOLES

Supermassive Black Hole Wakes Up

A BLACK HOLE WITH the mass of a million Suns had lain dormant for two decades when a switch flipped. A sudden flow of gas into the maw lit up as a flickering beacon, marking the awakening of an *active galactic nucleus* (AGN).

Known by the designation bestowed by the automated Zwicky Transient Facility that detected the source, ZTF 19acnskyy (nicknamed "Ansky") brightened at ultraviolet through infrared wavelengths leading up to and after its discovery. The kicker came four years later, though, when the newly awakened AGN began to erupt in a regular pattern of extremely energetic X-ray bursts that recurred about every 4½ days.

The observing team, led by Lorena Hernández-García (University of Valparaíso, Chile), now thinks that these *quasi-periodic eruptions* (QPEs) might often herald AGN wake-up calls. The results were published on April 11th in *Nature Astronomy.*

Hernández-García says the most likely scenario is that "Ansky is a newborn AGN and we are witnessing the awakening of its massive black hole in real time." While other possibilities are plausible — such that the black hole shredded a nearby star — she notes that the initial flickering and brightening don't match those scenarios as well.

Matt Nicholl (Queen's University Belfast, UK), who wasn't involved in the current study, agrees. "We haven't caught so many AGN in the act of turning on, and already we've found one with QPEs," he says, adding that this could mean awakening AGN might frequently exhibit such repeated bursts.

New flows of gas do not themselves create QPEs. The semi-regular eruptions that recur on short timescales probably come from something, such as a star, that's orbiting the black hole.

▲ This artist's concept illustrates the mechanism that's creating powerful X-ray bursts from a newly awakened black hole.

In Ansky's case, and perhaps more broadly in awakened AGN, new flows of inspiraling gas flatten into a disk wide enough that it may cross the orbits of stars that were already there. This scenario explains both the slightly longer period of Ansky's QPEs as well as their extreme energy.

■ MONICA YOUNG

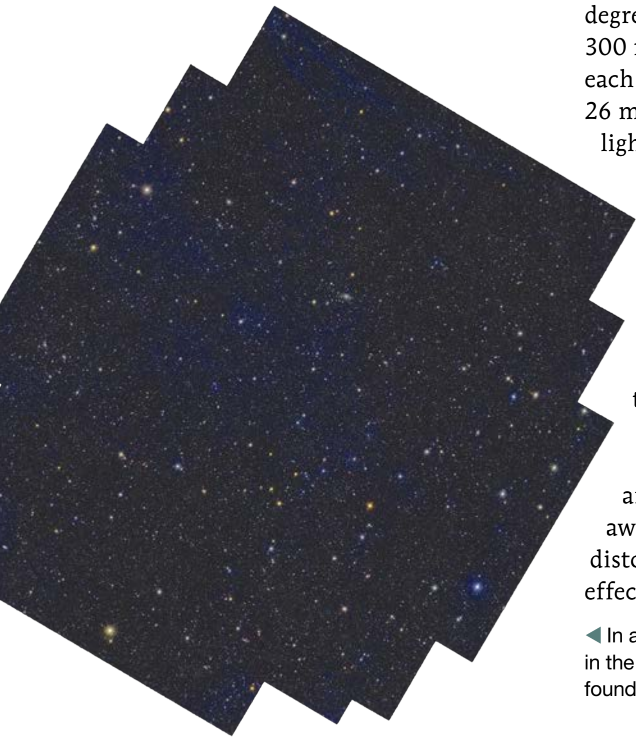
GALAXIES

Euclid's Treasure Trove

THE FIRST DATA RELEASE from the European Space Agency's Euclid space telescope is helping scientists sharpen the tools they'll need to unravel the nature of dark matter and dark energy.

At the heart of the release are mosaics of the three fields on the sky where Euclid will eventually provide the deepest observations of its mission. The fields, dubbed "North", "South" and "Fornax", cover a total area of 63 square degrees, the equivalent of more than 300 full Moons. With a single scan of each region so far, Euclid has spotted 26 million galaxies up to 10.5 billion light-years away. Ultimately, each field will be scanned between 30 and 52 times. Complementing these first images, the team has released 34 scientific papers that will appear in *Astronomy & Astrophysics*.

One major goal for the Euclid team is to construct a 3D map of dark matter by looking for *gravitational lensing,* in which mass bends and distorts light coming from faraway galaxies. Most of the time, those distortions are so tiny that the lensing effect is weak.



◀ In a single scan of Euclid's Deep Field North, in the constellation Draco, astronomers have found more than 10 million galaxies.

While quantifying weak lensing will take additional scans and analysis, the team has already found more than 500 strong-lensing candidates — even more than expected. In these cases, a massive foreground galaxy acts as a lens to strongly distort the image of a background galaxy.

The Euclid team also hopes to quantify dark energy using *baryonic acoustic oscillations*. These density waves formed fractions of a second after the Big Bang, and as the universe cooled, the waves imprinted themselves on galaxies' large-scale distribution. Cosmic expansion has stretched this fingerprint over time. By comparing snapshots of galaxies' arrangements at a dozen or so different times in cosmic history, astronomers can track the universe's expansion at early times — and in doing so, quantify dark energy.

While the work is only beginning, the next data release scheduled for October 2026 should contain preliminary cosmological results.

■ JAN HATTENBACH

Read the full story at https://is.gd/EuclidTreasure.

ARTIST'S ILLO OF BLACK HOLE: ESA; EUCLID: ESA / EUCLID / EUCLID CONSORTIUM / NASA; IMAGE PROCESSING BY J.-C. CUILLANDRE, E. BERTIN, G. ANSELMI

ASTEROIDS

Long and Lumpy Asteroid Donaldjohanson

NASA'S LUCY SPACECRAFT, heading outward toward Jupiter's orbit, captured a new addition to the menagerie of asteroids visited at close range when it flew within 1,000 kilometers (600 miles) of 52246 Donaldjohanson on April 20th.

Named for paleoanthropologist Donald Johanson, who discovered the hominid fossil nicknamed "Lucy," the asteroid was known to be an unusually slow rotator, taking 251 hours to complete a single spin. It's one of a family of fragments cleaved off much-larger 163 Erigone during an asteroidal collision 130 million years ago. Its unusually variable brightness hinted that it would either be a binary body or an extremely elongated one. It turned out to be both.

Lucy perfectly framed the asteroid as it whizzed past at a relative speed of 13.4 kilometers per second (30,000 mph). The first images revealed a lumpy world with two prominent lobes conjoined at a relatively narrow neck, a contact-binary shape common among small bodies in the solar system. The worldlet is covered in craters of varying crispness as well as the occasional boulder, and the surface bears linear features, especially in the neck area, that might have resulted from landslides.

◀ The unexpectedly large main-belt asteroid 52246 Donaldjohanson more than filled the frame of Lucy's imager.

Donaldjohanson held another surprise for the Lucy team: It's larger than had been estimated from Earth, about 8 km (5 miles) long at the widest point, so it spilled beyond the frame in images returned early on.

Lucy's team used the Donaldjohanson pass as a dress rehearsal of a complete science encounter. All three of Lucy's science instruments captured detailed data across Donaldjohanson's lumpy surface. The next encounter will be with the first Trojan target, the 3548 Eurybates-Queta binary system, in August 2027.

■ EMILY LAKDAWALLA

PLANET FORMATION

Tiny Disks Shed Light on Super-Earth Origins

MOST PROTOPLANETARY DISKS are small and likely to spawn compact systems of super-Earths, a new study finds.

Using the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile, a team led by Osmar Guerra-Alvarado (Leiden University, The Netherlands) has obtained high-resolution images of the 73 known protoplanetary disks in the Lupus star-forming region, 400 light-years away. These flattened, rotating disks contain gas, dust, and pebbles — and often forming planets.

Two-thirds of the Lupus disks — most of them around low-mass stars — turn out to have radii smaller than 30 astronomical units (au), the radius of Neptune's orbit. Some measure just 10 au across; the smallest would almost fit inside Earth's orbit of 1 au. "We knew most of the disks would be small," says Guerra-Alvarado, "but we didn't expect the majority to be that small."

The new results, to appear in *Astronomy & Astrophysics*, also reveal that the smaller disks lack conspicuous substructure like the concentric rings and gaps seen in many larger systems. That finding suggests those systems don't have giant planets, which in turn means dust can keep drifting inward, accumulating closer to the star.

"These compact disks provide optimal conditions for the formation of super-Earths," says team member Mariana Sanchez (also at Leiden University).

Super-Earths, rocky planets about twice as large and up to 10 times as massive as Earth, are among the most common planets in the universe. By studying a complete sample of protoplanetary disks in a star-forming region, it's now possible to compare the origin of known exoplanet populations, says Guerra-Alvarado.

"This is an important study," comments Carsten Dominik (University of Amsterdam), who wasn't part of the team. Dominik stresses that our own solar system is probably something of an outlier, as the formation of giant planets might have prevented material from drifting inward in our disk. The new study "gives a view into the small disks, which are the most numerous ones," says Dominik, "and therefore into the 'standard evolution' of a planetary system."

■ GOVERT SCHILLING

See images: https://is.gd/LupusDisks.

NASA / GODDARD / SWRI / JOHNS HOPKINS APL / NOIRLAB

IN BRIEF

Saturn Has 128 New Moons

A series of listings on March 11th by the International Astronomical Union's Minor Planet Center nearly doubled the number of known moons of Saturn to a total of 274. Although the data on the 128 new moons were reported all at once, the data had been collected intermittently since 1999. It took years of careful study to provide enough repeat observations to officially confirm that these objects — which span between 1 and 20 kilometers (0.6 to 12 miles) — were indeed going around Saturn. The orbits of the newfound moons are scattered (or *irregular*), backwards (or *retrograde*), and far from the planet. They can be grouped into a few clumps, with each clump representing debris from a specific collision. One of these clumps in particular shows strong evidence that the collision happened recently — less than 100 million years ago. Perhaps coincidentally, that's about the estimated age of Saturn's dramatic ring system (*S&T:* May 2019, p. 11). A recent collision could explain why the number of Saturn's moons dwarfs those of Jupiter.

■ DAVID L. CHANDLER

by Stephen James O'Meara

Curious Comet-like Meteors

Keep an eye out for unusual Perseid fireballs.

▲ **AN EVENING SURPRISE** The author's photo illustration shows the pale-yellow fireball of magnitude –5 that he witnessed on March 11th this year from Maun, Botswana. He described seeing dozens of points of light surrounding the fireball's round head.

PERSEID METEORS ARE noted for their remarkable fireballs, some with splendid colors and other rousing characteristics. For instance, on the morning of August 12, 2024, I was astonished by the sudden appearance of a Perseid of magnitude –4. This flaming yellow teardrop left a 35°-long train that continuously unfurled like a streamer. Its path ran parallel to the horizon, just above the treetops from our home in Maun, Botswana, spitting sparks along the way.

While the fireball was remarkable, its overall appearance could be considered as typical. Occasionally, however, a fireball can flash into view with such a bewildering display of comet-like characteristics that once gone, it could leave an observer in a state of confused astonishment.

That was how I felt that same morning when another Perseid fireball split the dawn sky. It streaked into view at magnitude –6 between blue-white Sirius and pale-yellow Canopus, exhibiting a rusty copper hue. In my decades of observing, I've witnessed only one other copper-colored meteor, which was also a Perseid. In both cases, I saw them against a twilight sky — I spotted this recent fireball about 15 minutes after the start of morning astronomical twilight, suggesting the possibility of a color-contrast effect.

More unusual was the meteor's stubby head, which was surrounded by a diffuse, comet-like coma. As the fireball descended at a steep angle toward the horizon from an altitude of about 25°, a fuzzy envelope wrapped around the meteor's head like a parabolic hood, flowing into a comet-like tail that tapered to a point. Even more curious, during the meteor's fall its outer coma scintillated like motes of dust in a sunbeam.

This sighting prompted me to do some research. In an 1883 issue of *Nature*, I found a report of a similar meteor. On the evening of June 3rd of that year, an observer in West London, England — who used only the initials P. F. D. — noticed a flash of light, which drew his attention to a curious, pale-yellow meteor near 102 Herculis, a 4th-magnitude star in the constellation's southeastern region.

According to the observer, in about five seconds the meteor, which appeared "not at all unlike a comet with a bushy tail tapering off to a point," traveled slightly more than half the distance from 102 Herculis to Altair, Alpha (α) Aquilae, where it "disappeared without any outburst."

More recently, on March 11th this year, I was scanning the sky with my unaided eyes when a pale-yellow meteor of magnitude –5 burst into view west of the waxing gibbous Moon. The fireball's round head traveled some 30° westward toward Pollux, Beta (β) Geminorum, sporting a narrow tail — not unlike a comet's ion tail — before it winked out.

What was most unusual was that the head was surrounded by dozens of points of lights. They didn't disperse like sparks; rather, these points moved with the head as it traversed the sky. I felt that if the Moon were absent and the sky were darker, these points could have been part of a dim coma, making it yet another perplexing example of a comet-mimicking meteor.

Such diffuse structures have also been recorded in high-altitude meteors. In a 2000 *Meteoritics & Planetary Science* paper, Czech astronomer Pavel Spurný and his colleagues discussed videos of Leonids captured in November 1998 that show the meteors quickly developing comet-like diffuse structures as they entered the atmosphere at altitudes greater than 130 kilometers (81 miles). When the meteors descended below 130 km, the diffuse structures quickly transformed to the usual meteor appearance, with a droplet-like head and a trail.

The researchers suspect that these comet-like Leonids were "very probably connected with electromagnetic processes in the upper atmosphere and with the more complicated structure of entering bodies of cometary origin."

Whether the visual observations I described here are related to these high-altitude meteors is uncertain. But the observations do exist.

■ Contributing Editor **STEPHEN JAMES O'MEARA** is renowned for his legendary eyesight and observing prowess.

Secrets of the *Great* Red Spot

Astronomers are delving into the details of what sustains Jupiter's iconic storm.

▶ **WORLD-SIZE STORM** This mosaic of frames from Voyager 1 taken during its 1979 visit to Jupiter shows the moon Europa transiting near the Great Red Spot. The black shadow above the storm was cast by Io. Since the craft's visit, the iconic storm has shrunk and circularized. Europa is one-quarter as wide as Earth.

Ever-changing and yet remarkably stable, Jupiter's best-known feature, the Great Red Spot (GRS), continues to intrigue and puzzle astronomers. The giant storm forms a large, ruddy oval that currently spans some 110 million square kilometers (42 million square miles), or roughly 1% of the planet's visible disk. Although that percentage sounds small, a comparably sized storm on Earth would cover a latitude and longitude range just smaller than the state of Alaska. The GRS is so prominent that small backyard telescopes can pick it up — although its sometimes pale appearance to the eye may surprise (and challenge) new observers.

The GRS has endured for at least 150 years, based on historical records. During that time, it has not been constant by any means, slowly shrinking and assuming a smaller, rounder shape. The shrinking has been well documented by amateur and professional astronomers alike, and its cause remains a riddle (*S&T:* Mar. 2016, p. 18).

Other storms in the solar system come and go. But even after a century and a half of study, we still don't understand why this enigmatic storm has lasted so long. Recent research has begun to focus on more complex questions that might shed light on the mystery. How deep does the GRS extend into the Jovian atmosphere? How has it maintained its strength and size? What will be its ultimate fate? And, maybe most importantly, what can these observations tell us about Jupiter's atmosphere on a larger scale?

We don't yet have complete answers to all these questions. But thanks to various observations and calculations, we are well on our way to finding them.

Cloud Diving

The GRS is a system of winds rotating counterclockwise around a high-pressure core, called an *anticyclone*, in Jupiter's southern hemisphere. (Its counterpart, a cyclone, has a low-pressure center and rotates in the opposite direction.) At the cloud-top level, the GRS's average winds exceed 380 km/h (235 mph) in a high-speed collar surrounding a stagnant core that appears to have little motion, somewhat like the eye of a hurricane.

As a storm, the GRS is not unique in the solar system, nor even on Jupiter — there are many long-lasting cyclones and anticyclones on the gas giant. But none is as large or as dramatic in color. Neptune also has large anticyclones, the first known of which was called the Great Dark Spot, but they typically only last a few years (*S&T:* Mar. 2025, p. 60). All the giant planets' spots are thought to be fueled the same way as storms on Earth are: Heat and humidity cause air parcels to rise, and as they rise, the planet's rotation deflects the parcels toward adjacent latitudes, causing the storm to spin up. This spin-up phenomenon is called the *Coriolis effect*.

We think the GRS partially owes its longevity to the fact that it is tightly bound to its latitude by strong east-west jet streams above and below it, which deflect around the storm's edges and hold it in place like a ball bearing in its races. As a result, although the GRS drifts slowly westward over time, taking more than 3 years to circumnavigate the planet, it cannot move north or south. Neptune's storms, conversely, are not bound in latitude and tend to fade away as they drift toward the equator or poles and encounter changing atmospheric conditions.

Two of our most powerful instruments for investigating the Great Red Spot are NASA's Juno spacecraft and the Hubble Space Telescope. Juno has orbited Jupiter since 2016, obtaining exquisite high-resolution views of the GRS, but it can only see the storm infrequently due to its highly elliptical polar orbit. Among its instruments, Juno has a color camera (intended for public outreach), an infrared spectrometer, and a microwave radiometer capable of sensing much deeper levels below the cloudtops. These give us a multiwavelength and multi-altitude look at what's happening in and around the storm.

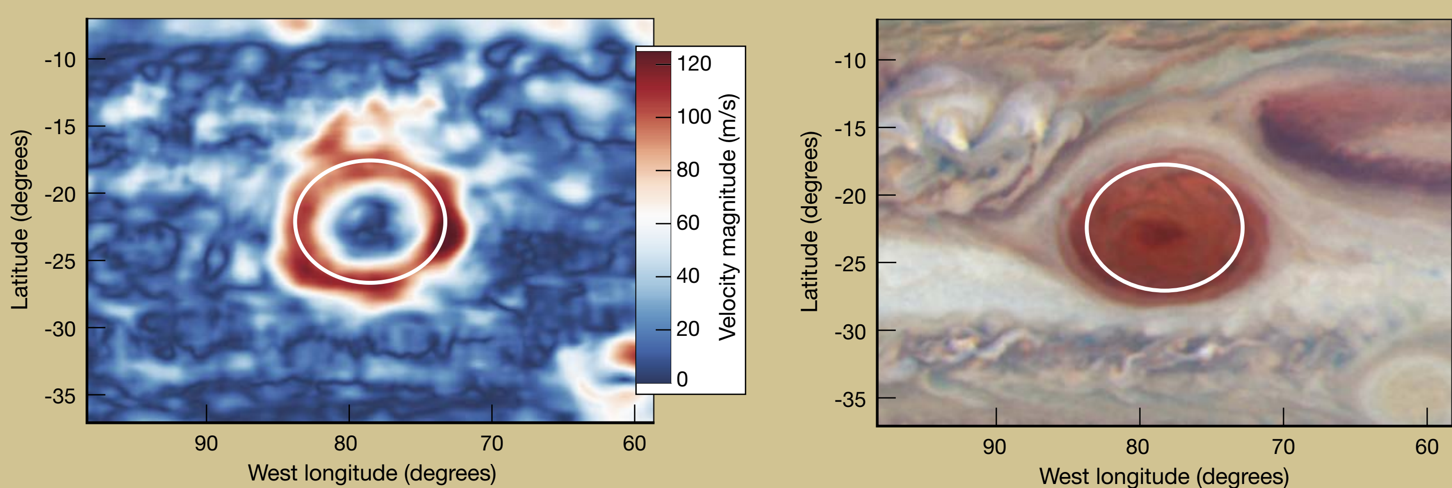
Paired with ground-based observatories, Hubble provides more frequent observations of the GRS (though at lower resolution than Juno does) at ultraviolet through near-infrared wavelengths. Hubble is especially useful because it can observe Jupiter frequently over most of the year. The dedicated Outer Planet Atmospheres Legacy project, which I oversee, also makes yearly observations of all four giant planets to understand their atmospheric dynamics and evolution over time. This monitoring program guarantees that we obtain GRS images with Hubble on at least a yearly basis.

One key question about the GRS is how deep it extends, as water vapor and heat available at greater depths may help to fuel this massive storm. In a gaseous planet, there is no surface to reference for altitude, but scientists often use the depth at which the atmospheric pressure matches Earth's at sea level (1 bar) as a milepost, and that is about the level where the visible clouds in Jupiter's belts and zones reside. However, the GRS extends much higher than the cloud deck that surrounds it. Based on brightness measurements of the GRS's high ammonia-ice clouds across multiple wavelengths, and how their brightness changes with viewing angle, scientists can calculate how high the storm clouds extend.

Using these techniques, we've determined that the GRS's cloudtops extend approximately up to the *tropopause,* or about 60 km (40 miles) above the 1-bar level. Convection-produced clouds generally don't rise any higher than this altitude: The atmosphere heats up above the tropopause, so warm air from below can no longer ascend unless the motion is so rapid that

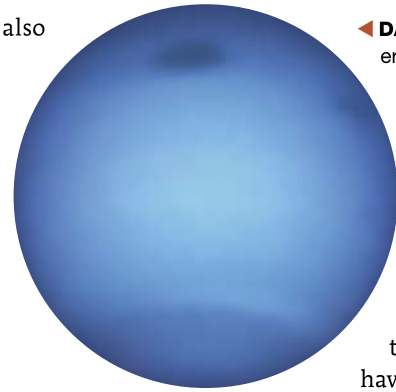
▼ **SWIRLING CLOUDS** When scientists subtract out the average wind field surrounding the Great Red Spot, they can see a ring of high-speed winds in the storm's outer reaches *(left)*. The white ring corresponds to the white ring in the color composite image *(center)*. Vectors trace the winds' speed and direction *(right)*, which blow counterclockwise. (A speed of 100 m/s corresponds to 220 mph.)

VORTEX: MICHAEL H. WONG ET AL. / *GEOPHYSICAL RESEARCH LETTERS* 2021 (3)



it temporarily overshoots that ceiling. This is also why when cumulonimbus clouds on Earth reach the tropopause, their tops spread out into a distinct anvil shape, like they're hitting a boundary.

Recent results using the Juno microwave radiometer and gravity measurements reveal that the storm plunges much deeper than it soars. From top to bottom, the GRS's full vertical extent is likely between 300 and 500 km, placing its bottom well below where water clouds first condense (roughly 50 to 100 km below the visible cloud deck) and therefore deep in an atmospheric sea of water vapor. This region provides the reservoir of heat and moisture needed to sustain this long-lived storm. Although 300 km sounds very tall, it is still pancake-thin when compared with the GRS's visible width of roughly 14,000 km.



◀ **DARK SPOTS** Two storms appear in Neptune's northern hemisphere in this January 2020 Hubble image. Astronomers first saw the larger storm in 2018; it migrated southward but then surprised observers when it took a U-turn later in 2020 and headed north again. The smaller one lasted a few months.

Weather Forecast: Sustained Winds

We cannot continuously monitor the GRS (or any aspect of Jupiter), which presents a problem: Because we don't have the Jovian equivalent of a weather satellite, we can't easily distinguish short-term variability from long-term trends. Instead, we rely on frequent amateur imaging and sporadic spacecraft observations to build up a more complete picture of the Great Red Spot's behavior.

Measuring the GRS's detailed winds is one task that requires Hubble-class spatial resolution, though. We can track the movement of small cloud patterns between closely separated images, and for this purpose the smaller the feature, the better. In the past, astronomers could only track cloud motions by eye, and they were limited to the highest contrast features that could be reliably identified. This tracking method often means focusing on images separated by only tens of minutes. While these short separations yield the best identification, they also come with higher uncertainties in the motion measurements because the clouds have not yet moved very far.

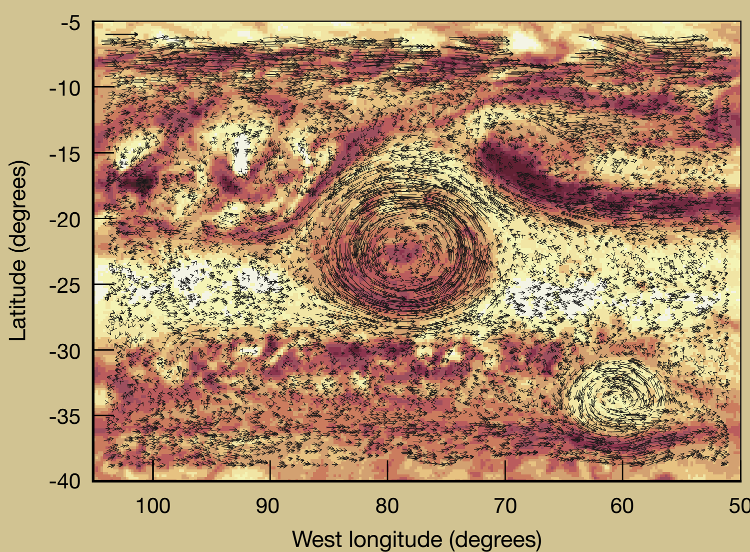
We can also use images with time separations of up to one Jupiter rotation (10 hours), but clouds can shear apart over that time. Furthermore, because the clouds follow a curved path around the inside of the spot, only the clouds' start and end locations are accurate.

Recent improvements in computer-tracking routines have now reached the point where we can determine accurate, two-dimensional *wind fields* over the entire GRS. (A wind field is a map of winds' velocities at different points in the atmosphere.) Next-generation cloud-tracking computer codes iterate back and forth between short and long intervals to find the path that best predicts the cloud's location at each time step. The codes enable us to better track all clouds within the field.

Using Hubble data, we found that the maximum velocities inside the GRS's windy "collar" have increased by 4% to 8% over the past 11 years. While only a small amount, it is consistent with the notion that the GRS is spinning up as it shrinks, similar to how figure skaters spin faster as they pull in their arms.

Some short-term studies have suggested that the storm might be also growing taller as it shrinks, to further main-

NEPTUNE: NASA / ESA / STSCI; M. H. WONG (UNIV. OF CALIFORNIA, BERKELEY) AND L. A. SROMOVSKY AND P. M. FRY (UNIV. OF WISCONSIN, MADISON)



Get Involved

If you'd like to help monitor the Great Red Spot, please consider submitting your images to the Planetary Virtual Observatory and Laboratory (PVOL): **http://pvol2.ehu.eus/pvol2.** Planetary scientists often search PVOL for context images for their research. You can also submit data to the Association of Lunar and Planetary Observers (**alpo-astronomy.org**) and the British Astronomical Association (**britastro.org**).

tain the balance. However, when we examined the storm's height over more than one decade (from about 2010 to 2023), such a change in height is not as obvious. Instead, it appears that cloud and haze altitudes at the storm's top can easily be affected by other clouds pulled into the GRS from the surroundings, rising up as they swirl inside the storm before disappearing.

Overall, the spot's size and winds seem to resist permanent changes due to passing interactions with other storms and clouds. Two recent examples demonstrate this stability.

In 2016, there was vigorous, large-scale storm activity in the South Equatorial Belt, where the spot lives. The GRS's winds appeared to change in response to an uptick in the churning convective motions that move heat and vapor inside the storm.

Then in 2019, during strong interactions with external clouds entering the flow around the GRS, long streams of red material appeared to be pulled off the storm or flung away, like its outer boundary was peeling. Yet while this flaking caused the GRS's size and shape to vary, the wind velocities inside it remained steady. And in both cases, the GRS returned to its normal size and behavior shortly thereafter.

While the singular 2016 and 2019 events are interesting in their own right, they don't represent the underlying behavior of the GRS. Instead, these rapid, short-lived changes again point to the need for much more frequent measurements and observations to determine which atmospheric events on Jupiter are outliers — merely bouts of severe weather, if you will — and which represent a real, lasting change in terms of the GRS's size, shape, color, and behavior.

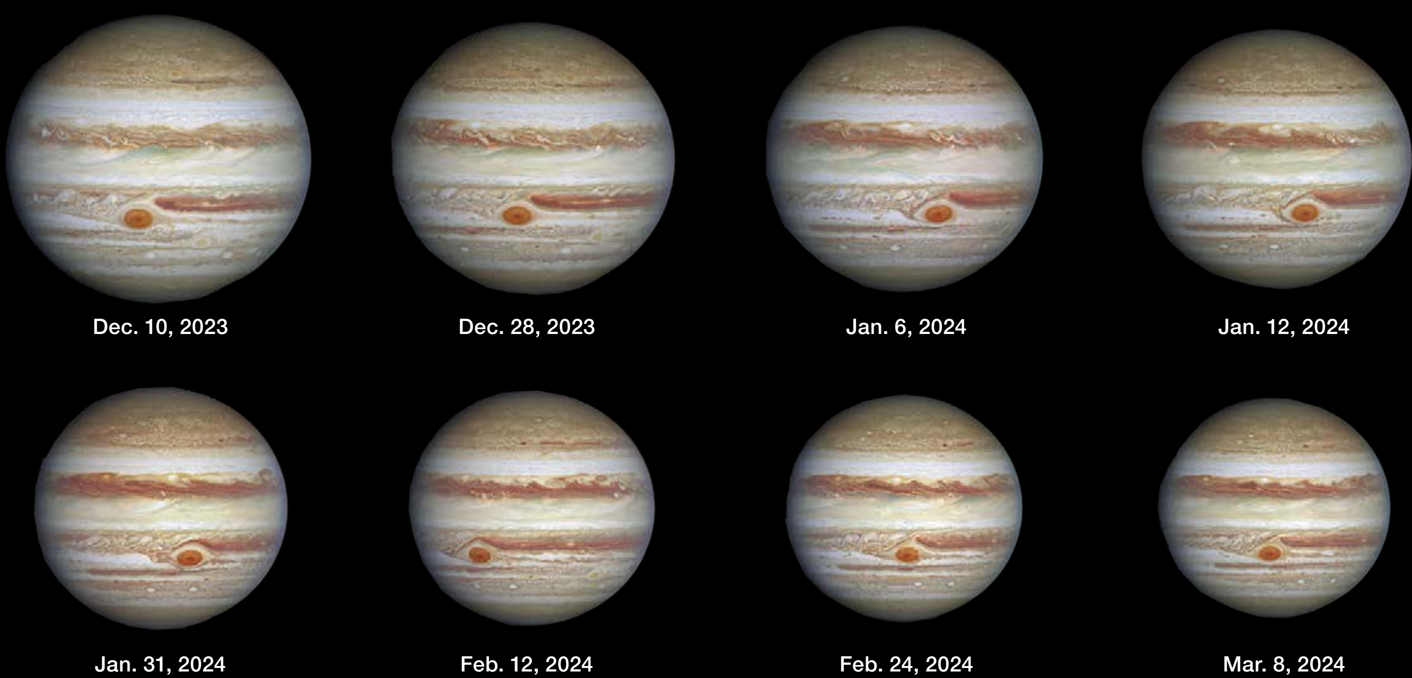
Have Wobble, Will (or Won't) Travel

Frequent monitoring data also reveal another interesting phenomenon. Throughout the historical record, observations indicate that the Great Red Spot does not drift around the planet at a constant rate. Instead, it speeds up and slows down with a 90-day period, even as its overall drift rate has increased over the years.

When Voyager 2 flew by Neptune in 1989, scientists found that the large storms there also wobbled with periods of tens of days — but not just in longitude. Some storms also moved in latitude and changed orientation, gliding and tilting across the planet's face. Essentially, they appeared to "slosh" around during the Voyager encounter.

Because giant storms display so much more freedom of movement on Neptune, scientists suspect the oscillations of this planet's dark spots arise in response to the changes in the winds encountered as the storms moved. In other words, Neptune's spots can freely adjust to changing surrounding conditions. But this model only works if the spots are relatively shallow and simple in structure. The same conclusions could not be definitively applied to Jupiter, because the GRS is not as free to move in latitude. However, based on what the twin Voyagers saw, the equations that describe the balance

NASA / ESA / STScI / Amy Simon (NASA-GSFC), Image processing: Joseph DePasquale (STScI)



JUPITER OVER TIME These Hubble Space Telescope images span approximately 90 days (from December 2023 to March 2024). Astronomers used these observations to detect a 90-day oscillation in the Great Red Spot's shape and size. (The GRS's longitudinal location in these images isn't due to the storm's drift around the planet — it's just that Jupiter's rotation doesn't line up perfectly with Hubble's orbits.)

between the shape of Neptune's dark spots, their rotational motion, and the latitudinal wind shear outside the storms appeared to hold on Jupiter as well.

Given the GRS's rapid changes in response to nearby storms in 2016, and the fact that it is so much smaller now than in 1979, could it now behave even more like a "sloshy" Neptunian storm? To test this theory, we acquired Hubble observations throughout a 90-day cycle from late 2023 through early 2024. In these images, there is still no evidence of latitudinal oscillations, nor any clear proof that the GRS changes its orientation. So the short answer is "no."

However, we did observe other intriguing changes. The most striking was that, as the GRS speeds up and slows down in its sideways drift, it also changes size. It is largest when moving slowly and more compact when moving faster.

At the GRS's current, historically small size, the speeds of the winds whirling around its core do not balance with the surrounding wind field in Jupiter's atmosphere, as was previously thought to be the case.

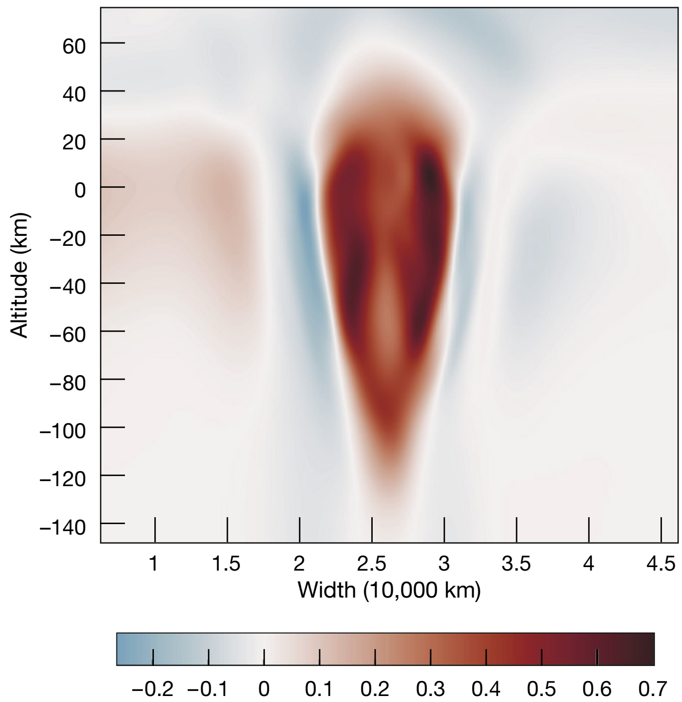
When we consider these factors as a whole, the GRS does not adjust to the surrounding atmosphere the way spots do on Neptune, even though both sets of storms have a 90-day wobble in their drift around their planets. (We don't yet know why they both follow a 90-day cycle — perhaps there's something fundamental about the planets' rotation and deep structure that sets the period.) The difference between the planets' storms is likely because the GRS has much more vertical structure than Neptune's spots do, and it reaches deeper into the atmosphere.

And maybe the storm's deep structure holds the key to the storm's longevity. Recently, scientists performed 3D calculations to understand what makes a vortex stable over long time scales on a giant planet. A key finding of this work is that very stable storms evolve to have stagnant cores, as we observe in the center of the GRS — but *not* in the centers of other Jupiter storms. The models also revealed, unexpectedly, that a stable storm's shape looks a bit like an ice-cream cone below the clouds, tapering with depth rather than being cylindrical.

These preliminary models predict that the GRS extends about 150 km below the visible cloud deck. When we add this length to the storm's 60 km extent *above* the deck, the result is roughly consistent with the overall height found in the Juno studies.

While these models may not yet fully describe the GRS, they do represent an important advance in our understanding: The GRS is truly three-dimensional, not as shallow as storms appear to be on Neptune, and it's likely drawing energy from deep below the visible clouds.

Understanding the long-term behavior of the GRS will allow us to deduce the nature of the atmosphere below the cloud decks: the change in temperature with depth, wind shear, and the amount of water available. These factors all affect the storm's size, strength, and longevity — but they're unmeasurable. The next step in our understanding will be to constrain Jupiter's atmospheric conditions at those depths using circulation modeling. A successful model will be able to replicate the GRS's long-term evolution, going from very large and oblong in the 1800s to smaller and rounder now, all while oscillating in size and shape. These findings would then provide a critical insight into Jupiter's atmosphere that we cannot reach using observational data alone.



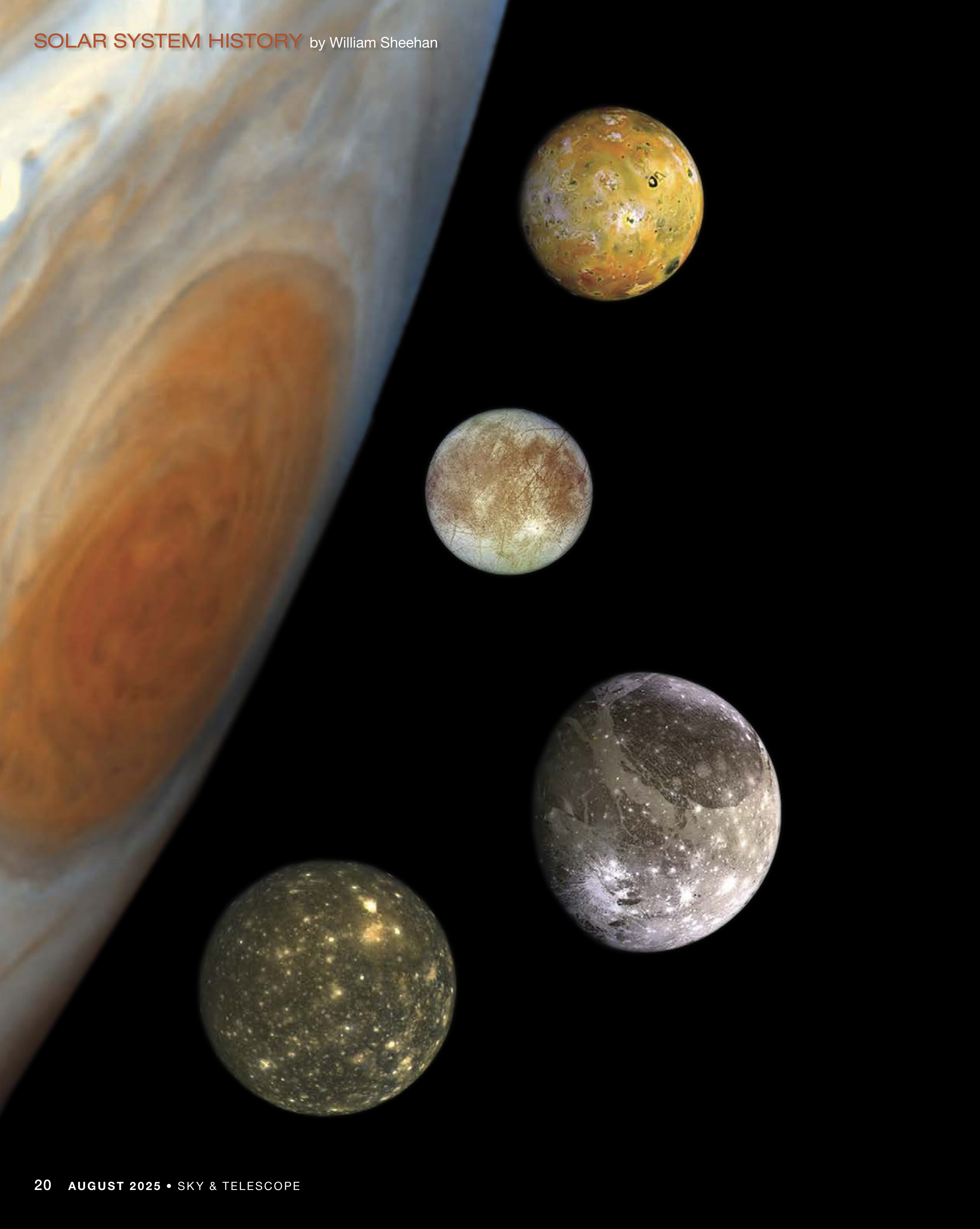
▲ **STABLE VORTEX** Using the temperatures and wind flows seen in Jupiter's atmosphere, scientists explored different kinds of long-lived 3D vortices that might match the GRS. They found the best matches have an elongated diamond shape with depth, rather like a tooth or an ice-cream cone. Here, the colors indicate how quickly the GRS rotates compared with the local planetary motion; red is anticyclonic motion, blue is cyclonic.

A. ZHANG AND P. S. MARCUS / *JOURNAL OF FLUID MECHANICS* 2024

And of course, observations — including those by amateurs — will continue to be pivotal, particularly as the GRS slowly becomes smaller than the latitudinal width of the belt in which the storm sits. Who knows what interesting behavior will be triggered once the storm can move more freely?

As for if or when the GRS might disappear, only time will tell. It's currently shrinking at a fairly constant rate, roughly 0.2° in length per year, corresponding to 230 km per year. The spot's size does fluctuate over the 90-day period, indicating that while its behavior and winds may not be governed by the surrounding atmosphere, it does readjust as it drifts along. It might yet reach a stable configuration and stop shrinking. Astronomers will certainly be watching to see what happens next!

■ **AMY SIMON** is a planetary scientist who uses robotic missions to explore many bodies in the solar system, often with the help of a furry feline.



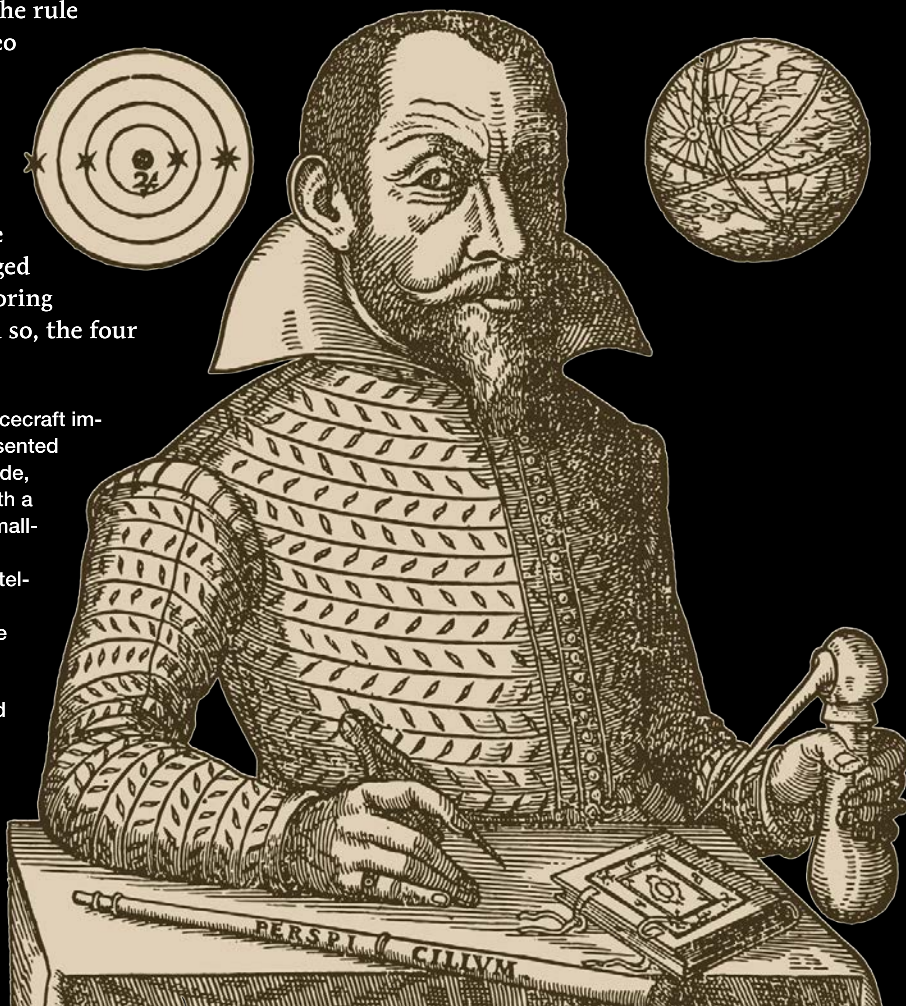
Who Named the Galilean Moons?

HINT: It's not who you think.

On January 7, 1610, Galileo Galilei turned his telescope toward Jupiter for the first time. The planet was then rising resplendent in the east near Aldebaran, in the constellation Taurus. Setting up the instrument in his garden, he noted three faint stars lying in a straight line with the planet — two east of the Jovian disk and one to the west. The following night, January 8th, he found three in a line, this time all on the west side. He continued to observe, and by January 13th he'd established there were four stars, not three. To Galileo they were nothing less than "small planets" orbiting Jupiter, just as the planets of the solar system orbit the Sun.

Although his position as a professor of mathematics was secure in Padua, which was then under the rule of the Most Serene Republic of Venice, Galileo was angling for a better position in Florence, under the Grand Duke of Tuscany, Cosimo II de' Medici. To further his cause, he initially decided to name the new planets *Cosmica Sidera* (Cosimo's stars). However, Cosimo's secretary suggested that the flattery might be multiplied four times if the name were changed to *Medicea Sidera* (Medicean stars), thus honoring all four Medici brothers. Galileo agreed. And so, the four new worlds appeared by this name in his book, *Sidereus Nuncius (Starry Messenger*), written quickly in the heat of the moment and published in Venice in March 1610.

By then, however, Galileo had a rival: Simon Mayr, or Simon Marius, the Latin name by which he is generally known. Marius had begun making telescopic observations at nearly the same time as Galileo and had recorded comets, novae, Venus's phases, sunspots. and even the Andromeda Galaxy. But it was his claim to have seen the satellites of Jupiter that got him into trouble with Galileo. The dispute became so fraught that even today Marius's reputation hasn't fully recovered.



◀ **GALILEAN GROUP PHOTO** This composite of spacecraft images shows Jupiter and the four Galilean moons presented to scale. From top to bottom are Io, Europa, Ganymede, and Callisto. Of the four, Ganymede is the largest, with a diameter of 5,262 km (3,270 miles) and Europa the smallest at only 3,122 km across. By comparison, Earth's Moon measures 3,475 km across. The four Jovian satellites were first glimpsed by Galileo Galilei in January 1610, though it was Simon Marius who gave them the names we use today.

▶ **FORGOTTEN PIONEER** Although an accomplished telescopic observer, Simon Marius never received the recognition that his contemporary, Galileo, achieved. It's ironic that the four Galilean satellites of Jupiter (shown in the diagram at upper left) are known universally by the names Marius proposed. This woodcut frontispiece, the only known portrait of the astronomer, appeared in his 1614 book *Mundus Jovialis* (*World of Jupiter*); it also includes the first image of an astronomical telescope ("perspicillum"), shown in the foreground.

JUPITER AND MOONS: NASA / JPL / DLR; MARIUS: MARKUS MAYER / ALAMY STOCK VECTOR

◀ **MOVERS AND SHAKERS** Galileo was clearly a master of self-promotion, as illustrated by this 1858 Giuseppe Bertini fresco called "Galileo Galilei showing the Doge of Venice how to use the telescope." The astronomer's first instinct after he discovered four satellites revolving around Jupiter was to name them Medicea Sidera (Medicean stars) to curry favor with the ruling Medici family.

Early Years

Marius was born in Gunzenhausen, Bavaria, Germany, on January 10, 1573, of a poor family. Showing obvious mathematical ability, on the recommendation of the Margrave of Brandenburg-Ansbach, George Frederick I, in 1586 Marius was admitted to the Margrave's Academy for talented poor boys in Heilsbronn. The school's purpose was to train young men for the ministry; however, Marius had shown so much promise as an astronomer that the plan for the ministry was dropped, and instead he was appointed the Margrave's official mathematician. In that role he was sent to Prague in 1601 to study with the world's most famous astronomer at the time, Tycho Brahe.

Even as Tycho neared the end of his life, his household was bustling, noisy, and chaotic. In addition to the great man's large family and numerous servants, he had several assistants, including a young Johannes Kepler, though Marius did not interact much if at all with him. He remained in Prague only a few months before leaving for Padua in September. Within weeks of Marius's departure, Tycho was dead.

In Padua, Marius began studying medicine and took several students, including Baldassarre Capra, with whom he wrote a book on a "new star" (subsequently known as Kepler's supernova) that had appeared in 1604. A few years later, Capra and Galileo became embroiled in a dispute over the invention of a military compass. Marius, of course, took the side of his student, but Galileo regarded Marius as the instigator. The stakes were high, as Galileo believed the theft

▼ **AN AMATEUR'S PLANET** From the 17th century to today, Jupiter and its four bright satellites have been a telescopic favorite for astronomy enthusiasts. This composite photo shows the planet and the Galilean moons as they appeared on September 14, 2024. From left to right, the moons are Europa, Ganymede, Io, and Callisto.

GALILEO AND DOGE OF VENICE: VILLA ANDREA PONTI / WIKIMEDIA COMMONS / PUBLIC DOMAIN; JUPITER AND ITS FOUR GALILEAN MOONS: SEAN WALKER of intellectual property was a crime worse than murder. Thus began Galileo's lifelong, bitter opposition to Marius.

Enter the Telescope

In the autumn of 1608, a nobleman friend of Marius saw a telescope offered for sale in Frankfurt. However, the price was exorbitant. Nevertheless, in the summer of 1609, his friend secured a very good copy of this novel device in Belgium. Marius afterward recalled in his 1614 publication, *Mundus Jovialis* (*World of Jupiter*):

> *From this time I began to look into the heavens and the stars with this instrument, whenever I was at the house of the nobleman . . . [S]ometimes he used to allow me to carry it home, and in particular about the end of November, when I was observing the stars according to my custom in my own observatory. Then for the first time I looked at Jupiter, who was in opposition to the Sun, and made out some tiny stars, sometimes following, sometimes preceding Jupiter in a straight line with him. . . . However, as Jupiter was then retrograding, and still I saw these stars accompanying him throughout December, I was at first much astonished; but by degrees arrived at the following view, namely, that these stars moved round Jupiter . . . I therefore began to record my observations. The first was taken on December 29 [Old Style], when three stars of this description were visible in a straight line from Jupiter towards the west.*

While Galileo had rushed his observations of the four small planets into print, Marius was unhurried. He said nothing about them in public until 1611, and only then in an almanac with a small, local circulation. Also, Galileo had drawn the nightly positions of the satellites relative to the planet, but Marius did not make any sketches — or at least never published any.

It was only when Marius at last published *Mundus Jovialis* in 1614 that his telescopic observations became widely known. In that work, he shows familiarity with what Galileo had already done, writing:

> *[What I have written here] is the exact truth. . . . In recounting all this, I am not to be understood as wishing to lessen Galileo's reputation, or to snatch from him the discovery of these Jovian stars among his countrymen in Italy — far from it. My object rather is, that it may be understood that these stars . . . were discovered and observed by me, by my own investigation, in Germany, almost at the very time, or slightly before it, at which Galileo first saw them in Italy. The credit, therefore, of the first discovery of these stars in Italy is deservedly assigned to Galileo and remains his. . . . So if this little book of mine shall reach Florence and come into Galileo's hands, I pray that he will receive it in the same spirit in which it is written by me.*

This was, as Marius probably knew, like waving a red flag before a bull. In suggesting that Galileo deserved priority only in Italy and that he had seen them slightly before, Marius took a calculated risk. If he meant to provoke Galileo, he succeeded.

A Temperamental Giant

Even under the best of circumstances, Galileo could be touchy to deal with. In his 2010 biography *Galileo*, science historian John L. Heilbron wrote that the great Italian astronomer "could not tolerate ambiguity in character any more than in geometry." He judged others — friends as well as

foes — in black-and-white terms. And he had already colored Marius black during the Capra affair, calling him a "poisonous reptile" and "an enemy of mankind."

For that matter, Marius could also be difficult. In 1619 Kepler, whom Marius referred to in *Mundus Jovialis* as a good friend, wrote in a letter to fellow astronomer Johannes Remus Quietanus that he wished Marius would "mind his own business" and that he regarded him as needy. Galileo and Marius were now in deadly enmity, and Galileo dealt a catastrophic blow in his 1623 book, *Il Saggiatore* (*the Assayer*), in which he wrote:

> *Four years after the publication of my* Sidereal Messenger, *this same fellow [Marius], desiring as usual to ornament himself with the labors of others, did not blush to make himself the author of the things I had discovered and printed in that work. Publishing under the title of* The World of Jupiter, *he had the temerity to claim that he had observed these Medicean planets which revolve about Jupiter before I had done so. But . . . [I can prove that he did not] observe said stars before me but even that he did not certainly see them until two years afterwards; and I say moreover that it may be affirmed very probably that he never observed them at all.*

Galileo pointed out that the earliest observation Marius produced — represented as having been made on December 28, 1609 — was actually identical to the second one Galileo had drawn on January 8, 1610. Galileo assumed Marius had simply plagiarized him.

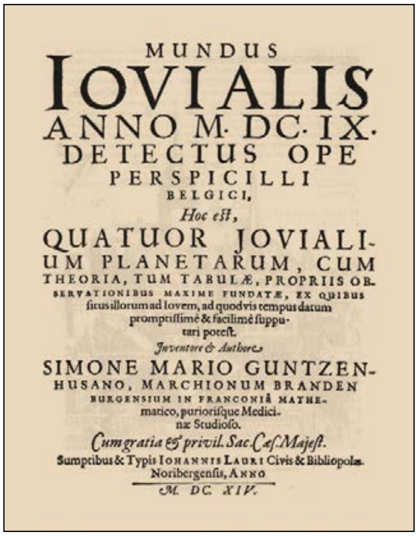
By the time *Il Saggiatore* appeared, Marius was close to death and unable to defend himself. But it's difficult to imagine what defense he could have offered. Galileo's accusation of plagiarism was so devastating that Marius's reputation was ruined. The Jesuit astronomer Christoph Scheiner, who himself became engaged in a bitter priority dispute with Galileo over the discovery of sunspots, noted that by waiting until 1614 to publish his observations, Marius had done so "in vain and too late."

It wasn't until 1903 that his case was reopened by two Dutch astronomers, Johannes Bosscha and Jean Abraham Chrétien Oudemans. They showed that Marius had determined orbital periods for the satellites that agree quite closely with modern values, had noted their orbital inclinations to the equator of Jupiter and the ecliptic, and had recognized their variable brightnesses. Marius had also been the first to construct tables of their motions, covering the period from 1608 to 1630. Most importantly, Bosscha and Oudemans

MATTHÄUS MERIAN / WIKIMEDIA COMMONS / PUBLIC DOMAIN

▲ **EARLY URBAN ASTRONOMY** This 17th-century woodcut illustration shows Ansbach, in the German state of Bavaria, where Marius observed the satellites of Jupiter and made the first telescopic observations of the Andromeda Galaxy. He served as court mathematician to the Margrave of Brandenburg-Ansbach from 1606 until his death in 1625.

provided detailed calculations showing beyond a reasonable doubt that Marius's observations had been carried out independently of Galileo's. They even managed to validate the observation of December 29, 1609, in which Marius's three stars in a line exactly match Galileo's of January 8, 1610. At that time in Germany, the old Julian calendar was still in use — while Galileo, in Catholic Italy, used the Gregorian calendar introduced under Pope Gregory XIII in 1582. By January 1610, the Gregorian calendar (New Style) was running ahead of the Julian (Old Style) calendar by 10 days. Once the calendrical discrepancy was sorted out, Bosscha and Oudemans showed that Galileo indeed had seen the new moons first, but only by a single day!

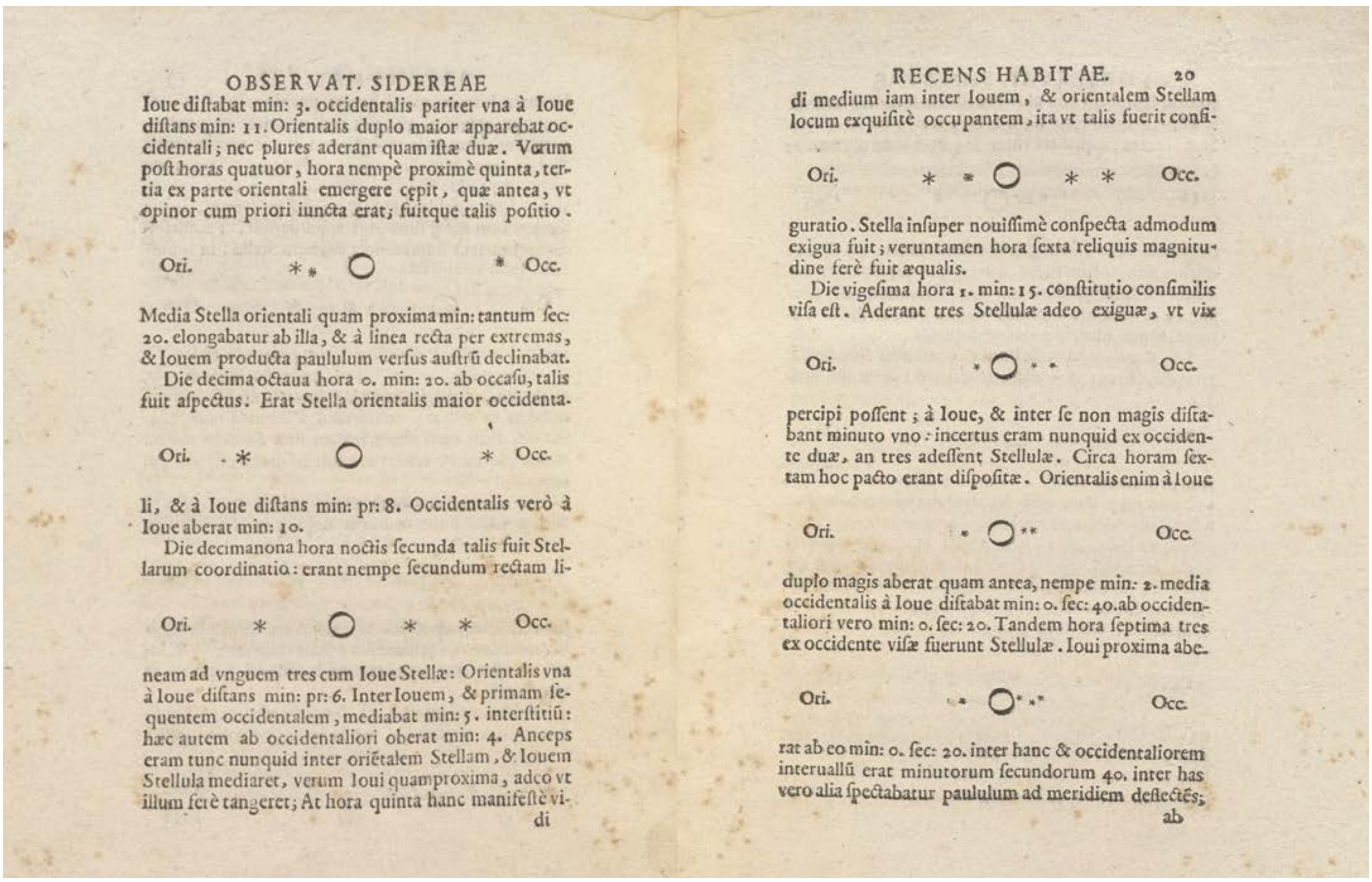

MUNDUS
IOVIALIS
ANNO M. DC. IX.
DETECTUS OPE
PERSPICILLI
BELGICI,
Hoc eſt,
QUATUOR JOVIALIUM PLANETARUM, CUM THEORIA, TUM TABULÆ, PROPRIIS OBSERVATIONIBUS MAXIME FUNDATÆ, EX QUIBUS ſitus illorum ad Iovem, ad quodvis tempus datum promptiſſimè & facilimè ſupputari poteſt.
Inventore & Authore
SIMONE MARIO GUNTZENHUSANO, MARCHIONUM BRANDENBURGENSIUM IN FRANCONIÂ MATHEmatico, puriorisque Medicinæ Studioſo.
Cum gratia & privil. Sac. Cæſ. Majeſt.
Sumptibus & Typis IOHANNIS LAURI Civis & Bibliopolæ Noribergenſis, ANNO
M. DC. XIV.

◀ **OPENING SALVO** In 1614 Simon Marius published his magnum opus, *Mundus Jovialis*, in which he presented his observations of the planet's four big moons and claimed to have seen them before Galileo, who, naturally, was outraged. In his 1623 book, *Il Saggiatore* (*The Assayer*), Galileo fired back, charging Marius with plagiarism — an accusation that destroyed Marius's reputation and was not refuted until centuries after his death.

The Name Game

As we are now four centuries after his death on January 5, 1625, Marius should not only be remembered as an independent discoverer of Jupiter's four largest satellites but also for the names by which these worlds are now known.

Calling the four bright Jovian moons the "Medicean Stars" had limited appeal outside France and Italy, where the Medicis were powerful. Marius, seeing the satellites as a miniature solar system, initially proposed calling them *Mercurius Jovialis*, *Venus Jovialis*, *Jupiter Jovialis*, and *Saturnus Jovialis*. However, at a conference at Ratisbon (Regensburg) in October 1613, he began to ponder Kepler's suggestion to name them for the mythical lovers of Jupiter. Marius seems to have been diffident at first, but by the time he wrote


OBSERVAT. SIDEREAE

Ioue diſtabat min: 3. occidentalis pariter vna à Ioue diſtans min: 11. Orientalis duplo maior apparebat occidentali; nec plures aderant quam iſtæ duæ. Verum poſt horas quatuor, hora nempè proximè quinta, tertia ex parte orientali emergere cępit, quæ antea, vt opinor cum priori iuncta erat; fuitque talis poſitio.

Ori. Occ.

Media Stella orientali quam proxima min: tantum ſec: 20. elongabatur ab illa, & à linea recta per extremas, & Iouem producta paululum verſus auſtrũ declinabat.

Die decima octaua hora o. min: 20. ab occaſu, talis fuit aſpectus. Erat Stella orientalis maior occidenta-

Ori. Occ.

li, & à Ioue diſtans min: pr: 8. Occidentalis verò à Ioue aberat min: 10.

Die decimanona hora noctis ſecunda talis fuit Stellarum coordinatio: erant nempe ſecundum rectam li-

Ori. Occ.

neam ad vnguem tres cum Ioue Stellæ: Orientalis vna à Ioue diſtans min: pr: 6. Inter Iouem, & primam ſequentem occidentalem, mediabat min: 5. interſtitiũ: hæc autem ab occidentaliori oberat min: 4. Anceps eram tunc nunquid inter oriẽtalem Stellam, & Iouem Stellula mediaret, verum Ioui quamproxima, adeo vt illum ferè tangeret; At hora quinta hanc manifeſtè vi-
di

RECENS HABITAE. 20

di medium iam inter Iouem, & orientalem Stellam locum exquiſitè occupantem, ita vt talis fuerit confi-

Ori. Occ.

guratio. Stella inſuper nouiſſimè conſpecta admodum exigua fuit; veruntamen hora ſexta reliquis magnitudine ferè fuit æqualis.

Die vigeſima hora 1. min: 15. conſtitutio conſimilis viſa eſt. Aderant tres Stellulæ adeo exiguæ, vt vix

Ori. Occ.

percipi poſſent; à Ioue, & inter ſe non magis diſtabant minuto vno: incertus eram nunquid ex occidente duæ, an tres adeſſent Stellulæ. Circa horam ſextam hoc pacto erant diſpoſitæ. Orientalis enim à Ioue

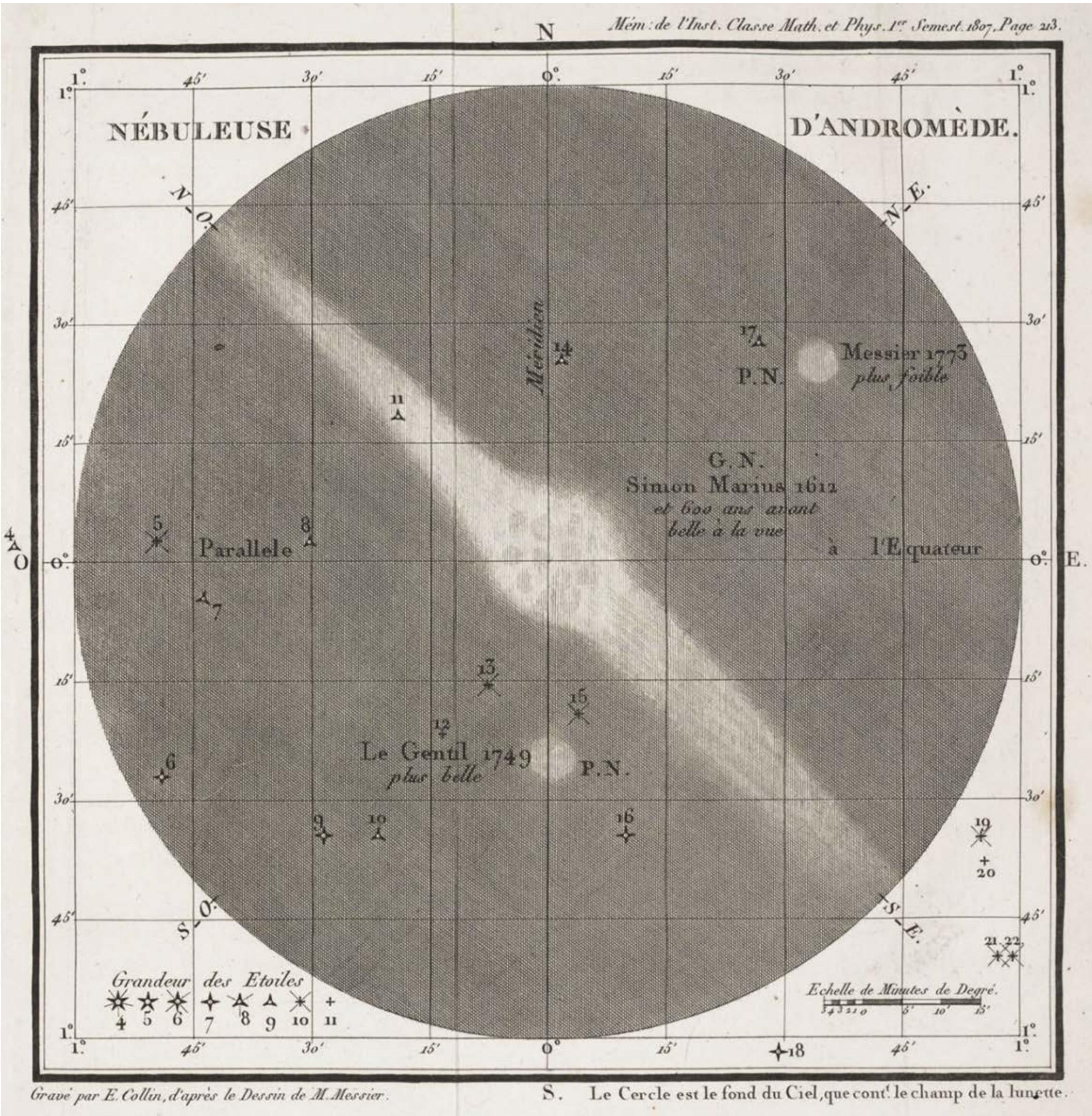
Ori. Occ.

duplo magis aberat quam antea, nempe min: 2. media occidentalis à Ioue diſtabat min: o. ſec: 40. ab occidentaliori vero min: o. ſec: 20. Tandem hora ſeptima tres ex occidente viſæ fuerunt Stellulæ. Ioui proxima abe-

Ori. Occ.

rat ab eo min: o. ſec: 20. inter hanc & occidentaliorem interuallũ erat minutorum ſecundorum 40. inter has vero alia ſpectabatur paululum ad meridiem deflectẽs;
ab

▲ **GALILEAN MOONS** This two-page spread from Galileo's *Sidereus Nuncius* (*Starry Messenger*) depicts Jupiter and the four moons he first saw on January 7, 1610. The sketches shown depict their changing positions from January 17th to 20th. Anyone who has viewed Jupiter with a small telescope at low magnification will be familiar with the configurations presented by Galileo.



▲ **MESSIER AND MARIUS** Apart from his independent discovery of the satellites of Jupiter, Simon Marius made many other important observations and is remembered for his observations of the Andromeda Galaxy with a telescope. In *Mundus Jovialis* he described the object as glowing ". . . like the flame of a candle seen through horn." This annotated sketch by Charles Messier attributes the galaxy's discovery to Marius, though in fact he was only the first to view it in a telescope.

PUBLIC DOMAIN

Mundus Jovialis, he decided to endorse the notion:

> *Jupiter is much blamed by the poets on account of his irregular loves. Three maidens are especially mentioned as having been clandestinely courted by Jupiter with success. Io, daughter of the River Inachus, Callisto of Lycaon, Europa of Agenor. Then there was Ganymede, the handsome son of King Tros, whom Jupiter, having taken the form of an eagle, transported to heaven on his back, as poets fabulously tell . . . I think, therefore, that I shall not have done amiss if the First is called by me Io, the Second Europa, the Third, on account of its majesty of light, Ganymede, the Fourth Callisto.*

This naming scheme long withered on the vine because Marius's claim to priority for their discovery was believed to be fraudulent. Other naming ideas were proposed, including one by Giovanni Domenico Cassini, director of Paris Observatory. After his own set of mythological names — Pallas, Juno, Themis, and Ceres — failed to win acceptance, Cassini, following Galileo's practice of marking the satellite closest to Jupiter with one dot, the next one with two dots, and so on, simply wrote Jupiter-I, Jupiter-II, Jupiter-III, and Jupiter-IV — the Roman numerals being assigned in order of each moon's distance from the planet, from closest to farthest. This proved convenient and remained in general use through the 19th and into the 20th century. So long as there were only four satellites and they were effectively mere dots in a telescope (and so long as Marius remained scorned as a fraud) there seemed no reason to change it.

A New Complication

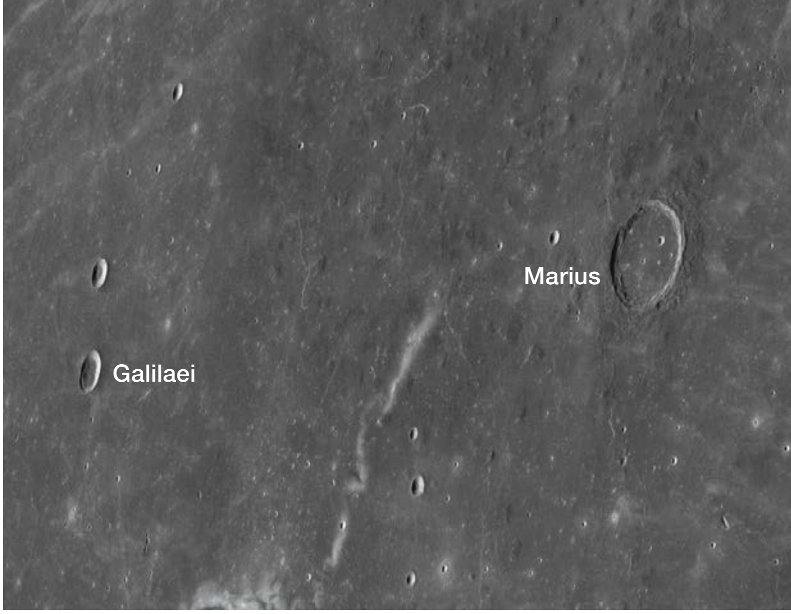
On September 9, 1892, the situation suddenly became more complicated when Edward Emerson Barnard used the 36-inch refractor at Lick Observatory in California to discover a fifth moon orbiting Jupiter. This satellite was tiny compared to the other four but orbited inconveniently close to the planet, ruining Cassini's established closest-to-farthest numbering scheme. Now, thanks to Barnard's discovery, new satellites had to be assigned numbers based on the order of discovery instead. Barnard continued to call his find "the Fifth Satellite," and disliked the name Amalthea (Jupiter's mythological nurse) proposed by the French astronomer Camille Flammarion. "The smallness of the satellite would make this name rather inappropriate," Barnard wrote.

Meanwhile, Simon Marius's naming scheme began to gain ground, in part owing to Bosscha and Oudemans's rehabilitation of his reputation and also because more and more tiny moons were being discovered, making the sequence of numerals hopelessly jumbled and confused. Thus, by 1951, when Seth B. Nicholson added a 12th Jovian satellite, the list became (outward from Jupiter): V, I, II, III, IV, VI, VII, X, XII, XI, VIII, IX.

In addition, improvements in the ability to resolve surface detail on the four big satellites, especially by Bernard Lyot and Audouin Dollfus at France's Pic du Midi Observatory in the 1940s and '50s, led to increased interest. The roman numerals no longer seemed appropriate for these planet-sized worlds. But how did the names proposed by Marius end up being the ones we use today? I asked Tenielle A. Gaither of the U.S. Geological Survey, who replied, "I have not been able to find a definitive answer to the question. There is nothing specific to the International Astronomical Union's approval of them on the Naming of Astronomical Objects page."

It appears that the names of the Galilean moons were simply grandfathered in by the IAU like the mythological names of the planets. One must conclude that they simply came into increasingly common use gradually. By the time the two Voyager spacecraft made their historic flybys of Jupiter in 1979, the names were already universally accepted and had been in use for many decades.

Small satellites have continued to turn up in scads. This year alone, Saturn gained 128 "new" moons, raising its total count to 274. After adopting mythologically based names for 59 of the 95 known Jovian satellites, the IAU threw in the towel and decided that in future mythological names will be issued only for newly discovered objects of significant scientific interest. (I challenge readers to recite even a handful of Jupiter's 59 by heart!) It appears that the naming scheme championed by Simon Marius has finally run its course.

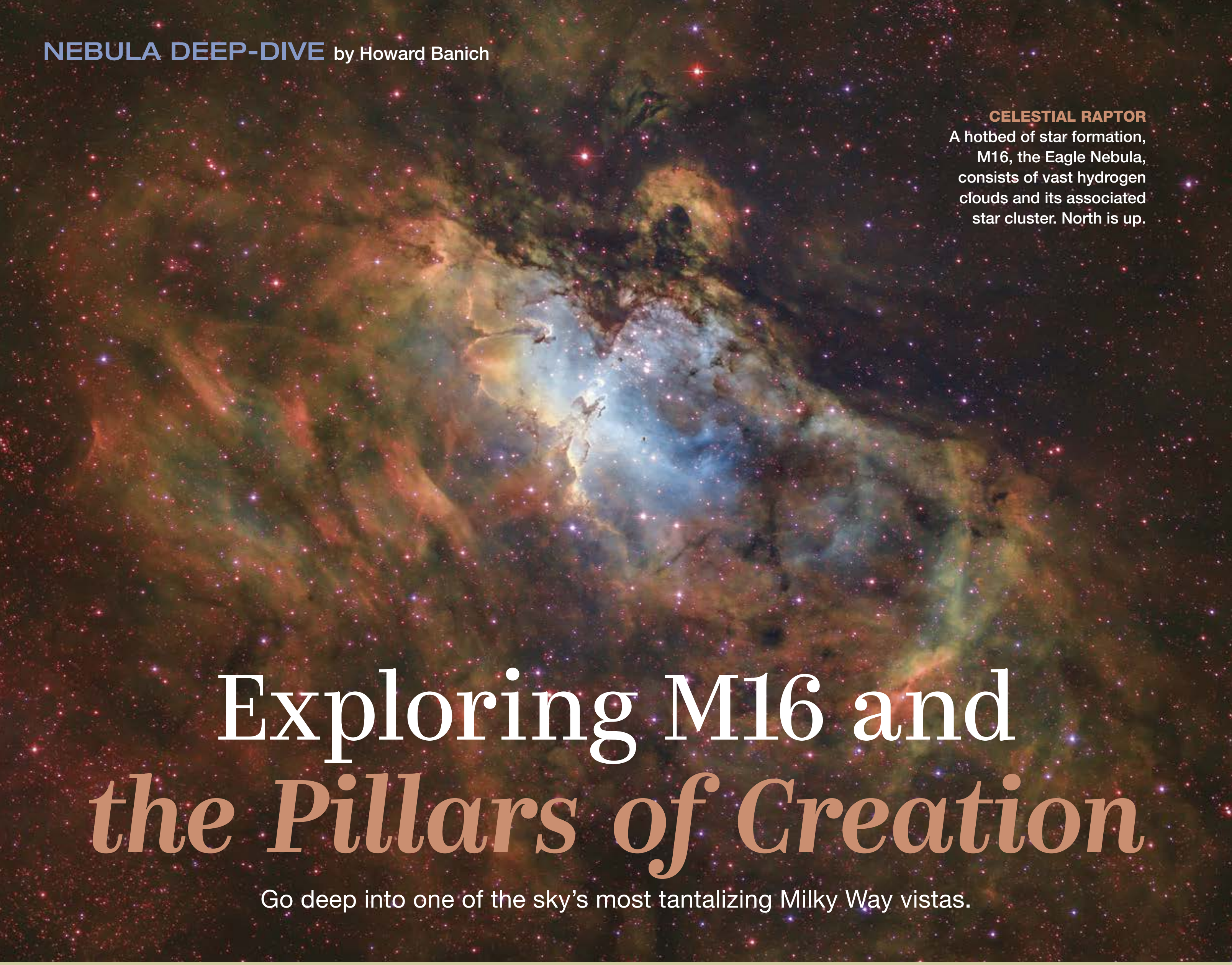


NASA / LRO

▲ **LUNAR TRIBUTE** Galileo Galilei may be more famous, but Simon Marius definitely has the better lunar crater. Marius spans 40 km (25 miles), and the German astronomer's name is also applied to the nearby 15-km-wide crater Marius A (and a collection of lesser ones), Rima Marius, and the lumpy volcanic formations called the Marius Hills. Galileo, on the other hand, is commemorated with a comparatively modest 16-km-diameter crater named Galilaei. As it happens, both craters are separated by only 350 km in Oceanus Procellarum. The reason Marius received the greater honor is that Giovanni Riccioli, the Jesuit priest-astronomer who devised the Moon's system of nomenclature, was a geocentrist, as was Marius; Galileo, on the other hand, had been condemned by the Church for advocating the heretical heliocentric system.

■ Contributing Editor **WILLIAM SHEEHAN** is the author of 30 books, including *Jupiter* (with Thomas Hockey). He also served on the IAU's Working Group for Planetary System Nomenclature for eight years.

 by Howard Banich



CELESTIAL RAPTOR A hotbed of star formation, M16, the Eagle Nebula, consists of vast hydrogen clouds and its associated star cluster. North is up.

Exploring M16 and *the Pillars of Creation*

Go deep into one of the sky's most tantalizing Milky Way vistas.

To my surprise, I've recently become enthralled by **M16**, the Eagle Nebula. Ever since I first became aware of this emission nebula/open star cluster combination in the constellation Serpens, the Serpent, I wanted to see as much detail as possible in the Eagle Nebula itself, the clouds of which are designated IC 4703.

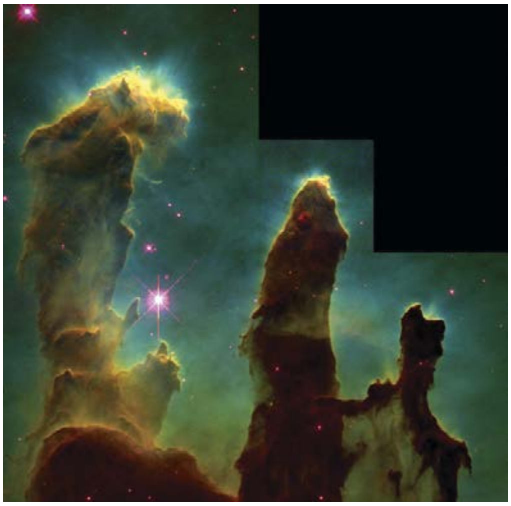
Unlike the dark channels and swirls so plainly visible in nearby M17 (the Omega Nebula) or M8 (the Lagoon Nebula), both in Sagittarius, the Eagle Nebula and its associated dark clouds are very challenging to observe. Regardless of the telescope or nebula filter I used, the nebula itself always looked uninspiring. M16's loosely scattered cluster of stars dominated the view, and that was never especially striking either. That's too bad since photographs show the region is filled with spectacular, intricate nebula structures.

The Eagle Nebula gained worldwide recognition in 1995 when the Hubble Space Telescope captured its iconic portrait (see page 29). Even though with my big scopes I could make out the vague, dark shape of the **Pillars of Creation** — towering tendrils of cool molecular hydrogen and dust — in the heart of IC 4703, it soon became obvious that I'd never be able to see much detail.

But M16 kept calling me back, and on the best summer nights I'd return to see if I could detect more features. The answer was always a disheartening "no" — that is, until one happy night in June 2022 while attending the Golden State Star Party in Northern California. That's when my friend Ed Allen introduced me to his night-vision device (NVD) while I was observing the Pillars. This bit of technology works by amplifying available light, even at very low levels (see the March issue, page 25).

With understated but unmistakable glee, Ed attached his NVD PVS-14 night-vision monocular fitted with a hydrogen-alpha (Hα) filter into the focuser of my 30-inch f/2.7 telescope. This would be my very first look through a modern NVD, and I didn't know what to expect. After Ed showed me how to focus it and adjust the brightness, I peered into the device's eyepiece-like viewscreen.

But before I describe the view, let's explore M16's physical nature and its layered history to give some context to what I saw through Ed's miraculous optoelectronic device.



◀ **HUBBLE EGGS** This iconic portrait of M16's Pillars of Creation, captured by the Hubble Space Telescope in 1995, shows dense, compact pockets of interstellar gas called evaporating gaseous globules, or EGGs, where newborn stars emerge. The field is about 2½′ wide.

The Star Queen Nebula

M16, also cataloged as NGC 6611, is located about 5,700 light-years away in the Sagittarius arm of our Milky Way Galaxy. Its most powerful star is **HD 168076**, which shines at magnitude 8.3 and is a binary comprising two O stars with a combined 80 solar masses. Together, they put out about 1 million times the luminosity of the Sun. This powerhouse couple is estimated to be about 1 to 2 million years old, but the overall age spread of M16's stars is about 1 to 6 million years.

The next most powerful O star is neighboring **HD 168075** (magnitude 8.8). Together, HD 168076 and HD 168075 are the two main sources of the intense ultraviolet radiation responsible for ionizing and dispersing the clouds of hydrogen in the entire IC 4703 region. (These processes are called *photoionization* and *photoevaporation*, respectively.) Both stars are classified as *young stellar objects*, which means they're still maturing toward the main-sequence stage.

Swiss astronomer Jean-Philippe Loys de Cheseaux discovered M16 around 1745. Famed French astronomer Charles Messier rediscovered the cluster in 1764 and made it the 16th object on his now-famous list. Messier's description is intriguing: "A cluster of small stars, enmeshed in a faint glow . . . with an inferior telescope it appears like a nebula."

As a counterpoint, William Herschel didn't see any nebulosity in 1783 with his 12-inch telescope, but he estimated perhaps 100 stars were part of M16's open cluster. Modern estimates put the stellar count far higher, at around 8,100 members, the vast majority of which are not visible through amateur telescopes.

The nebulosity (subsequently cataloged as IC 4703) was definitively observed in 1876 by French astronomer-artist Étienne Léopold Trouvelot using the 26-inch refractor at the U.S. Naval Observatory in Washington, DC. His discovery notes read, in part:

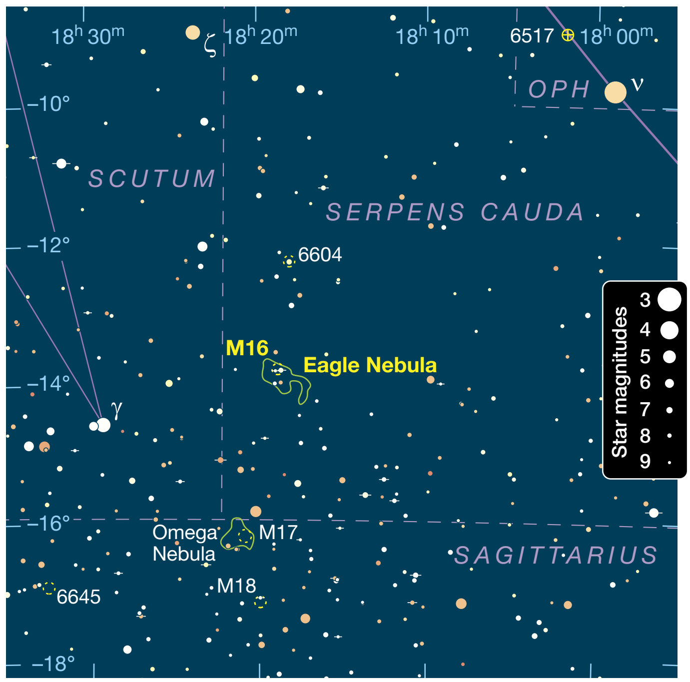
> *. . . its general form is that of an open fan, with the exception that the handle is wanting, with deeply intended branches on the preceding side, where the brightest stars of the cluster are grouped. From this peculiar form, this object might appropriately be called the Fan nebula.*

While Trouvelot's proposed name didn't stick, the name Star Queen Nebula coined by American astronomer Robert Burnham, Jr., in 1978 has fared slightly better. Burnham thought the name Eagle Nebula "seems perhaps a little too prosaic for a vista of such cosmic splendor." He has a point, but the overall shape of IC 4703 does resemble a large bird, so the Eagle name fits. Who coined it, and when, seems lost to time, though.

Whatever the name, the Eagle Nebula spans approximately 55 by 70 light-years across. More precisely termed an *H II blister*, the photoionized/photoevaporated nebula we see is just part of a much larger molecular cloud. The Eagle Nebula was likely formed by the collision of two vast molecular clouds about 1 to 2 million years ago, which kick-started its latest round of star formation.

Cosmic Pillars

It was American astronomer John C. Duncan who first noted the so-called Pillars of Creation in 1920 with the 60-inch telescope on Mount Wilson in California. His discovery photo clearly shows the Pillars, which he initially thought



▲ **IN SERPENS** The Eagle Nebula is located in the tail (Cauda) of Serpens, the celestial Serpent, at right ascension 18^h 18.8^m, declination −13° 47′ (J2000.0). The fan-shaped nebulosity lies 2½° west-northwest of 4.7-magnitude Gamma (γ) Scuti, in the rich star fields of the Milky Way.

NASA / ESA / STSCI / ASU / J. HESTER & P. SCOWEN might have been a photographic artifact:

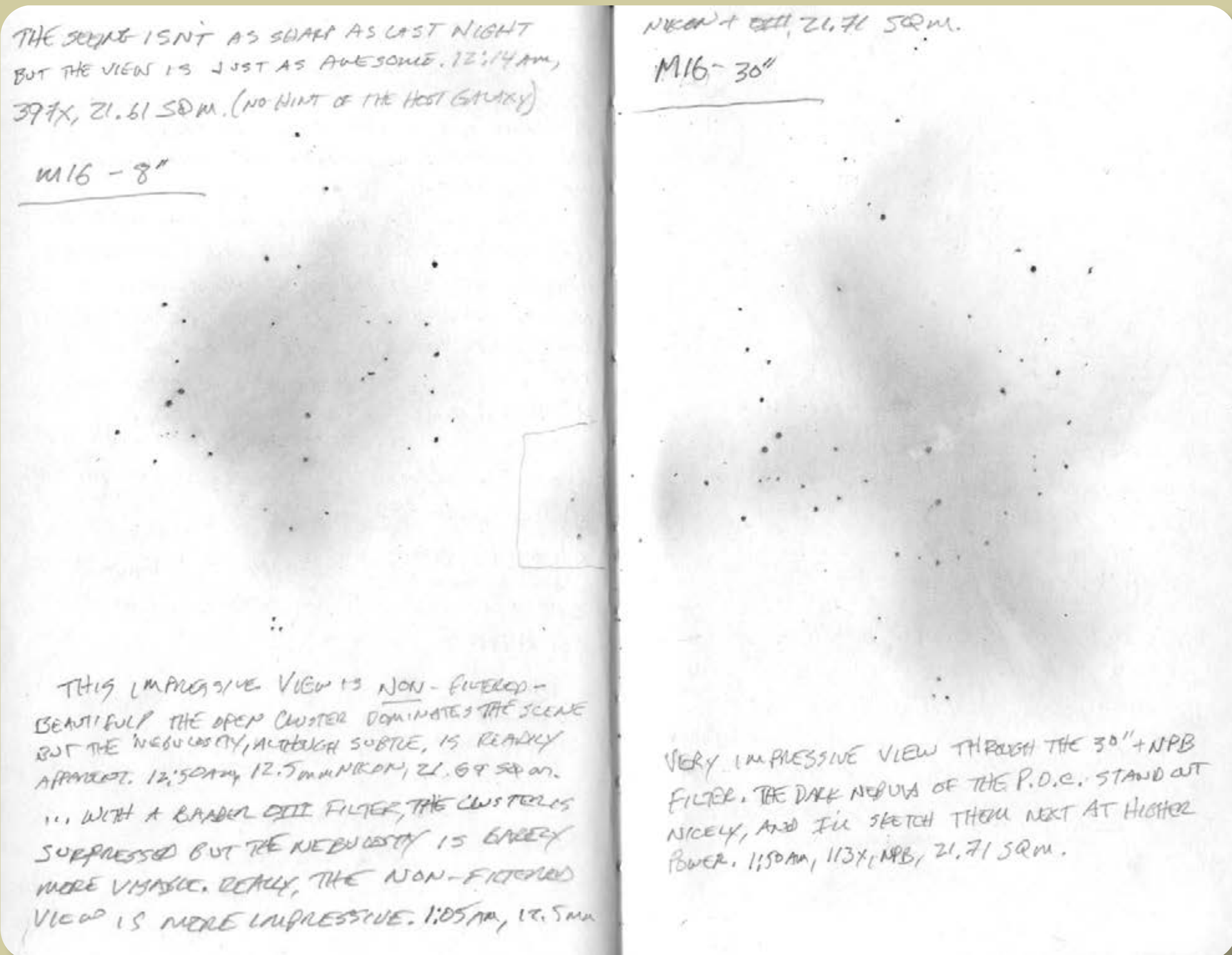
> *The most interesting feature, however, as disclosed by the present photograph, is the system of sharply defined dark markings of which the most conspicuous is on the southeast side, extending inward beyond the center. This marking so resembles the result of irregular flow of [photographic] developer that, when it appeared on an earlier negative, its reality was questioned until it was fully verified by the present plate . . .*

Duncan also commented that visually, the nebulosity of M16 was "no more difficult than the nebula in the Pleiades, and I have seen it easily with the 12-inch refractor of the Whitin Observatory [in Wellesley, Massachusetts]."

However, Duncan didn't come up with the name Pillars of Creation. Instead, the phrase appears to originate from an 1857 sermon given by English preacher Charles Spurgeon. At the time, Spurgeon used it to connote the physical and spiritual forces that held up the universe. The name somehow became associated with M16 thanks to the Hubble's famous image.

The three main Pillars are designated **I**, **II**, and **III**, from east to west. Pillar **V** is known as "the Spire," while **IV** is a thin, much less-defined feature to the south of I, II, and III. The Pillars are made of interstellar gas and dust with a dense molecular cap that's being slowly photoevaporated by the intense ultraviolet radiation from the aforementioned O stars. The caps temporarily protect the less dense gas and dust of the Pillars behind them.

These Pillars, or "elephant trunks," are sites of star formation and could be eroded away before their young stars are fully formed. The Pillars' edges are serrated with many *evaporating gaseous globules*, or EGGs, which are essentially smaller versions of the Pillars themselves.



▲ **STAR LOG** The author's very first eyepiece sketches of the Eagle Nebula, made during the 2023 Oregon Star Party, illustrate the difference between the view through his 8-inch telescope (at left) and his 30-inch. Note how the Pillars of Creation and the Spire appear only like subtle shadows through the 30-inch fitted with a narrowband nebula filter. North is to the left.

For a sense of scale, the Spire is about 9.5 light-years long, making this structure approximately one light-year longer than the distance from Earth to Sirius. I can't help but think of this every time I look at Sirius.

Finally, there are the relatively small, dark, dense **Bok globules** scattered throughout the Eagle that are also likely spots of star formation. These globules are the cherries on top of a remarkable H II region.

Visual Impressions

To my eye, there are four levels of detail that I can discern within M16. The first is the open cluster, which is visible in an 80-mm scope even under a light-polluted sky. The second level is the Eagle Nebula itself, which can be seen with an 8-inch scope without a nebula filter under excellent sky conditions. The third is the Pillars of Creation, which can be detected with a much larger telescope. And now, fourth, is the NVD-amplified view of the nebulosity with an Hα filter.

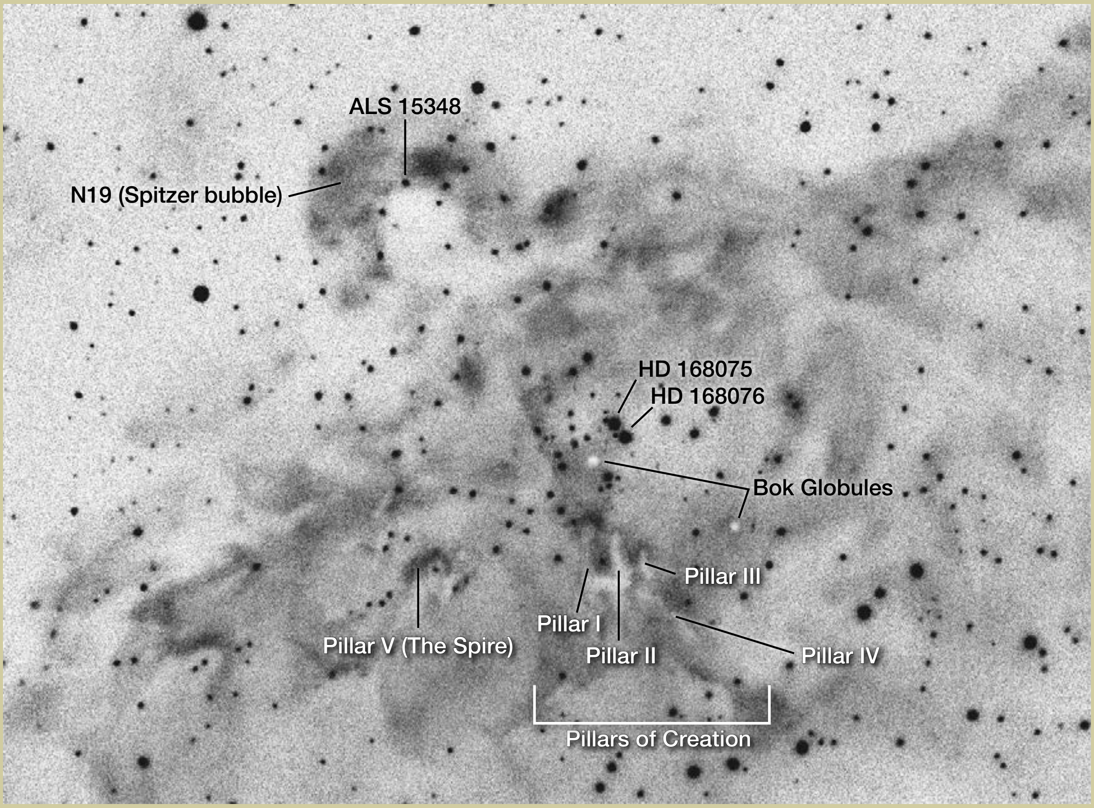
As with all deep-sky objects, a dark, transparent sky free from atmospheric gunk and light pollution, along with properly dark-adapted eyes, are required to see the Eagle Nebula and the Pillars at their best. It doesn't take much to degrade the view, so if you don't see much detail at first, it doesn't mean you never will.

To my surprise, the most enjoyable sighting of M16 through my 8-inch f/3.3 Dobsonian was without a nebula

Night-Vision Technology

Although night-vision devices can help observers see faint deep-sky objects, they are expensive to purchase (ranging from about $2,000 to $5,000) and are subject to export restrictions.

▲ **A MAELSTROM OF MAGNIFICENCE** "All I could say was 'Wow!' over and over again," says the author. "My sketch gives an idea of what I saw using a night-vision device and hydrogen-alpha filter on my 30-inch, but it falls short of conveying the impact of seeing the Eagle Nebula this way for the first time." For this drawing, he attached his NVD with 6.5-nanometer-bandpass Hα filter to a 41-millimeter eyepiece, which gave an effective magnification of 58×. He also added a grainy texture that simulated the electronic noise of the NVD. North is to the upper left.


ALS 15348
N19 (Spitzer bubble)
HD 168075
HD 168076
Bok Globules
Pillar III
Pillar I
Pillar V (The Spire)
Pillar II
Pillar IV
Pillars of Creation

◀ **A PLETHORA OF DETAILS** *Top:* This close-up of the Eagle Nebula, which the author sketched using his 30-inch scope and NVD with Hα filter, pinpoints the location of the features discussed. *Bottom:* Compare the drawing to this image captured by California astrophotographer Jim Thommes with an Explore Scientific 152-mm Maksutov-Newtonian telescope and SBIG ST8300M camera. The total exposure time was 112 minutes through Hα and LRGB filters. North is to the upper left in both views.

▶ **LIMITING FACTOR** According to the author, one of the shortcomings of the NVD is that it doesn't support magnification very well. "Much past 180×, electronic noise in the NVD is magnified enough to be bothersome," he says. "I did use 183× with the 30-inch at times, but I found 113× gave a cleaner image while sketching the Pillars region." North is up.

filter during the 2023 Oregon Star Party. In my observing log, I wrote:

This impressive view is non-filtered — beautiful! The open cluster dominates the scene but the nebulosity, although subtle, is readily apparent. With a Baader O III filter, the cluster is suppressed but the nebulosity is barely more visible. Really, the non-filtered view is more impressive. 53×, 21.70 SQM [Sky Quality Meter].

However, a narrowband nebula filter helped enhance the view through my 30-inch:

Very impressive view through the 30-inch and NPB filter. The dark nebula of the POC [Pillars of Creation] stands out nicely . . . 113×, 21.71 SQM.

Although my drawings of M16 aren't spectacular, the process of sketching focused my attention and finally helped me appreciate the visual features of the Eagle Nebula.

Night-Vision Observing

Let's return to the story of my first encounter with M16 using Ed's NVD monocular and Hα filter. When I peered into the eyepiece-like viewscreen, I saw the Eagle Nebula of my dreams!

There was *sooo* much nebulosity, and it was not only everywhere, but it was also bright and exquisitely detailed. I saw swirls, streamers, and dark nebulae throughout the field of view. The Pillars of Creation were so obvious, as was the Spire with its dragonlike head. It was indeed, as Burnham described it, "a vista of such cosmic splendor" that any Star Queen would be happy to call home.

My observing notes captured my excitement:

Then everything changed. Ed Allen brought over his image intensifier and knocked me out. Gobsmacked. Amazed. Stunned. Incredulous — WOW!!!

That might be the biggest "wow" I've ever written in my notebooks, but then this was about the biggest leap I've experienced in my observing. Right away, I resolved to get one of those gadgets. And a few months later, I did.

Since that night, I've observed M16 many times and at different magnifications using my Hα-filtered NVD. I have a new appreciation for the nebula's name: It really does look like an eagle through the NVD in both my 8-inch and 30-inch scopes.

The feature that surprised me the most was the large nebulous loop on the north side of IC 4703. If I knew it existed before, I'd forgotten. Seeing it was a thrill. It's designated **N19** and is an example of a "Spitzer bubble," likely created by the collision of the two molecular clouds mentioned earlier and is photoionized by the 12th-magnitude O star **ALS 15348**.

Because the views provided by the NVD were so overwhelming, I printed an Hα photo of M16 I found online to use at the scope as a sketching guide. To my delight, the match between the photo and what I could see with the NVD and my 30-inch was excellent. In the scope I was observing as much detail as in the photograph, except in real time!

I began sketching, but thick smoke from wildfires severely limited my telescope time during the summers of 2023 and 2024. I finished the drawings presented here using my notes and the guide photo.

However, my favorite experience was showing NVD views of M16 to others during public night at last year's Golden State Star Party. I fondly remember two friendly amateurs who wandered over for a look. One reacted much the same way I did two years earlier — he could barely believe what he was seeing. Then his astrophotographer buddy looked, and after an initial outburst of excitement he went silent.

After a few moments, I heard him half-whisper to himself, "I hope my M16 image turns out this well . . ."

■ Contributing Editor **HOWARD BANICH** enjoys using a night-vision device but remains a visual observer at heart.

OUR GALAXY
The Milky Way's disk as seen from Saskatchewan Summer Star Party in August 2024.

ALAN DYER

A Stargazer's Guide to the Milky Way

Most of what we see in the night sky reflects the structure of our galaxy and the mix of stars it has created.

On a dark night far from city lights, stars stretch from horizon to horizon: a red supergiant here, blue giants there, aging orange giants to the north, and white main-sequence stars overhead. Meanwhile, winding across the sky, a ghostly band of light shimmers — our edge-on view of the Milky Way Galaxy.

All Stars Great and Small

In fact, it's the Milky Way Galaxy that largely dictates why we see what we see among the stars. Every star the naked eye can spy belongs to our galaxy, but some stellar types are more common than others. You might think that the easiest stars to observe are the ones that are the most numerous, but no, ordinary stars are actually difficult, because they're small and feeble, emitting little light into space. In contrast, though the most luminous stars are rare, they're easy to see, because they shine across vast distances.

Let's start with the most familiar star, the Sun. The Sun is far above the stellar average. Most stars — 95% of them — emit less light than the Sun. That's because the Milky Way's frigid star-making clouds create far more small stars than large ones. About 75% of stars are red *M*-type main-sequence stars, which are much smaller, cooler, and dimmer than the Sun. Red dwarfs eke out so little light that not a single one is visible to the naked eye — even though one red dwarf, Proxima Centauri, is the nearest individual star to the Sun. Another 11% of stars are orange dwarfs, or *K*-type main-sequence stars. Though larger, warmer, and brighter than red dwarfs, orange dwarfs are still less luminous than the Sun, and few are visible to the naked eye. An additional 6% of stars are white dwarfs (*S&T:* Dec. 2022, p. 28), all of which elude the naked eye.

This leads to an apparent contradiction. Even though most stars that exist are less luminous than the Sun, if you point to any star you can see with your unaided eye, there's an overwhelming chance the star emits more light than the Sun. Thus, with few exceptions, we see stellar celebrities.

These appear among the Milky Way's various stellar populations. A stellar population is a widespread group of stars that share similar locations, kinematics, chemical compositions, and ages. Our galaxy has several such populations: the pancake-shaped *thin disk*, which sports the spiral arms; the older and puffier *thick disk* that intermingles with it; and a rounder *halo* of old stars that came mostly from small, metal-poor galaxies that crashed into the young Milky Way long ago. We can see denizens of each of these populations above our heads.

Welcome to the Thin Disk

The thin disk makes the biggest splash in our sky. Not only do we live in the thin disk, which means it's all around us, but the thin disk is also the galaxy's youngest, brightest, and most flamboyant stellar population (*S&T:* Aug. 2023, p. 34).

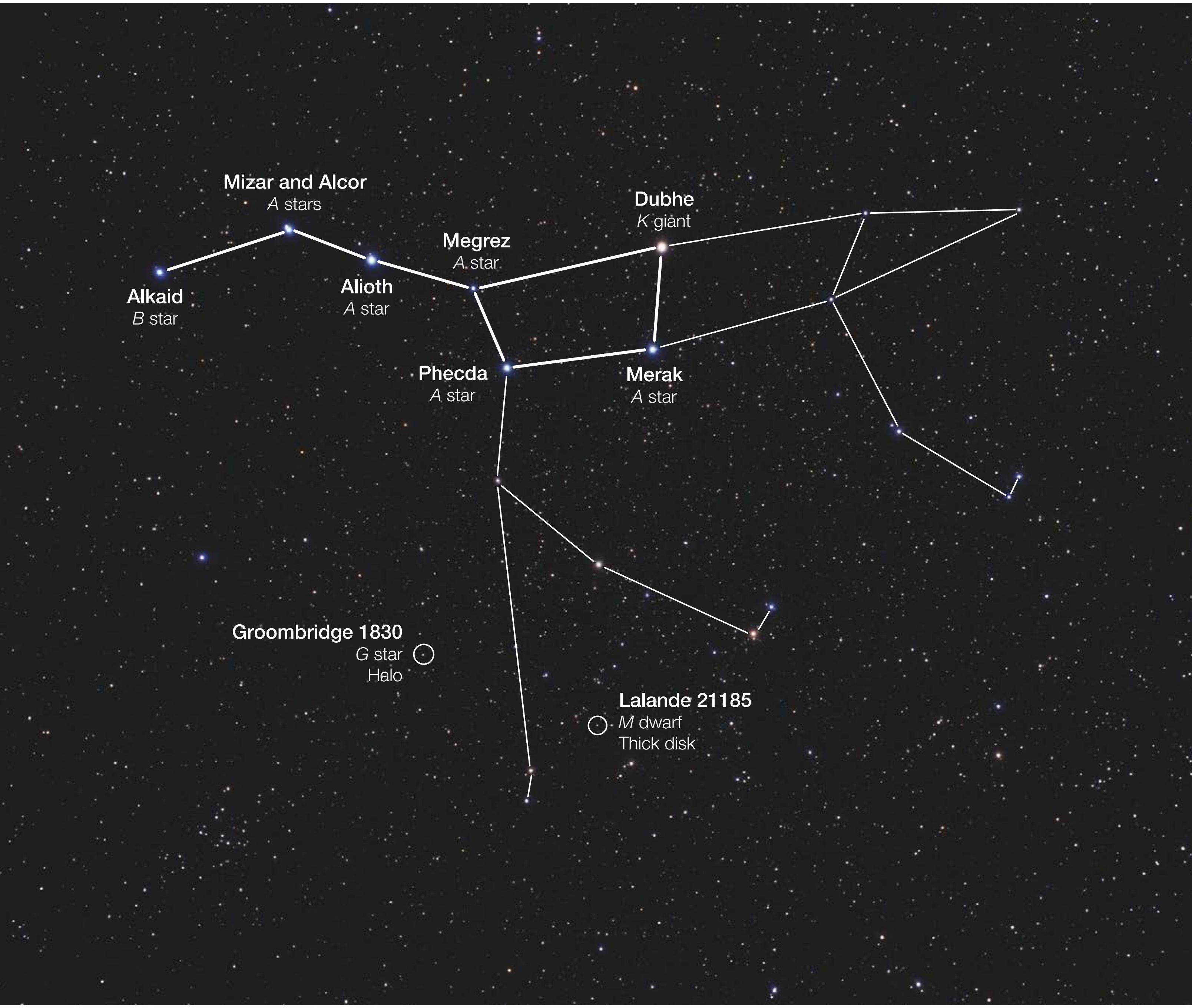
As its name implies, the thin disk is flat. It is some 120,000 light-years in diameter but only about 2,000 light-years thick in the Sun's vicinity. The Sun and Earth reside just 68 light-years above the disk's midplane, according to an analysis of data from the Gaia spacecraft that Morgan Bennett and Jo Bovy (both at University of Toronto) published in 2019. This number is small potatoes compared with the thin disk's height. That's why we see equal numbers of stars above and below the disk.

When I started to learn the night sky, I was struck by how many stars are either white *A*-type main-sequence stars or else orange *K*-type giants — and disappointed by the lack of yellow *G*-type main-sequence stars like the Sun. The brightest nighttime star, brilliant Sirius, is an *A*-type main-sequence star. So are the summer gems Vega and Altair, plus autumn's Fomalhaut and winter's Castor, a sextuple system that features two *A* stars. And three of the brightest stars — Arcturus, Aldebaran, and Pollux — are *K* giants.

I saw this same trend in the best-known star pattern of all, the Big Dipper. Five of its seven stars are *A* main-sequence stars, and another — Dubhe, the star closest to Polaris — is

What is a main-sequence star?

A star, like the Sun, that generates its power from nuclear reactions that convert hydrogen into helium at the star's center. Most stars are main-sequence stars. The chief exceptions: *pre-main-sequence stars*; *subgiants* (stars transitioning from the main sequence to the giant stage), *giants*, and *supergiants*; and *white dwarfs*.



▲ **THREE IN ONE** Ursa Major boasts well-known stars that belong to all three stellar populations: the thin disk (including stars of the Big Dipper, mentioned in the text, which are labeled here), the thick disk (Lalande 21185), and the halo (Groombridge 1830). Of the Big Dipper's stars, only Dubhe has evolved off the main sequence to become an orange giant.

AKIRA FUJII

an orange giant. Plus, the bowl of the Little Dipper has its own orange giant, Kochab.

There's a reason for all this. First, *A*-type main-sequence stars are about twice as massive as the Sun, so they shine more brightly, which makes them easy to see. Of all the stars located within 30 light-years of Earth, the most powerful is Vega, followed by Sirius, Fomalhaut, and Altair — *A* stars all. Yes, they're rather rare, accounting for only 1% of nearby stars, but they're not as rare as more massive stars. They therefore occupy the sweet spot between high luminosity and extreme rarity.

Second, these stars are younger than the Sun, because their greater luminosities come with a cost: The stars die within a couple billion years of their birth. They therefore exist here in the thin disk, which is still forming new stars.

And the orange *K* giants? Well, after *A* main-sequence stars exhaust the hydrogen fuel at their centers, the stars expand and eventually become orange giants. Ditto for most *B*-type main-sequence stars as well as all *F*- and *G*-type main-sequence stars. Furthermore, orange giants are luminous, generating roughly 100 times the light of the Sun. So they're easy to see. Of all the stars located within 100 light-years of Earth, the most powerful is Aldebaran, the beautiful orange giant glinting in the eye of Taurus, the Bull.

The second most powerful star within that same distance marks the blue heart of Leo, the Lion. Regulus is a *B*-type main-sequence star. Because of their great luminosity, *B* stars also spangle the night: for example, Spica in Virgo, the southern star Achernar in Eridanus, and Alkaid, the star at the tip of the Big Dipper's handle. *B* stars outweigh *A* stars and so are rarer. In fact, Regulus is the nearest one, 79 light-years from Earth. Within that same distance shine more than a dozen of the less luminous *A* main-sequence stars, including two — Denebola and Delta Leonis — in Leo itself.

And yellow *G* stars like the Sun that I had hoped to see? These stars are appealing because they might possibly have someone on an orbiting planet looking our way. But glimpsing Sun-like stars is not so easy. *G*-type main-sequence stars have decent numbers, accounting for 5% of all stars, but these suns emit just a fraction as much light as an *A* star. Thus, although a number of *G*-type main-sequence stars are visible to the naked eye, only one such star — our close neighbor Alpha Centauri A — ranks among the very brightest nighttime stars, and it's too far south for most of us to see.

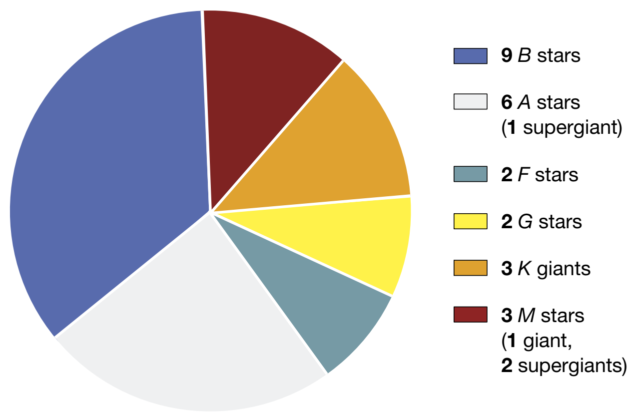
Welcome to the Local Spiral Arm

On the positive side, we are lucky to live in a spiral arm (*S&T:* Nov. 2019, p. 16). The Local Arm adds luster to the night, because spiral arms create most of the galaxy's stars. The elite among these are quite massive, so they die soon after birth, never leaving their spiral arm. Before they perish, though, they shower the galaxy with so much light that we can see them from great distances. Indeed, of the 25 brightest stars in our sky, the four most remote are all massive and extremely luminous: the red supergiants Antares in Scorpius and Betelgeuse in Orion, the white supergiant Deneb in Cygnus, and the blue supergiant Rigel in Orion.

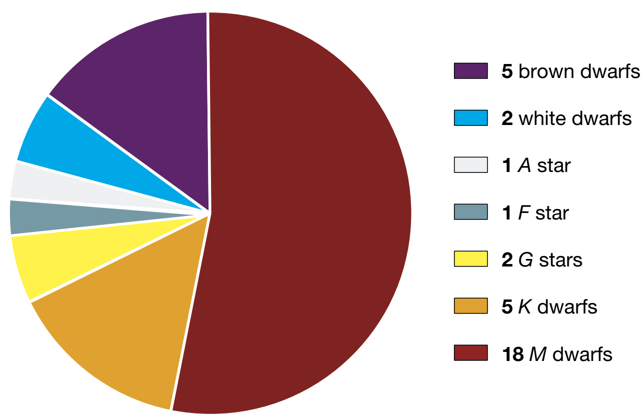
These four luminaries are so far off that we don't know their exact distances. That means we don't know their exact luminosities, either. But despite the uncertainties, we know that Rigel, located perhaps 800 or 900 light-years from Earth, is the most luminous of the many millions of stars within 1,000 light-years of us. And Deneb, which may lie as much as 2,600 light-years away, is even more powerful. If that distance is correct, then Deneb emits more light in a single minute than the Sun does in four months.

It's no surprise that such a powerful and distant star shines in Cygnus, for in this constellation we look down our own spiral arm. Cygnus is rich in many other far-off sights, including the North America Nebula, the Veil Nebula, and two of the first black holes ever found, Cygnus X-1 (7,200 light-years from Earth) and V404 Cygni (7,800 light-years).

Brightest Nighttime Stars



Nearest Stars to the Sun



▲ **MORE THAN MEETS THE EYE** The brightest stars we see tend to be intrinsically big and luminous, but they aren't representative of the small, dim dwarfs that are the Sun's most common neighbors. Three stars belong to both categories: Sirius (type *A*), Procyon (type *F*), and Alpha Centauri A (type *G*).

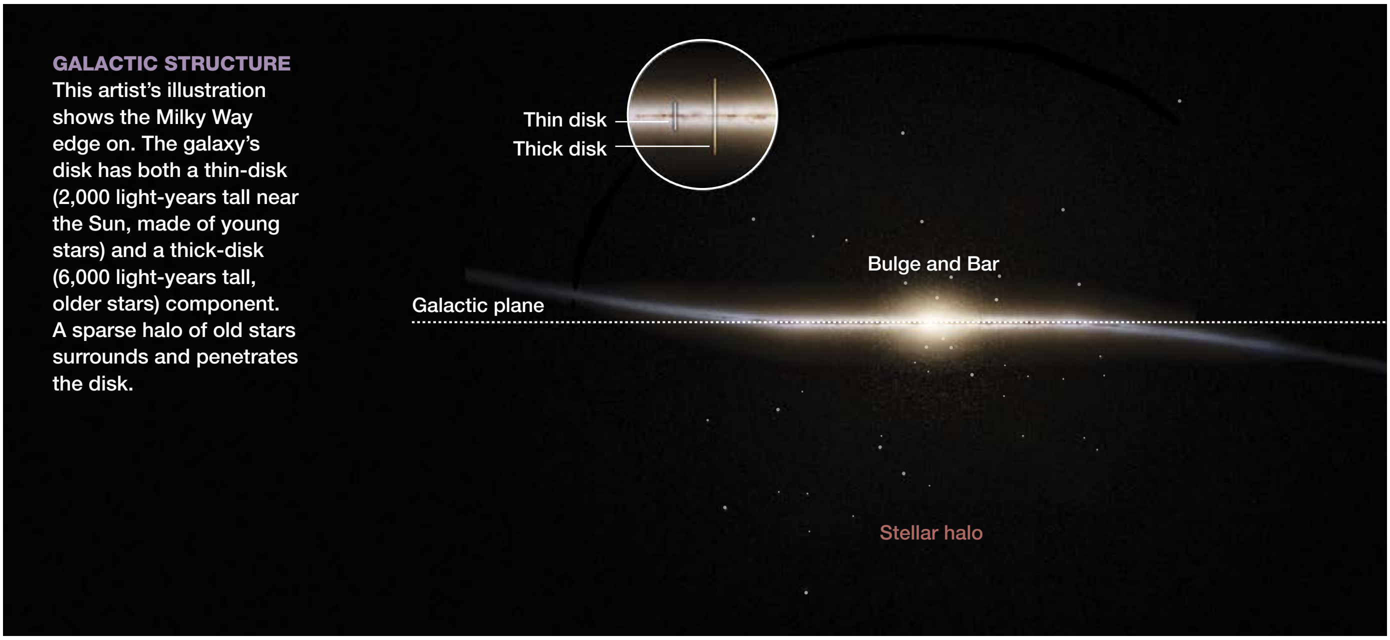
BEATRIZ INGLESSIS / *S&T*, SOURCE: THE AUTHOR

Spectral Type

Class	Visual Color
O	Bluish
B	Blue-white
A	White
F	Yellow-white
G	Yellowish
K	Orange
M	Reddish

The Local Arm harbors interstellar gas and dust that give birth to new stars. For example, the Rho Ophiuchi cloud complex spawns stars some 450 light-years from us. At a similar distance lie the clouds of Taurus and Auriga, which have created the prototype newborn star T Tauri (*S&T:* Feb. 2021, p. 12). Farther afield, and visible to the naked eye, is the Orion Nebula, 1,350 light-years from Earth and just south of the Belt of Orion.

At the inner edge of the Local Arm shines the Scorpius-Centaurus Association, a group of massive stars that formed



GALACTIC STRUCTURE This artist's illustration shows the Milky Way edge on. The galaxy's disk has both a thin-disk (2,000 light-years tall near the Sun, made of young stars) and a thick-disk (6,000 light-years tall, older stars) component. A sparse halo of old stars surrounds and penetrates the disk.

STEFAN PAYNE-WARDENAAR / MPIA

during the past 22 million years. Most of these bright stars, such as Beta and Delta Scorpii, are blue. But there's a beautiful exception: red Antares, the heart of Scorpius, the Scorpion. Antares was once blue like its bright mates but expanded into a cool supergiant. It will probably be the next star in the Scorpius-Centaurus Association to explode as a supernova.

At still greater distances, you can glimpse two naked-eye sights in neighboring spiral arms. The Lagoon Nebula, 4,000 light-years from Earth in the constellation Sagittarius, is forging new stars. This nebula belongs to the Sagittarius Arm, the spiral arm interior to our own. And in the opposite direction, in the constellation Perseus, lies the youthful Double Cluster, h and Chi Persei, sporting red and blue supergiants. It's about 7,600 light-years from Earth in the Perseus Arm, the spiral arm exterior to the Local Arm.

But if you know where to look, you can spot newborn stars much closer to home. A mere 32 light-years from Earth, east of Sagittarius and west of Fomalhaut, shines the 8.6-magnitude red star AU Microscopii. It's so young it doesn't yet generate its light the way the Sun does. Instead, this pre-main-sequence star shines almost entirely from gravity power: The star's own gravity squeezes its gas. By the laws of thermodynamics, if you squeeze a gas, it heats up. The heat causes the gas to start emitting visible light, and a star is born. Thus, to be a star, you don't have to use nuclear reactions.

Very early in its life, before AU Microscopii was 1 million years old, it did use nuclear power to consume its deuterium, a heavy isotope of hydrogen that burns at just 1 million kelvin (1.8 million Fahrenheit). But the star is now some 22 million years old. Regular hydrogen, the same fuel that powers the Sun, currently makes no real contribution to this young star's light — and won't for tens of millions of years, until AU Microscopii's core finally gets hot enough to burn this potent fuel in earnest.

Another pre-main-sequence star, AP Columbae, is even closer, 28 light-years from Earth. Also a red star, AP Columbae is fainter, glowing at 13th magnitude south of Orion.

The Plot Thickens

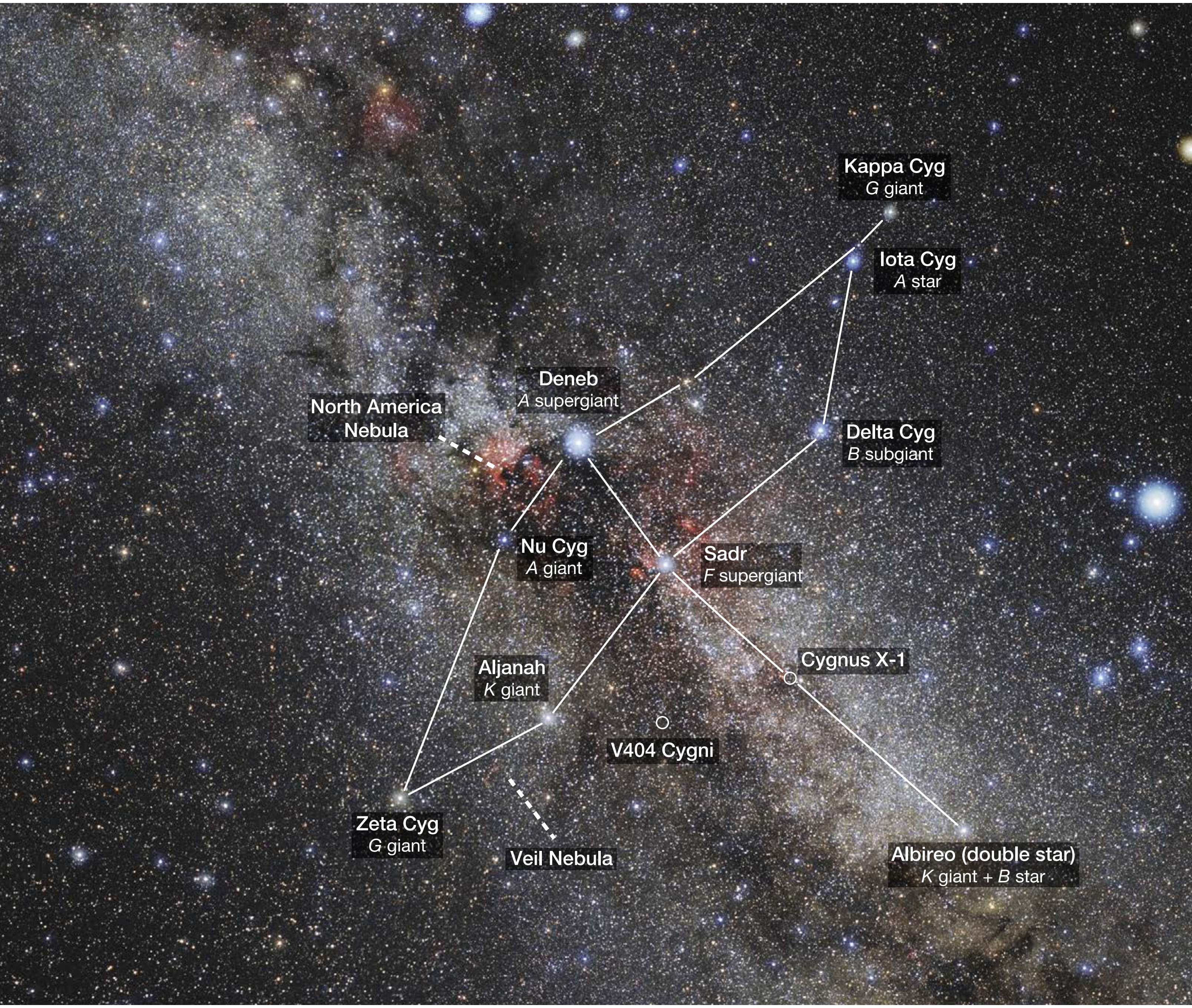
Although the thin disk decorates the night with countless stars, other stellar populations also contribute. The fourth-brightest star in the night — orange Arcturus in Boötes — belongs not to the thin disk but to an older stellar population known as the thick disk.

Whereas the thin disk measures about 2,000 light-years from top to bottom in the Sun's vicinity, the thick disk is about 6,000 light-years thick. Its diameter is not as great as the thin disk's, which means that if we were much farther from the galactic center than we are, we'd see few thick-disk stars near us.

As it is, 10% to 15% of the nearest stars belong to the thick disk. In work published in 2022, Maosheng Xiang (now at National Astronomical Observatories, China) and Hans-Walter Rix (Max Planck Institute for Astronomy, Germany) estimated that thick-disk stars range in age from 8 to 13 billion years old. All of the thick disk's massive stars have therefore died; the most luminous thick-disk stars are aging giants like Arcturus.

Arcturus is about as massive as the Sun but has already used up the hydrogen at its center and expanded to become a *K* giant. It shows what our own star will look like many billions of years from now.

As a thick-disk star, Arcturus has quite an elliptical orbit around the galactic center. The star's velocity relative to the Sun is therefore high, because the Sun's orbit around the galactic center is fairly circular. Thus, Arcturus led to the discovery of stellar proper motion — by French astronomer Jacques Cassini — back in 1738 (*S&T:* June 2022, p. 30).



▲ **CYGNUS** The stars of Cygnus, the Swan, blend into the dusty plane of the Milky Way in this image, which looks into the Local Arm. The North America Nebula and the Veil Nebula lie here, as do two black holes that were once massive stars like Deneb.

ECKHARD SLAWIK / NOIRLAB / NSF / AURA / M. ZAMANI

As Arcturus revolves around the galactic center, the star stays close to the galactic plane. In contrast, most other thick-disk stars journey thousands of light-years above and below this plane.

We can deduce which nearby stars likely belong to the thick disk by examining their motions. One is Barnard's Star, a 9.5-magnitude red dwarf in Ophiuchus, just 6 light-years from Earth. Because of the star's closeness and its large speed relative to us, Barnard's Star boasts the greatest proper motion of any star in the night (*S&T:* May 2024, p. 60).

Brighter but slightly farther away is another likely thick-disk star, Lalande 21185 in Ursa Major, just 8.3 light-years from Earth (*S&T:* June 1995, p. 68). This star, also a red dwarf, is magnitude 7.5. Although currently near the galaxy's midplane, Lalande 21185 is racing down through it at 68 kilometers per second (152,000 mph). Someday the star will shine many thousands of light-years beneath the galactic plane, where thick-disk stars outnumber those from


▲ **GLOBULAR CLUSTERS** Most globular clusters, such as M4 *(left)*, belong to the galactic halo. But the motions and metallicities of some, including 47 Tucanae *(right)*, suggest they belong to the thick disk instead.

the thin disk. In contrast, the Sun, whose vertical velocity is only 7 km/s, never travels more than a few hundred light-years above or below the galactic midplane, so we stay forever lodged in the thin disk.

The Stellar Halo

An even more extreme stellar population pervades the Sun's neighborhood. The stellar halo consists primarily of ancient metal-poor stars from lesser galaxies that crashed into the Milky Way long ago. Xiang and Rix say the greatest crash happened 11 billion years ago.

The most prominent members of the stellar halo are globular clusters. The closest, M4 in Scorpius, appears in the sky near Antares but is actually located far beyond it, 6,000 light-years from Earth. Other prominent globular clusters in the stellar halo are M13 in Hercules and M15 in Pegasus. Although the stellar halo has most of the galaxy's globular clusters, some globulars, such as M71 in Sagitta and 47 Tucanae, belong to the thick disk instead. Still others are members of the galactic bulge.

The halo is so named because its stars and clusters exist not only within the disk but also far above and below it, forming a faint cloak around the disk. Unfortunately, the name "halo" can incorrectly imply that most halo stars reside beyond the edge of the galaxy's disk. Although some lonely halo stars do shine out there in the remote darkness, most halo stars actually lie closer to the galactic center than the Sun does.

But a few halo stars zip through our vicinity. They constitute less than 1% of the nearest stars but stand out because of their low metallicities and odd orbits around the galactic center. The nearest halo star is 13 light-years away in the southern constellation Pictor, the Painter: Kapteyn's Star, discovered in 1897 by Dutch astronomer Jacobus Kapteyn and Robert Innes, a Scottish-born astronomer working in South Africa. The 9th-magnitude *M* star orbits the galaxy backward, opposite the direction of the Sun and the thin and thick disks.

Farther but brighter is another famous halo star, Groombridge 1830. It's a 6.5-magnitude *G* main-sequence star 30 light-years from Earth in Ursa Major, south of the Big Dipper (*S&T:* May 1974, p. 296). Meanwhile, a bright halo giant, HD 122563, shines in Boötes. Located 1,050 light-years from Earth, the star is magnitude 6.2.

The Milky Way also has a second and much larger halo, one that really does lie mostly beyond the edge of the Milky Way's disk. As far as we know, though, this halo emits no light. Still, the dark halo harbors most of the galaxy's mass, outweighing the thin disk, the thick disk, and the stellar halo put together. The best guess is that this mysterious component consists of subatomic particles that rarely if ever interact with ordinary matter.

Although you can't see the dark halo, trillions of these dark-matter particles pass through you every second — something to contemplate as you witness the magnificent beauty of the Milky Way Galaxy and its innumerable stars.

■ Contributing Editor **KEN CROSWELL** earned his PhD for observing distant stars in the Milky Way's halo. He is the author of a book about our galaxy, *The Alchemy of the Heavens*, and a book about stellar evolution, *The Lives of Stars*.

M4: ESO, ACKNOWLEDGMENT: ESO IMAGING SURVEY; 47 TUC: ESO / M.-R. CIONI / VISTA MAGELLANIC CLOUD SURVEY, ACKNOWLEDGMENT: CAMBRIDGE ASTRONOMICAL SURVEY UNIT

3 **DUSK:** Face south to see the waxing gibbous Moon hanging about 1° below Antares, the heart of the celestial Scorpion. The view becomes more dramatic as twilight transitions into night. Turn to page 46 for more on this event and others listed here.

11 **EVENING:** Look toward the east to see the waning gibbous Moon rise with Saturn in tow, trailing by some 5°.

12 **MORNING:** The dazzling view of Venus and Jupiter less than 1° apart rising above the east-northeastern horizon is a must-see. Follow the pair until the rising Sun washes the sight away.

12–13 **ALL NIGHT:** The Perseid meteor shower is expected to reach maximum, but the bright waning gibbous Moon will interfere with the show. See page 48 for details.

16 **MORNING:** In the east, the last-quarter Moon gleams some 3½° upper right of the Pleiades.

19 **MORNING:** A stunning tableau adorns the east-northeastern horizon. The waning crescent Moon, Jupiter, and Venus are arrayed in a vertical arc around 14° tall about 10° right of Gemini's twin lights, Castor and Pollux. You can admire this sight until sunrise.

20 **MORNING:** Look toward the east-northeast to see a thin lunar crescent some 4° upper left of Venus. Pollux shines about 2½° to the Moon's left, while Jupiter gleams upper right of the trio.

21 **DAWN:** The Moon, two days from new, climbs above the east-northeastern horizon accompanied by Mercury around 4½° lower right.

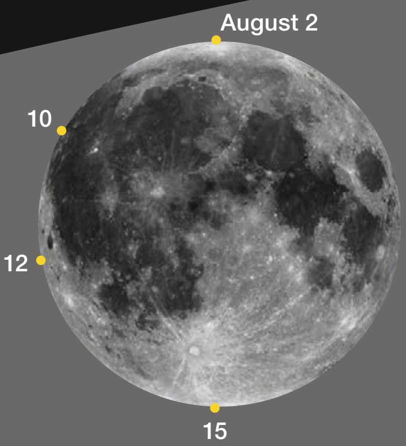
26 **DUSK:** Low on the west-southwestern horizon, the three-day-old waxing crescent Moon is some 6° lower left of Mars.

27 **DUSK:** The lunar crescent and Spica, Virgo's brightest star, sink toward the west-southwestern horizon in tandem, with about 5½° between them.

30 **DUSK:** The almost-first-quarter Moon is back in Scorpius where it gleams around 4½° lower right of Antares. Face south-southwest to admire this sight.
—DIANA HANNIKAINEN

▼ The Summer Milky Way stretches above the peaks in Banff National Park, Alberta, as a random meteor streaks across. The Eagle Nebula, M16, is the topmost of the chain of nebulae at right in the image (go to page 28 for more on M16). ALAN DYER

AUGUST 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
August 1
12:41 UT

FULL MOON
August 9
07:55 UT

LAST QUARTER
August 16
05:12 UT

NEW MOON
August 23
06:07 UT

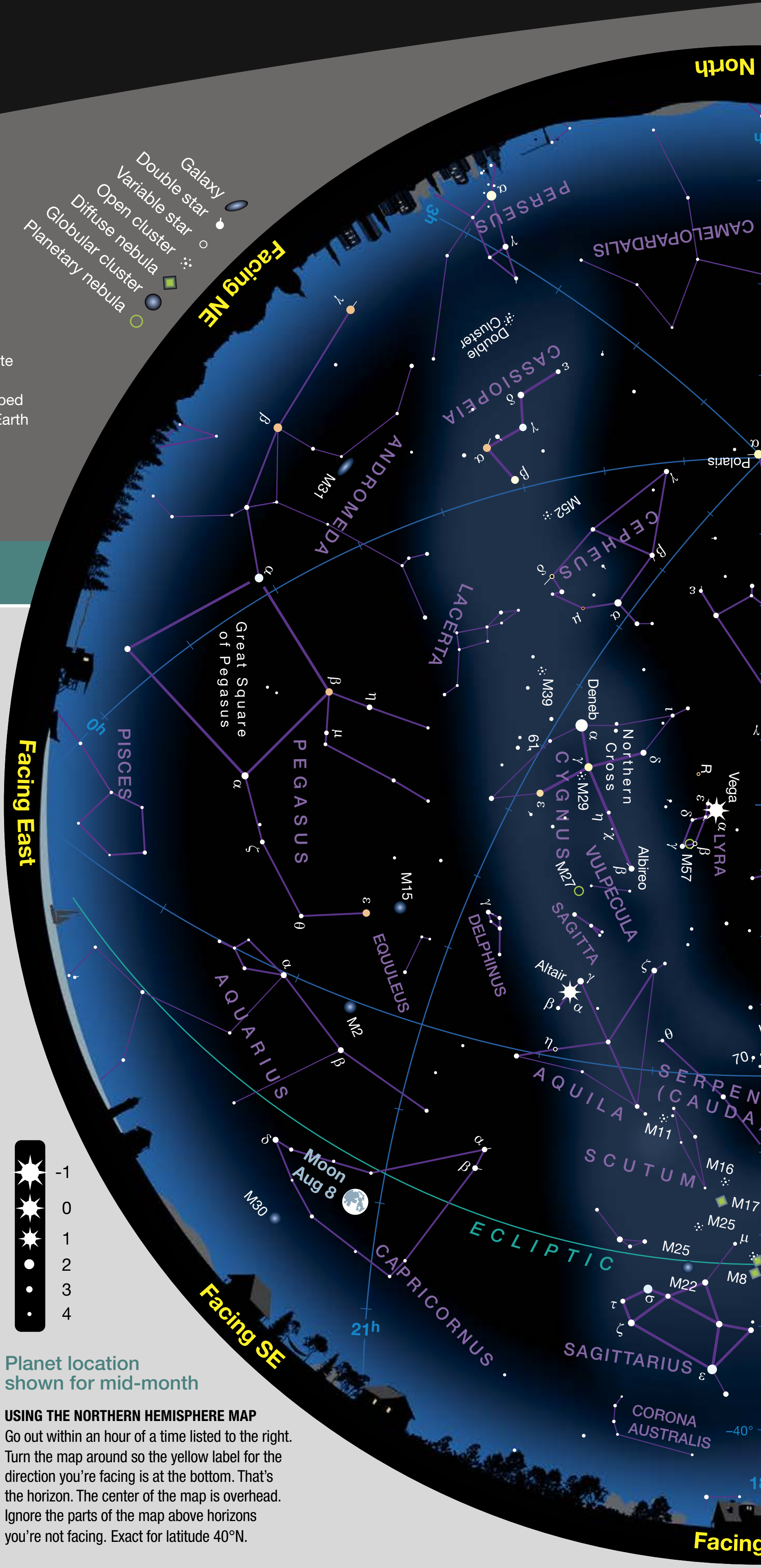
FIRST QUARTER
August 31
06:25 UT

DISTANCES

Apogee 404,161 km	August 1, 21^h UT Diameter 29′ 34″
Perigee 369,289 km	August 14, 18^h UT Diameter 32′ 22″
Apogee 404,547 km	August 29, 16^h UT Diameter 29′ 32″

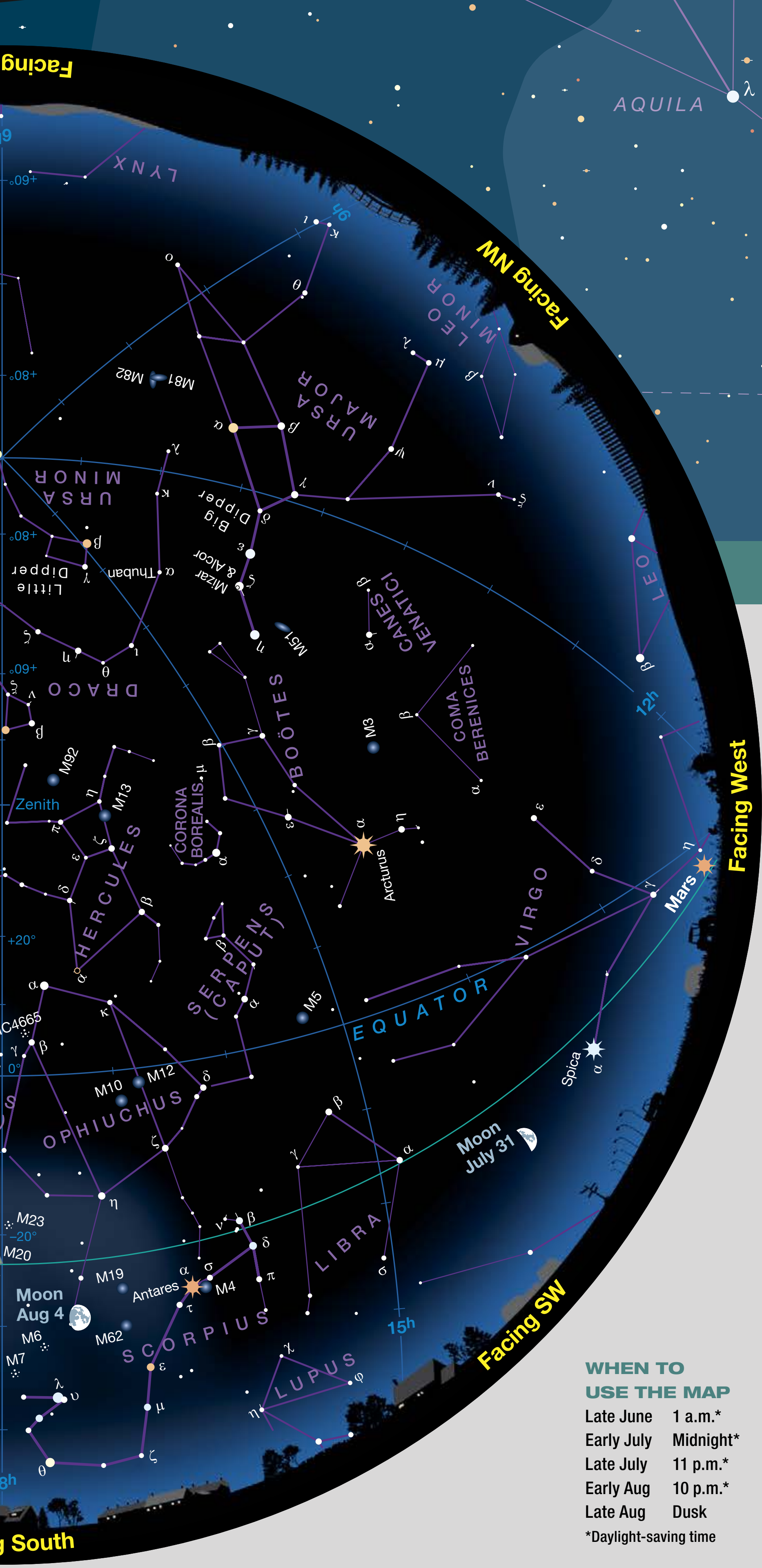
FAVORABLE LIBRATIONS

• Gioja Crater	August 2
• Röntgen Crater	August 10
• Lacus Veris	August 12
• Cabeus Crater	August 15



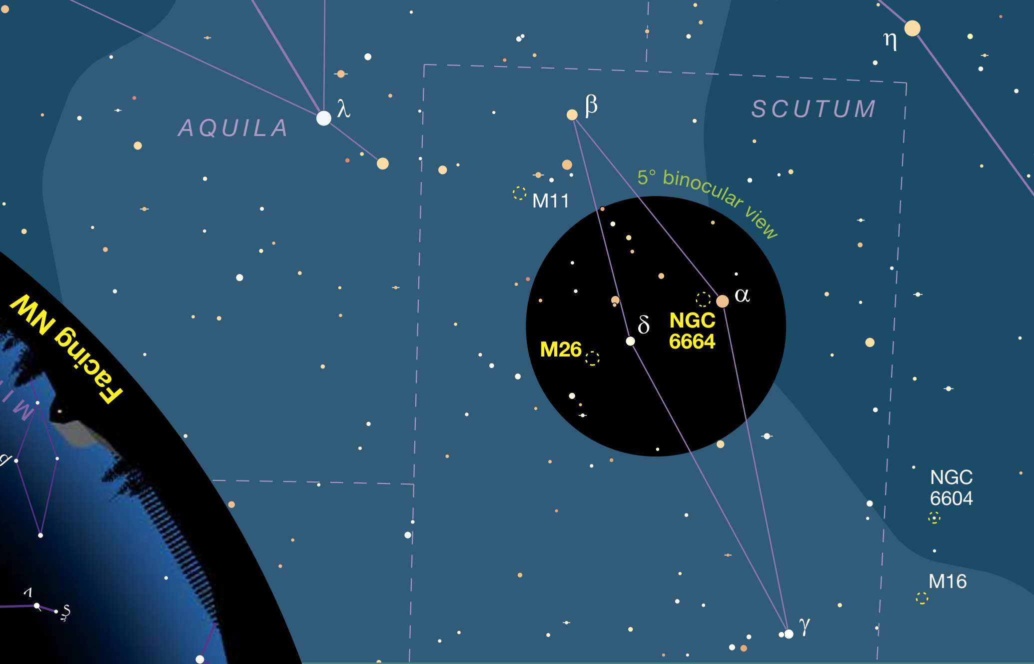
Planet location shown for mid-month

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 June	1 a.m.*
Early July	Midnight*
Late July	11 p.m.*
Early Aug	10 p.m.*
Late Aug	Dusk

*Daylight-saving time



Binocular Highlight by Mathew Wedel

Challenging Scutum Clusters

You'd think by the 10th year writing this column that I would have seen most of the not-quite-famous objects lurking near the best-known deep-sky treasures. But I still meet new ones — or bump into old acquaintances — all the time.

One example is **M26**, an 8th-magnitude open cluster in Scutum, the Shield. Being a Messier object, it isn't exactly obscure, but I'm certain it gets a lot less attention than Scutum's other Messier, M11, the Wild Duck Cluster. Not-quite-famous M26 is worth a visit, especially because it adorns an attractive starfield near the crowded center of our galaxy.

By comparison, non-Messier Scutum cluster **NGC 6664** was a real forehead-slapper for me. At magnitude 7.8, it's actually a bit brighter than M26, making it the second-brightest deep-sky object in the constellation. And I'd seen it before. A quick check of my logbook turned up a surprisingly detailed account from 2012, but the cluster had long since fallen out of my head and off my radar. That's surprising because it isn't hard to find, lying less than 20′ east-northeast of Alpha (α) Scuti, and additionally it makes such an obvious comparison to M26. Not only are both objects similarly bright, they're also roughly equidistant, about 6,200 light-years away for M26 and 6,900 light-years for NGC 6664.

Under good conditions I can detect both M26 and NGC 6664 with 10×50 binoculars. But darker skies and the extra magnification and aperture of my 15×70s do a better job of teasing them from their rich and complex environs. Indeed, this region of sky can keep a binocular observer busy for a long time.

■ **MATT WEDEL** enjoys observing star clusters and nebulae both as objects in their own right, and as signposts to the large-scale structure of the Milky Way.

AUGUST 2025 OBSERVING

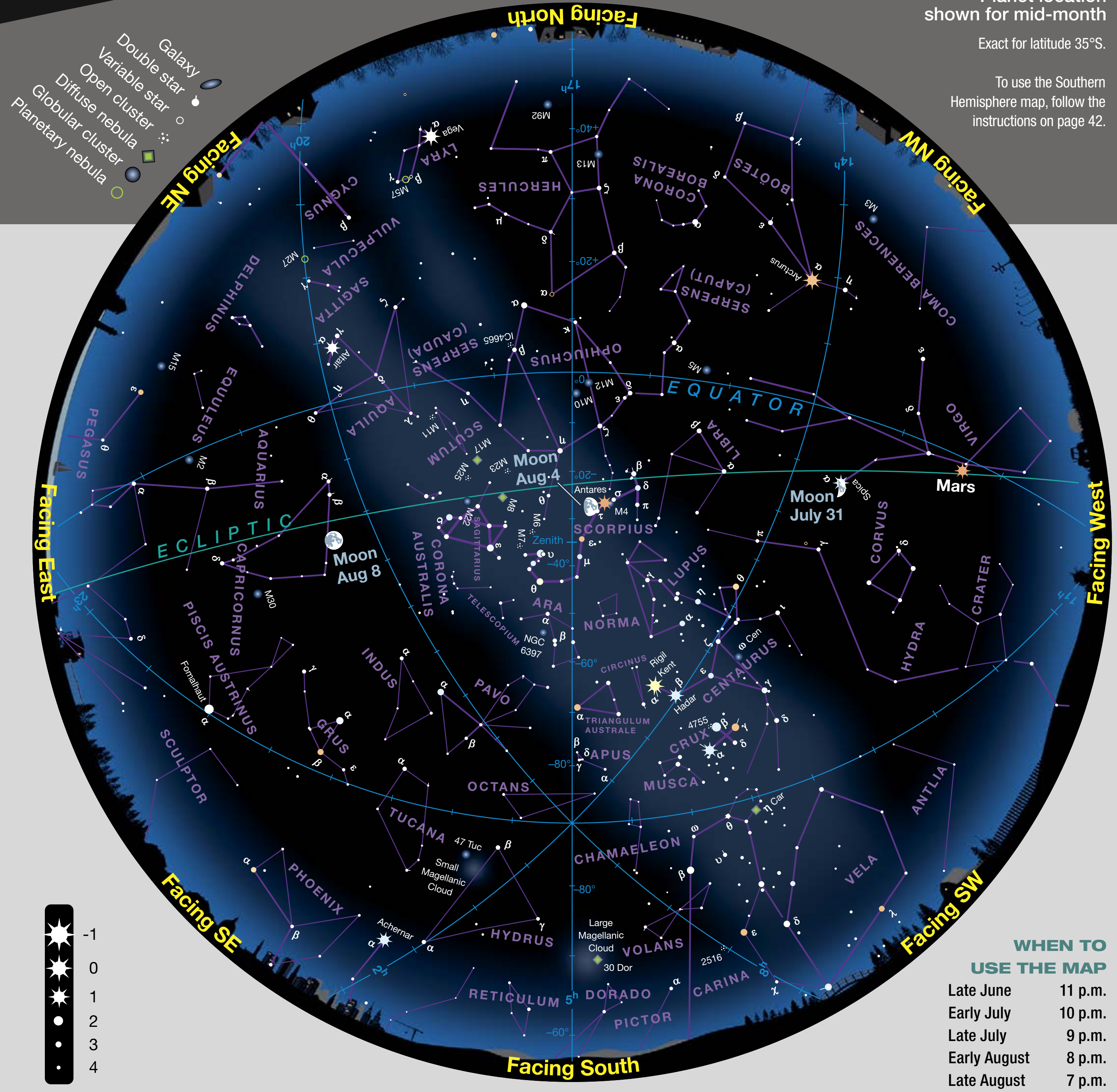
Southern Hemisphere Sky Chart

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

LOCATED VERY CLOSE to the south celestial pole, **Apus** is the constellation of the bird of paradise of the island of New Guinea. The name comes from the Greek *apous*, meaning "without feet." That's because the feet and wings of the first non-living specimens sent to Europe had been removed before transport (the plumage was cherished by the islanders).

None of the bird's stars are very bright. Its four main lights are led by Alpha (α) Apodis, a 3.8-magnitude orange giant star 1,000 times brighter than the Sun. Next are 4.2-magnitude Beta (β), 3.9-magnitude Gamma (γ), and Delta (δ), a double star comprising a slightly variable primary (magnitude 4.7 to 4.9) and a 5.4-magnitude secondary. The Delta stars are far enough apart that those with good eyesight and dark skies can split them without the need for binoculars or a telescope. ■

Tales from the Garden of the Hesperides

The tales of Draco have varied outcomes, leaving you to decide this celestial serpent's fate.

▲ *The Garden of the Hesperides*, a circa 1892 oil on canvas by Lord Frederick Leighton. The Hesperides were guardians of the tree that produced golden apples. Note the serpent in the tree.

LADY LEVER ART GALLERY / WIKIMEDIA COMMONS / PUBLIC DOMAIN

This month Draco, the Dragon, the eighth-largest constellation, is at its highest after dark. Use the center star chart on pages 42–43 to find its most prominent feature: a trapezoid of four stars known as the Head of Draco, though it's not labeled as such on the chart. You'll find the Head's golden Gamma (γ) star under the foot of Hercules close to the zenith, the point directly overhead. The rest of the Dragon's body courses around the Little Dipper like a meandering stream. These three star patterns — Draco, Hercules, and the Little Dipper — are intimately tied to an ancient mythical tale involving golden apples, possibly sheep, and a dubious act of heroism.

Classical myths about Draco vary greatly. In most versions of the tale, Draco is Ladon, the serpent appointed to guard the tree that produced golden apples. Hera received the tree from Gaia (Earth) on her wedding day and planted it in the Garden of the Hesperides, the goddess nymphs of the evening and the golden light of sunset. While tending this beautiful garden, the Hesperides had the habit of picking the apples. So Hera placed Ladon in the garden to prevent further incident.

Enter Hercules, who was tasked to steal the golden apples as one of his 12 labors and bring them to King Eurystheus of Tiryns and Mycenae. Hercules succeeds, but how he gets the apples is . . . well, up to you. According to the many stories and depictions, Hercules defeats the dragon by either wrestling or clubbing it. Others say that he shot the creature with poisoned arrows. In another not-so-amazing feat, Hercules never even confronts the dragon. Instead, he had Atlas, the father of the Hesperides, pick the apples for him. In turn, Hercules temporarily relieved Atlas of his burden: supporting the vault of the heavens on his shoulders. Or, if you wish, you can rely on some artistic impressions that emasculate the hero, showing him dining with the Hesperides who freely give him the apples.

For something completely different, you can refer to the story told by Greek historian Diodorus Siculus (circa 90–20 BC). In his *Bibliotheca Historica*, Siculus writes, "others assert that the Hesperides possessed flocks of sheep which excelled in beauty and . . . the sheep had a peculiar color like gold." The sheep were guarded by a shepherd named Drakon, "a man who excelled in strength of body and courage, who guarded the sheep and slew any who might dare try to carry them off" — until Hercules slew him.

Well, this is just a taste of the myth of the golden apples. Like a "choose-your-own adventure" book, you get to decide which story you'd like to tell. Most of the tales have a similar ending, with a god or goddess placing the serpent in the sky as Draco, to rest forever under the celestial apple tree, which could be represented by the Little Dipper. This celestial tree has two golden apples: the yellow and orange giant stars Polaris and Kochab, around which winds the Dragon's long, serpentine body.

As for Hercules, we see him in the sky in a pose of visual bravado — with his foot on Draco's head, apparently in a clear sign of victory. But we now know that's not always how the story was told.

■ 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.

A Quartet of Dawn Planets

Jupiter and Venus meet for a close morning conjunction.

SUNDAY, AUGUST 3

This evening as twilight fades, look south to see the waning gibbous **Moon** about 1° below **Antares**, the flickering red heart of Scorpius, the Scorpion. This is the closest the Moon gets to a bright star all month — for that reason alone it's worth a look. Another reason is that the neutral grey of the lunar surface always seems to enhance the color of whatever star or planet the Moon is near. See if you don't think Antares looks extra colorful this evening. Binoculars make this more apparent, so don't hesitate to get optics involved in the view.

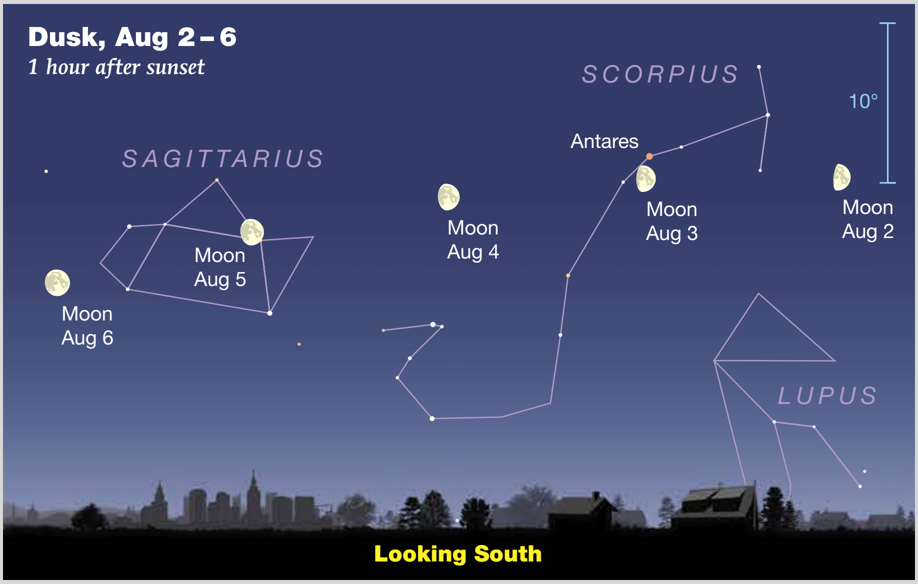
With a declination of –26° 26′, Antares is well south of the ecliptic — and tonight the Moon is well south of Antares. This arrangement is courtesy of the ongoing major lunar standstill (*S&T:* Apr. 2025, p. 49). It's unusual for the Moon's path across the sky to carry it below Antares. Equally odd is seeing the Moon among the stars of the Sagittarius Teapot, as it is on the evening of the 5th and morning of the 6th.

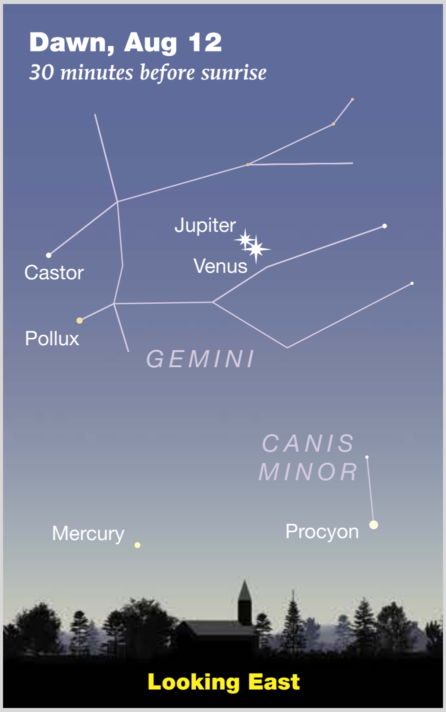
TUESDAY, AUGUST 12

Without doubt, the month's most alluring naked-eye event is this morning's close conjunction between **Venus** and **Jupiter**. So, set an early alarm to enjoy the spectacle of seeing the sky's two brightest planets (notwithstanding the infrequent, short spans when Mars is marginally brighter than Jupiter) separated by less than 1°. This morning, Jupiter shines at magnitude –1.9 while Venus gleams seven times brighter at magnitude –4.0. (Turn to page 49 for more about this conjunction.)

This is one of those rare sky sights that your non-astronomy friends, neighbors, and relatives are sure to ask about. And one question they'll likely have is: How often does it happen? Conjunctions involving the two planets aren't terribly rare — they occur about once a year. However, because Venus is often near the Sun, pairings that you can actually observe are less frequent. That said, the next one takes place at dusk in June 2026, though the two planets are farther apart. For a conjunction that's as good as today's you have to wait until November 9, 2028, when

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



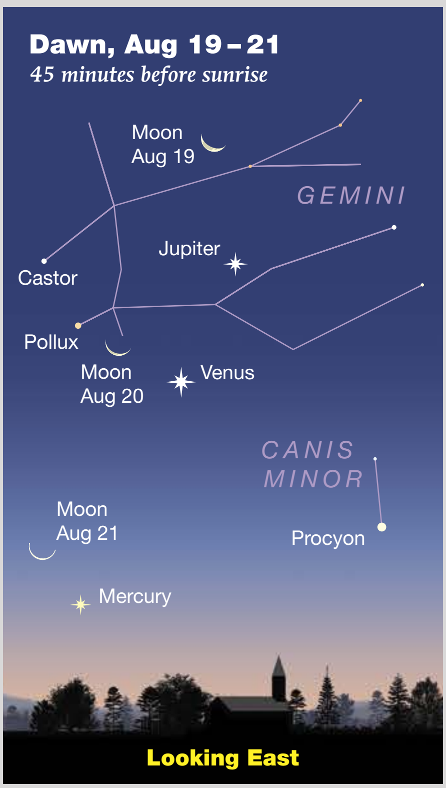


▲ The Sun and planets are positioned for mid-August; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

Jupiter and Venus are even closer at dawn — just 37′ apart.

On the morning of August 12th, the planetary duo rise shortly after 3 a.m. local daylight time, with Venus trailing Jupiter by about 4 minutes. But if the weather doesn't look good, you have a couple of "make-up" dates: the 11th and the 13th. The twosome won't be quite as close on those mornings, but they'll still look very impressive.

If you can tear your eyes away from Jupiter and Venus, this morning also features the month's closest conjunction between the **Moon** and a planet. Look toward the south-southwest to see **Saturn** sitting 3½° left of the 89%-illuminated waning gibbous Moon. Saturn shines at magnitude +0.8, so it stands up reasonably well to its lustrous companion.



WEDNESDAY, AUGUST 20

Although the tight pairing of **Venus** and **Jupiter** on the 12th likely will get most of the attention this month, dawn today presents a scene that's very nearly as compelling. The bright planetary pair have drifted apart with Jupiter ascending as Venus descends. Today the gap between them is a shade more than 8°, but now they're joined by a wafer-thin **Moon** enhanced by earthshine. The 9%-illuminated lunar crescent sits a bit more than 4° upper left of Venus. Most months, this combination alone would top a skywatcher's "must-see" list. But wait — there's much more!

Hanging above and left of the Moon are the Gemini stars, Castor and Pollux. Together with the Moon and Venus they form a gentle, 11°-wide arc. Want more? How about a luminous triangle that includes the Morning Star, +0.4-magnitude **Procyon**, and yet another planet: **Mercury**. The innermost world shines at magnitude –0.3, which helps make it relatively easy to spot despite its low altitude.

Mercury reached its greatest elongation from the Sun on the 19th (19° west) but is now at its highest for the current dawn apparition. However, there's more here than meets the (naked) eye. Before morning twilight grows too bright, train your binoculars on Mercury and see if you can detect the delicate sparkle of the **Beehive Cluster** (M44) about 2° upper left of the planet. Mercury serves as a temporary, bright stray bee.

TUESDAY, AUGUST 26

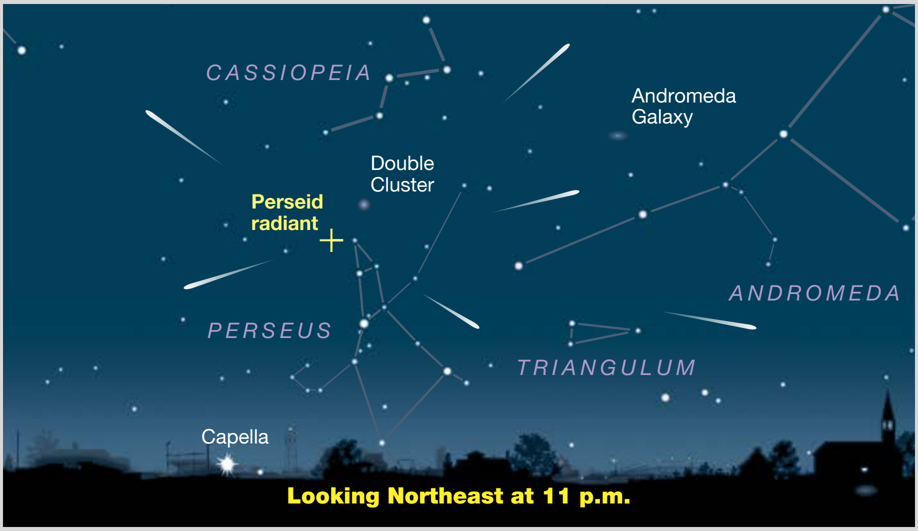
While the most exciting conjunction action this month has been in the morning sky, August wraps up with a pretty dusk gathering that includes **Mars**, the **Moon**, and **Spica** — Virgo's brightest light. As the darkness gathers, look to the west-southwest to see all three arrayed in a shallow V with the waxing lunar crescent sitting between Spica about 6½° to its upper left and Mars a little less than 6° to its upper right.

At magnitude 1.6, Mars is obviously fainter than 1st-magnitude Spica. The two objects are also of different hues, with the star's cool white contrasting nicely with the Red Planet's orangish tint. Of course, even though the trio appear gathered together in the same 12°-wide swath of sky, they are at radically different distances. The Moon is about 400 *thousand* km (250 thousand miles) from Earth, Mars is 336 *million* km away, and Spica about 2.4 *quadrillion* km distant. Talk about extreme depth of field!

■ Given enough planetary action, even Consulting Editor **GARY SERONIK** can be moved to get up before dawn.

Perseids Versus the Moon

The year's best meteor shower toughs it out against a luminous rival.



▲ The Perseid meteor shower is active from mid-July though the third week of August, allowing for numerous opportunities to catch Perseids here and there despite bright moonlight on the peak night of August 12–13.

The Perseids are the people's meteor shower — a rich display that coincides with some of the year's finest weather. You really can't do better than August nights when temperatures are pleasant and clear skies are common. And under the right conditions the display produces 50 to 100 meteors per hour, practically guaranteeing that even a casual observer will see something.

Perseid meteoroids start their lives as debris sloughed from Comet 109P/Swift-Tuttle. Every 133 years the 26-kilometer-wide (16-mile-wide) comet swings by the Sun, shedding fragments destined to delight skywatchers each summer. As Earth plows headlong through the comet's dust-strewn orbit, it intercepts the material at more than 214,000 kilometers per hour. When a Perseid strikes the atmosphere, it rapidly compresses the air along its path,

◀ A picturesque Perseid fireball blazes across the constellation Taurus just below the Hyades star cluster on August 13, 2013. Although a waning gibbous Moon washes out this year's display, the brightest meteors will still put on a worthwhile show. Thankfully, next year's shower will be moonless!

heating the particle and birthing a *meteor* — a bright, short-lived streak of ionized atoms and molecules.

Like all meteor showers, the Perseids play cat-and-mouse with the Moon. When it's a thin crescent or new, we get dark night skies conducive to seeing many meteors. This time around, however, an 84%-illuminated, waning gibbous Moon brightens the sky from end of twilight until dawn on the night of August 12–13, when the shower is expected to peak. Lunar glare erases the fainter shower members, meaning that meteors brighter than 2nd magnitude will comprise most of what we'll see. This greatly reduces the Perseid count from better than one-per-minute to one every few minutes, or about 20 to 25 per hour.

Despite the bright Moon, I find the Perseids hard to resist. One approach is to observe early — from late evening twilight through to about 11 p.m. local time on the 12th before moonlight becomes too strong. The radiant is low in the northeastern sky, but this is the best time to see *earthgrazers* — comet scraps arriving nearly tangentially to the atmosphere, often producing long, sky-spanning trails.

Another strategy is to delay your Perseid session until later, when the radiant is highest. Set your alarm to wake you in the early morning so you can watch from about 2 a.m. to 5 a.m. By facing north and keeping the Moon at your back, you'll optimize your dark adaptation and enjoy a modest show, perhaps punctuated with an occasional fireball. As a bonus, you can catch a wonderful coda in the northeastern sky at dawn. That's when you can see Venus and Jupiter beaming less than 1½° apart in the east-northeast.

Jupiter and Venus Team Up

IN WHAT MAY BE this year's most anticipated planetary conjunction, Jupiter and Venus nestle just 53′ apart at dawn on August 12th (see page 46 for details). For several mornings before and after that date, they'll fit comfortably in the same binocular field of view.

Their proximity to each other presents an interesting daytime observing opportunity. Venus, at magnitude –4.0, shines about 36° west of the Sun — far enough from the solar glare to see with the unaided eye in a clear, blue sky. However, on this occasion you can use brilliant Venus to guide you to the much more elusive daytime planet, Jupiter. To see them together in a blue sky, you can follow them from twilight and past sunrise with binoculars. But you can also find them much later in the day if you have a Go To scope or one on a polar-aligned equatorial mount fitted with setting circles.

The first step is to locate Venus. Knowing that it leads the Sun by 36°, you can probably stumble upon it by using your scope's finderscope and sweeping the sky in approximately the right location. More reliably, you can use your equatorial mount's setting circles. First, retrieve the celestial coordinates for Venus and the Sun from a stargazing app or software. Subtract Venus's right ascension and declination from the Sun's to determine their separation. Now, attach a solar filter to your scope, center and focus the Sun, then offset the calculated distance to the west and north. Finally, remove the filter and Venus should be in the field of view. The planet will look like a tiny, gibbous Moon 13.5″ across. A degree or so north-northwest of Venus you'll spot the much paler but larger disk of Jupiter. Can you tease out its two main equatorial belts?

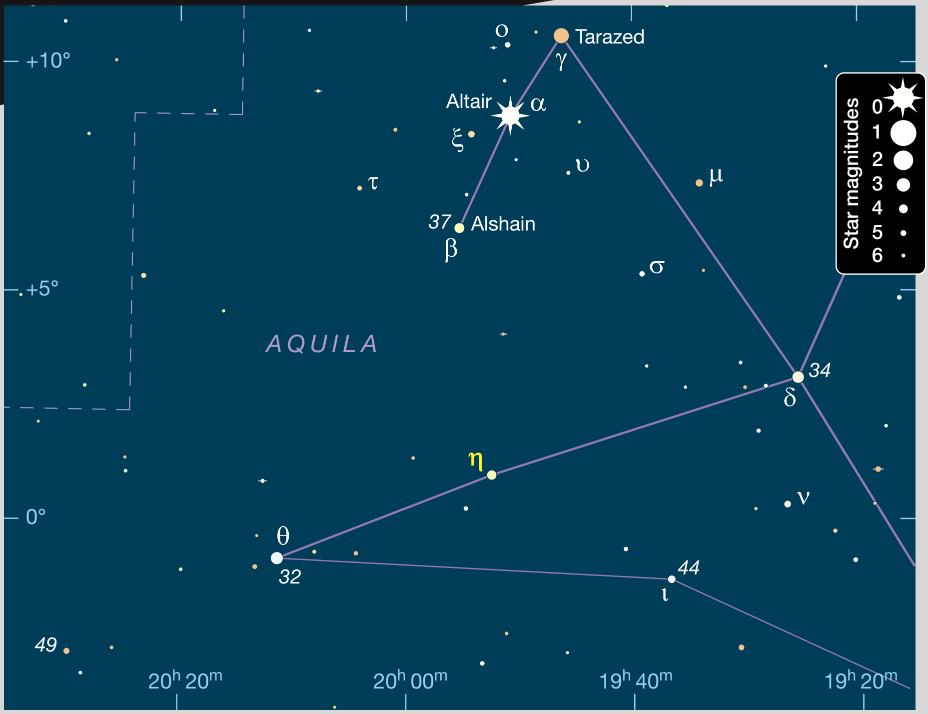
▲ Venus and Jupiter were just 7′ apart on the afternoon of August 27, 2016, when Consulting Editor Gary Seronik photographed them. As the image shows, Venus stands out boldly while Jupiter is a ghostly presence in the daytime sky. On August 12, 2025, the pair are farther apart (separated by 52′) but should be visible in binoculars in a clear, haze-free sky.

Minima of Algol

Aug.	UT
2	12:25
5	9:14
8	6:03
11	2:51
13	23:40
16	20:28
19	17:17
22	14:06
25	10:54
28	7:43
31	4:31

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457360.307 + 2.867351E, where E is any integer. They were derived by Roger W. Sinnott from 15 photoelectric series in the AAVSO database acquired during 2015–2020 by Wolfgang Vollmann, Gerard Samolyk, and Ivan Sergey. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.

▲ Perseus approaches the zenith during predawn hours in August. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).



Summer Nights with Eta Aquilae

AUGUST IS THE PERFECT time to get acquainted with one of the sky's brightest naked-eye variable stars. Say hello to Eta (η) Aquilae, a pulsating Cepheid variable located about 8° south-southeast of Altair in Aquila, the Eagle. Eta crosses the meridian around the end of evening twilight, making it ideally placed for observing for the remainder of the summer and throughout the coming autumn.

Eta Aquilae is roughly 890 light-years away and was born a mere 100 to 200 million years ago during the age of the dinosaurs. Like many of those outsized reptiles, it's a lumbering giant — a yellow-white supergiant, to be exact. It's 6 times the mass of the Sun, 60 times its diameter, and some 3,400 times more luminous. Unlike our (currently) reliable Sun, Eta has entered an unstable phase in its life cycle, in which internal changes cause it to fluctuate in size and brightness.

Every 7.18 days the star varies from magnitude 3.5 to 4.3 and back again. It's brightest when expanding and faintest when contracting. The variations are obvious with the naked eye. At peak light, the star is similar in brightness to its neighbors Delta (δ) Aquilae (magnitude 3.4) and Theta (θ; magnitude 3.2). As shown in the chart above, the trio forms a nearly straight line, making Eta easy to locate no matter where it is in its cycle. At minimum, the star is a near-match to Iota (ι) Aquilae and blends in with the constellation's fainter stars.

▲ Conveniently placed for viewing, Eta (η) Aquilae is a bright Cepheid variable star in Aquila easily visible without optical aid throughout its approximately weeklong cycle. (Comparison star magnitudes are given without decimal places, e.g., *34* indicates magnitude 3.4.)

Like other classical Cepheids, Eta quickly rises to maximum in about 2 days, then declines to minimum more slowly over approximately 5 days. The star's ups-and-downs were first recognized by the sharp-eyed English astronomer Edward Pigott in September 1784. A little more than a month later, his friend John Goodricke discovered the variability of the prototype of the Cepheid variables, Delta Cephei. Delta has nearly the same range in brightness but a shorter period.

On the next clear August night, take a moment to glance up at Eta Aquilae. It's always up to something.

Action at Jupiter

JUPITER AT LAST climbs high enough for detailed telescopic inspection during August. By mid-month it achieves an altitude greater than 30° before sunrise. That positions the planet well above the worst effects of our churning atmosphere, allowing reasonably steady, high-magnification views. The viewing prospects continue to improve throughout the month and by the 31st the planet sits 45° above the east-southeastern horizon at sunrise.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The moons change positions along an almost straight line from our point of view on Earth. Use the diagram on the facing page to identify them on any given date and time. All the observable interactions between Jupiter and its satellites are tabulated on the facing page.

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

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

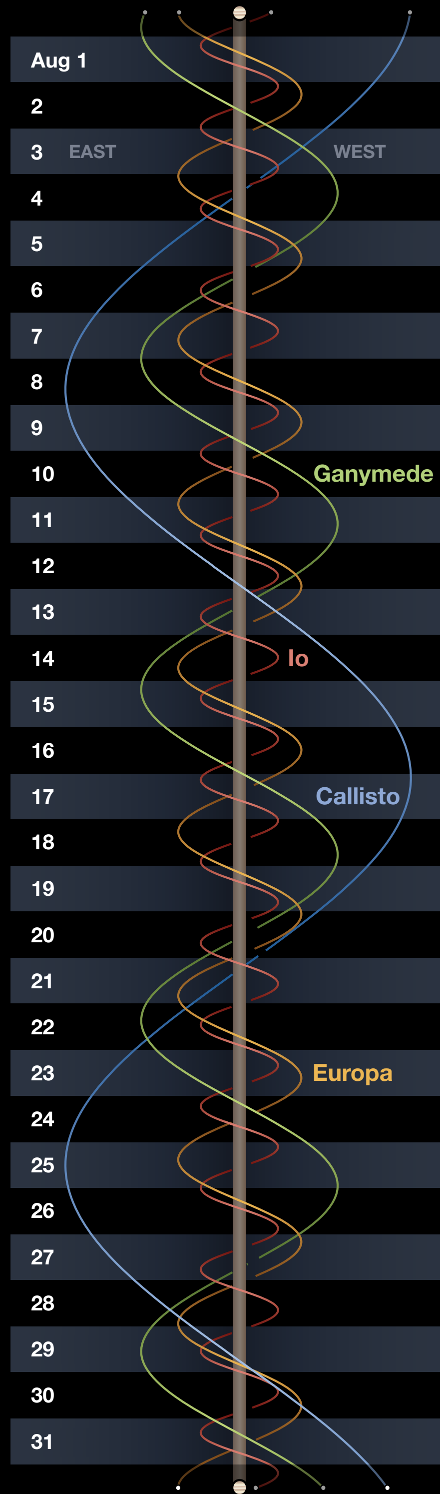
These times assume that the spot will be centered at System II longitude 80° on August 1st. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 80° and 1⅔ minutes later for each degree more than 80°.

Phenomena of Jupiter's Moons, August 2025

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

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

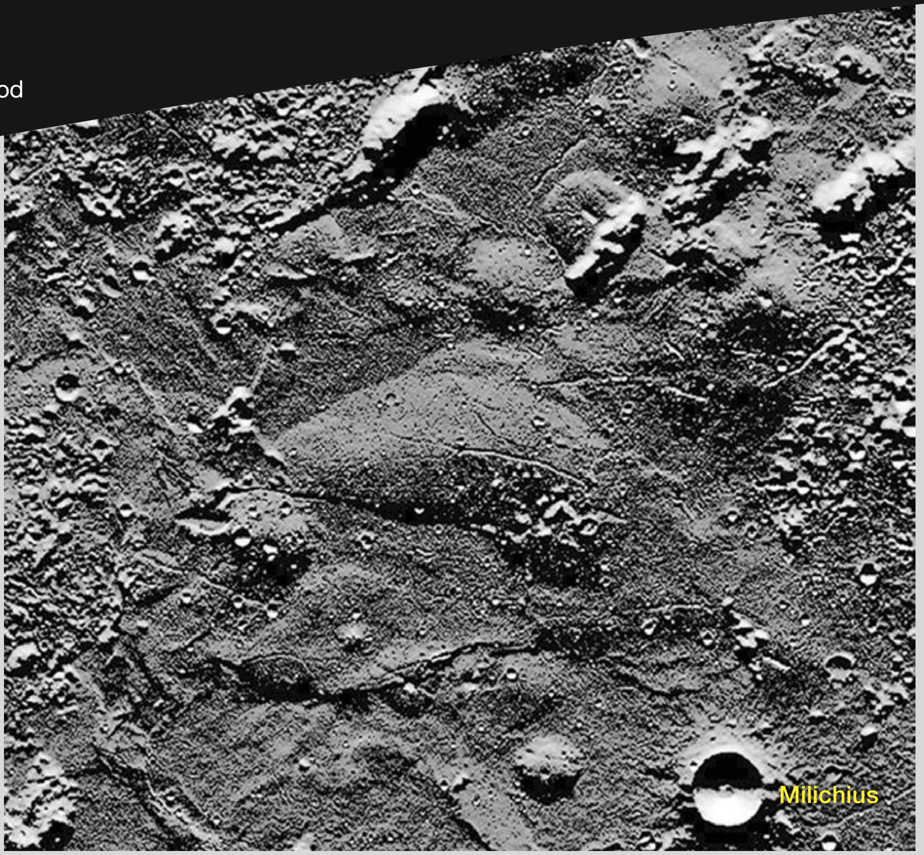
Jupiter's Moons



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

Domes and Swells

Hunt for these elusive lunar features.



▲ Lunar domes and swells are clearly revealed in this image generated using a digital elevation model created from data recorded by the Lunar Reconnaissance Orbiter. This large lunar swell dubbed "The Whale" by the author is located 50 kilometers (31 miles) northwest of Milichius crater.

Lunar domes are subtle features that warrant a closer look. These shallow bumps typically hide in plain view on mare lavas, briefly revealed twice a month when the low, raking light of sunrise and sunset highlight their tenuous contours.

These features are the focus of study for an intrepid group of observers known as the Geologic Lunar Research Group (**https://is.gd/gltfbgroup**), particularly Raffaella Lena and Christian Wöhler. Their work determined that most domes are gently sloped, circular humps, typically 10 kilometers (6 miles) in diameter or less with a slope of 1° to 3°. Domes are often clustered in groups and most are capped with a crater vent. They're small shield volcanoes similar to those found on Earth, forming when fluid lava erupts from a small summit vent. Many terrestrial shields are found in Iceland, the Snake River Plains of Idaho, Hawai'i, and other volcanic regions. West of Copernicus we see the well-known lunar domes near the craters Milichius, Tobias Mayer, Marius, and Hortensius.

Landforms that resemble lunar domes are often lumped into the same category, but in reality they're very different features. They have diameters of up to 20 times larger than the domes but are formed due to the uplift of preexisting surfaces by the intrusion of subsurface magma. On Earth, such *laccoliths* often consist of basaltic magma (as on the Moon), but the largest are silica-rich magma called granite that uplifted huge peaks such as the Rocky Mountains that stretch from Canada south to the state of New Mexico. Lunar laccoliths are smaller and don't form in long chains since they aren't produced by the subduction of the edges of tectonic plates, of which there are none on the Moon. The most famous lunar laccolith is the informally named Valentine Dome spanning about 40 × 30 km at the western edge of **Mare Serenitatis**. This moniker comes from its cartoon-heart shape. Wöhler and Lena note that such large uplifts have slopes less than 1°. To differentiate them from domes, I prefer to call them *swells*, since they form from pressure below the surface.

A 2024 publication in the *Journal of Geophysical Research* reports the discovery of a second swell just southeast of the Valentine Dome. The authors note that the very shallow slope of this new feature makes it very difficult to detect. Shallow slopes are likely the reason so few swells are known.

Using a new technique, New Zealand amateur Maurice Collins and I have identified some three dozen lunar swells, including the one near Valentine Dome. We used the free software *Lunar Terminator Visualization Tool* or *LTVT* (**https://is.gd/LTVTsoftware**) to convert digital elevation models (DEM) recorded with NASA's Lunar Reconnaissance Orbiter into images of lunar topography. The program then allows us to change the illumination to come from any direction and at any angle above the horizon, resulting in a simulation that highlights gently sloped topographical features. In our new book, *Extreme Illumination Atlas of the Moon*, we use unusual lighting directions and an extreme grazing-illumination-angle of 0.1° to reveal many low-slope swells, lava flows, and rilles.

Using this new approach, we can refine measurements of these features. For example, one swell designated M13, located near the crater **Milichius** just north of **Mare Insularum**, was determined by Wöhler and Lena to be 28 km wide and 500 meters high. However, with our technique, the swell is sharply defined as an oval about 60 km long, 30 km wide, and about 150 m high. Such swells are much more common on maria and on crater floors than previously

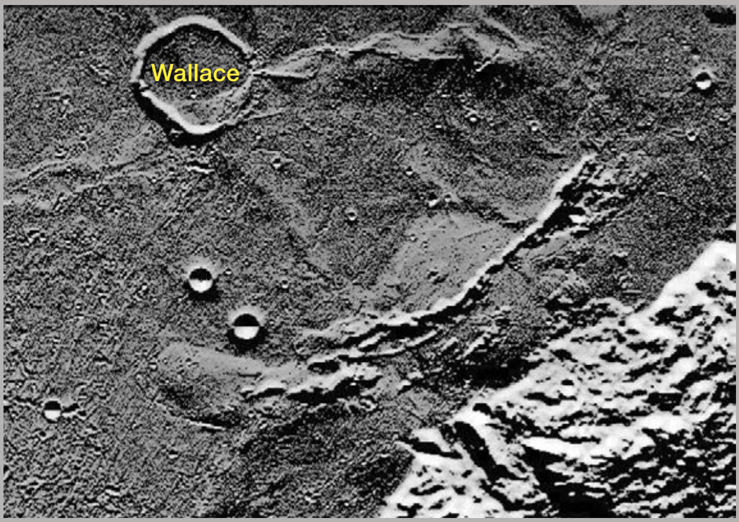
EXTREME ILLUMINATION ATLAS OF THE MOON BY CHARLES WOOD & MAURICE COLLINS (4) known. The majority of them, like M13, are crossed by rilles, implying that these linear features are the result of extensional fracturing as a swell is pushed up and domed by subsurface intrusions of magma, rather than from volcanic eruptions. This also explains why swells typically don't have the summit craters that domes often do.

A line of mountains cuts across a more delicate swell in **Mare Imbrium**, near the 26-km-wide crater, **Wallace**. This beautifully round swell is 45 km across and 300 m high, with the line of peaks rising higher. An elongated oval swell measuring about 50 km by 15 km lies just to its southwest.

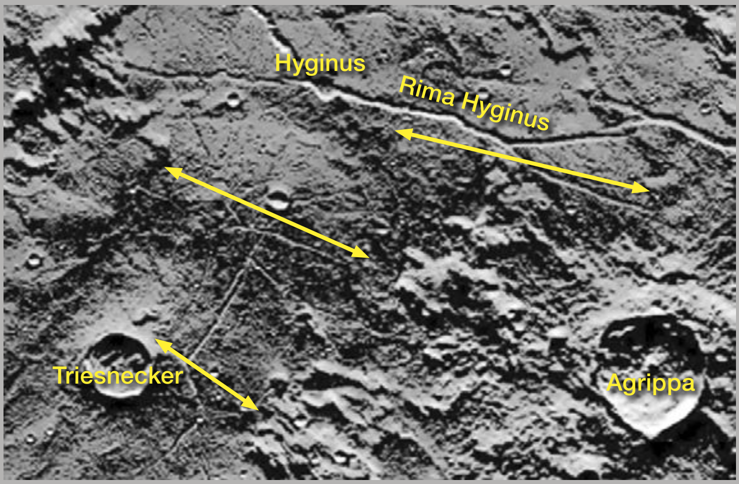
Three large swells near **Triesnecker** and **Hyginus** craters help explain the locations of rilles there. The well-known Triesnecker Rilles is a complex of intersecting linear rilles immediately to the northeast of the crater, and another set lies between Triesnecker and the volcanic caldera Hyginus. This T-H complex crosses an oval swell 100 km long, 60 km wide, and 450 m high, with a dozen rilles ending near the edges of the uplift. A rille complex east of Triesnecker lies on a less distinct swell about 50 m wide that nearly butts up against T-H. A third conspicuous swell is centered on the Y-shaped intersection that connects the east segment of the **Rima Hyginus** with the diagonal transfer to the **Rima Ariadaeus**. This egg-shaped swell is 110 km by 40 km by 250 m, and rilles are its dominant feature.

The northeastern side of Mare Tranquillitatis is covered by an 800-m-high mega-swell spanning 270 km by 150 km. The swell itself is interpreted as a giant shield volcano akin to those that make up the Hawaiian Islands and is surrounded by numerous small volcanic domes. Both **Rima Cauchy** and **Rupes Cauchy** traverse the swell, ending precisely where it flattens into the surrounding terrain. This is another example of how the force of a rising subsurface mass of magma produces rilles and faults.

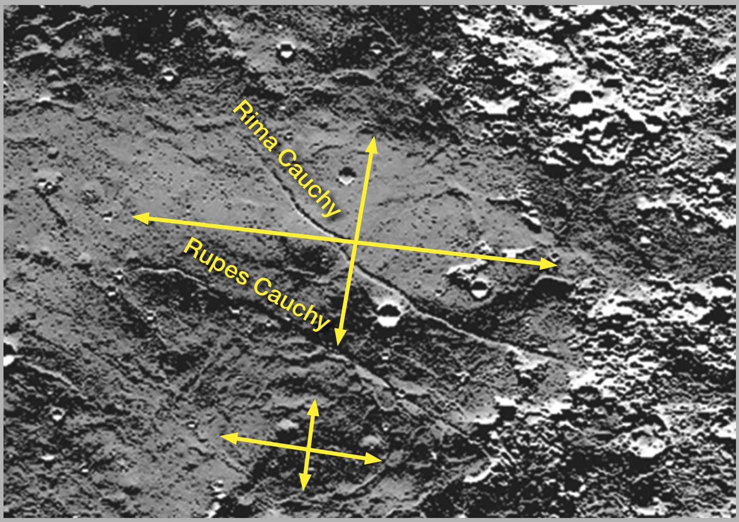
The hunt for swells is ongoing. On page 175 of *Extreme Illumination Atlas of the Moon* there is a map showing the ones I found — including those located on the floors of craters such as **Struve**, **Repsold**, and **Fracastorius** — but there are undoubtedly more to identify!



◀ Some 75 km southeast of the flooded crater Wallace is a large swell capped by a line of mountains traversing the bump from the west to the northeast.

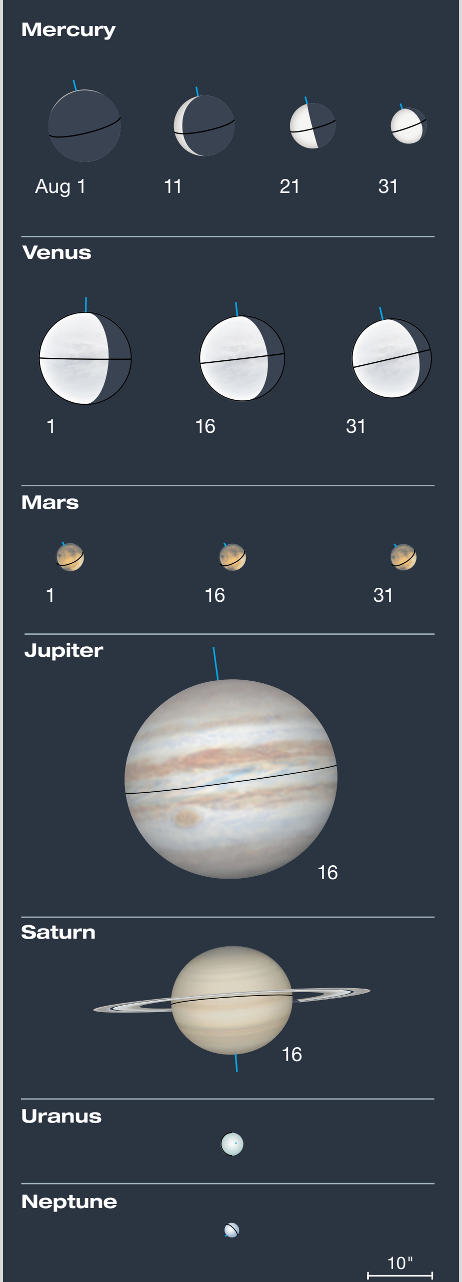


◀ Three swells are located in the region to the northeast of Triesnecker, with one seen below the Y-shaped split in Rima Hygenus at upper right.



◀ The putative Tranquillitatis mega-swell is cut by both rille and fault (Rima Cauchy and Rupes Cauchy). A smaller volcanic cone is suspected to the south.

■ Contributing Editor **CHUCK WOOD** is coauthor of the newly published *Extreme Illumination Atlas of the Moon* available at **amazon.com**.



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

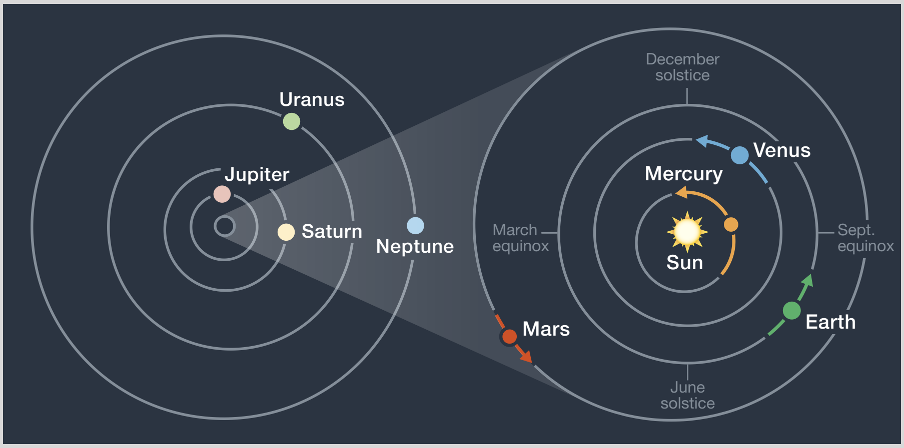
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during August. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn starting on the 13th • **Venus** visible at dawn all month • **Mars** visible low in the west at dusk • **Jupiter** rises before dawn and visible all month • **Saturn** rises in the late evening and transits in the predawn.

August Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	8^h 44.4^m	+18° 05′	—	–26.8	31′ 31″	—	1.015
	31	10^h 36.8^m	+8° 45′	—	–26.8	31′ 41″	—	1.009
Mercury	1	8^h 39.0^m	+13° 20′	5° Mo	+5.4	11.3″	1%	0.595
	11	8^h 21.7^m	+16° 08′	15° Mo	+1.9	9.4″	14%	0.711
	21	8^h 46.9^m	+17° 28′	18° Mo	–0.4	7.1″	48%	0.949
	31	9^h 50.4^m	+14° 34′	13° Mo	–1.2	5.6″	85%	1.202
Venus	1	6^h 02.6^m	+21° 55′	38° Mo	–4.0	14.3″	75%	1.163
	11	6^h 52.9^m	+21° 53′	36° Mo	–4.0	13.6″	78%	1.230
	21	7^h 43.5^m	+20° 51′	34° Mo	–3.9	12.9″	81%	1.293
	31	8^h 33.6^m	+18° 50′	32° Mo	–3.9	12.3″	84%	1.351
Mars	1	11^h 46.1^m	+2° 11′	47° Ev	+1.6	4.4″	94%	2.118
	16	12^h 20.2^m	–1° 42′	42° Ev	+1.6	4.3″	95%	2.194
	31	12^h 55.3^m	–5° 38′	37° Ev	+1.6	4.1″	96%	2.259
Jupiter	1	6^h 49.4^m	+22° 52′	27° Mo	–1.9	32.7″	100%	6.037
	31	7^h 15.1^m	+22° 17′	50° Mo	–2.0	34.3″	99%	5.755
Saturn	1	0^h 08.5^m	–1° 40′	127° Mo	+0.8	18.6″	100%	8.916
	31	0^h 02.9^m	–2° 23′	158° Mo	+0.7	19.3″	100%	8.615
Uranus	16	3^h 55.3^m	+20° 08′	82° Mo	+5.7	3.6″	100%	19.627
Neptune	16	0^h 07.2^m	–0° 42′	142° Mo	+7.8	2.3″	100%	29.087

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**.



Urban Astrophotography

Try these tips and techniques for imaging under city lights.

For many aspiring astrophotographers, living in an urban environment seems like an insurmountable barrier to capturing the wonders of the night sky. The oppressive glow of streetlights, and brightly lit buildings creates a persistent veil that diminishes the visibility of stars and deep-sky objects.

Although remote dark-sky locations are an astrophotographer's dream, sticking close to home can provide some distinct advantages. Incorporating city skylines or landmarks into your compositions creates a striking juxtaposition between celestial and terrestrial sights. Such hybrid images might even have special appeal to viewers unfamiliar with traditional astrophotography.

Most importantly, your backyard or front deck can be the perfect training ground to learn how to operate your equipment at night. Familiar surroundings make it easier to concentrate on mastering the technical aspects of imaging, such as polar alignment, focusing, camera settings, and composition without the additional complication of navigating unfamiliar territory in complete darkness. When you do eventually travel to new locations, you'll spend less time troubleshooting your equipment and more time making use of those precious dark-sky moments.

Shiny Objects

The Moon offers an ideal first target for urban astrophotographers (*S&T:* Feb. 2025, p. 55). Its brightness easily overcomes even the worst sky glow, allowing successful imaging under severely light-polluted skies. Through a telescope or telephoto lens, the lunar *terminator* — the boundary between light and dark on the Moon — creates dramatic shadows that highlight different features during each lunar phase.

Beyond its inherent beauty, our natural satellite provides exceptional wide-field compositional possibilities when paired with urban landscapes. A full Moon rising behind a city skyline creates breathtaking juxtapositions of natural and human-made forms. The warm glow of city lights contrasting with the cool luminescence of this celestial body produces appealing visual narratives.

Bright planets like Venus, Jupiter, Mars, and Saturn similarly cut through urban light pollution. When any of them is in conjunction with the Moon, you have a celestial event ideally suited to urban imaging. Such compositions even benefit from the very light pollution that frustrates deep-sky photog-

▲ **CITY ASTROPHOTOGRAPHER** Bright city lights present serious challenges for astroimaging, but thankfully there are techniques and strategies to help minimize their impact. Here, the author's friend Chris Boar is helping set up an equatorial mount equipped with an astro-modified Canon EOS 60D camera and Canon 300-mm telephoto lens for a night of close-to-home imaging.

ALL IMAGES COURTESY OF THE AUTHOR

▲ **CRESCENT CONJUNCTION** A tripod-mounted camera using a telephoto lens is limited to very short exposures, but that's not a problem when shooting bright targets. This ¼-second twilight portrait recorded with a Canon 70D DSLR (at ISO 3200) and 300-mm f/4 telephoto lens shows the July 15, 2018, conjunction of the Moon and Venus.

▲ **CITY MOONRISE** Although normally regarded as a nuisance, city lights can help enhance the beauty of a scene if care is taken with the composition. This 1–second exposure captured the waning gibbous Moon rising over a cloudy city skyline. The author used a Canon 80D DSLR (at ISO 400) and 300-mm f/4 telephoto lens for the shot.

raphy, as the ambient glow illuminates foreground elements and adds color to the overall scene.

For a complete escape from light-pollution concerns, consider our nearest star, the Sun. Solar imaging represents a domain in which urban astronomers are on equal footing with their rural counterparts. With a proper, full-aperture solar filter for your telescope or telephoto lens, you can capture sunspots, granulation, and other fascinating solar phenomena regardless of your location. Shooting the Sun is especially exciting now that we're at solar maximum — a period marked by increased sunspot numbers.

Diving Deeper

Beyond our solar system, some deep-sky objects prove more accessible from urban locations than others. Bright star clusters and emission nebulae are excellent targets for city astrophotographers. The Orion Nebula (M42) and the Lagoon Nebula (M8), for example, emit substantial amounts of ruby-red hydrogen-alpha light, which you can isolate using specialized filters to create stunning images even under heavily light-polluted skies.

Capturing deep-sky objects from a city requires an understanding of light pollution. Unlike clouds or smoke, it doesn't block starlight but instead adds an artificial glow that reduces contrast. Photons from celestial objects still reach your camera sensor but must compete with a brightened sky. While you can't completely eliminate light pollution (except during rare power outages), strategic techniques can help minimize its impact.

It's important to remember that light pollution generally diminishes with increasing altitude. Targeting deep-sky objects when they reach their maximum height above the horizon (when they *culminate*) significantly improves your results. Planetarium software and apps such as *Stellarium* or *SkySafari* allow you to determine when specific objects will culminate in your local sky. For example, in August, the North America Nebula (NGC 7000), culminates around midnight when northern Cygnus is highest, while the Andromeda Galaxy (M31), reaches its maximum altitude a few hours later.

The early morning hours also offer additional advantages. Many residential and commercial lights are switched off by this time, significantly reducing the ambient glow. Reduced vehicle traffic means fewer airborne particulates that scatter light, resulting in darker skies. Plus, the predawn environment often provides superior visibility, as cold, dry air creates better imaging conditions than the warm, humid air prevalent in the evening. This is why some of the best times for urban astrophotography occur after midnight rather than during the evening. You may also consider pursuing your targets when they culminate "out of season" in the predawn hours. For instance, the Orion Nebula culminates around 4 a.m. in late October.

Seasonal variations also deserve consideration. Cold, dry, winter air often produces clear, transparent skies that scatter less artificial light. Additionally, winter nights are longer, offering extended imaging windows despite the challenges of operating equipment in frigid temperatures.

Your specific location may require customized tactics. From the suburbs, skyglow will likely be more intense in the direction of downtown. The opposite horizon might be darker but could feature localized light domes from neighboring communities or commercial complexes like shopping malls, car dealerships, airports, or industrial facilities. Often, minor glows don't reveal themselves except in photos. Experience, or the use of a Sky Quality Meter will show you which parts of your local sky are darkest.

Technical Tools

Light-pollution filters will significantly improve your urban imaging capabilities. They allow the emission lines from certain nebulae to pass through while blocking light from artificial sources. I've used an Astronomik CLS (City Light Suppression) filter for years with my astro-modified Canon 60D DSLR. However, the transition to LED streetlights has made such filters less effective. Narrowband options, like the Optolong L-eNhance or the emission-line filters from Astronomik, though, still work well, allowing for much longer exposures before reaching the city sky-fog limit.

Finding the correct exposure involves balancing ISO settings, lens aperture (focal ratio), and sky conditions. Take test exposures and evaluate them using your camera's histogram display rather than relying on the LCD preview. In urban environments, you'll need to push the histogram "hump" farther to the right than you would under dark skies. This ensures you won't underexpose your celestial subject, whose contribution to the histogram might be masked by sky glow — just be wary of clipping (overexposing) your highlights. And always shoot in RAW mode to allow for maximum flexibility during post-processing.

Capturing multiple exposures and stacking them together into a single image with software such as *DeepSky-Stacker* or *Siril* is essential in urban environments (*S&T:* Apr. 2022, p. 54). This technique significantly improves the signal-to-noise ratio, revealing faint details amid the noise caused by light pollution. Just plan to capture considerably more frames than you would at a dark-sky location.

Wide-field astrophotography presents unique challenges, primarily due to the uneven nature of light pollution. Artificial light sources result in brightness and color variations across your images, especially near the horizon and toward urban centers. While light-pollution filters can reduce overall sky glow, they don't eliminate these complex gradients. Specialized software, such as *GraXpert*, can help, but it's definitely an uphill struggle.

Editing your urban deep-sky images takes significantly longer than those captured in dark skies. It requires a delicate balance between subduing the background skyglow while still retaining the delicate, faint objects you're trying to capture. The results can still be rewarding, but to avoid frustration, set realistic expectations about how much additional capture and processing time you'll need.

If all of this seems too complicated, you may want to consider a new class of instruments known as *smart telescopes* or *digital telescopes* that have appeared on the market recently. Devices like the DWARF 3 or ZWO Seestar S30 (*S&T:* Jun. 2025, p. 68) offer a simplified, relatively inexpensive entry point into the hobby of astrophotography. These integrated systems combine optics, tracking, and image processing, often automating complex tasks like polar alignment and stacking. While the results may not equal the quality of traditional setups, their ease-of-use and ability to produce pleasing photos in light-polluted environments make them an appealing option for beginners eager to image the night sky.

Hometown Hero

As a side benefit to urban astrophotography, you have a rare opportunity to raise awareness about light pollution within your community. By sharing your images on social media and explaining the effort needed to overcome skyglow, you help educate others on the importance of preserving the night sky. Your photos can inspire more people to appreciate the stars — and perhaps even take steps to reduce excessive outdoor lighting.

While light pollution presents challenges, I encourage you to embrace the upsides of urban astrophotography. Imaging from home gives you the chance to regularly and conveniently capture and refine your shots without the hassle of travel. And the specialized skills you develop to overcome city light pollution — mastering exposure, stacking, and post-processing — will always serve you well. As Frank Sinatra once sang of New York City, "If I can make it there, I'll make it anywhere."

And each successful shot proves that the night sky is within reach, no matter where you call home.

TONY PUERZER is a retired professional photographer and an avid amateur astrophotographer. He loves the convenience of imaging the night sky from the comfort of his own home.

START SPREADING THE NEWS Big-city lights present serious challenges for astroimaging, but even in New York City the crescent moon managed to (just barely) punch through the urban glow. Given its brightness, the Moon makes a good target for beginners. A Canon EOS 5D Mark II was set to ISO 400 for this 1.3-second exposure using a Canon EF 15-mm f/2.8 Fisheye lens.

BIRD'S HEAD GALAXY
NGC 6745 in Lyra is a fascinating example of a galactic collision. The larger spiral interacts with another smaller galaxy (partly outside the field of view). North is to the upper right.

GARY IMM

Galaxies of the Summer Triangle

Explore faint fuzzies in Lyra and Cygnus.

Being a fan of even the most-nondescript galaxies, I enjoy hunting for them in unexpected places. I've observed many of them near the summer Milky Way's northern expanse, but they dwell far away from the plane of the dust-choked, star-strewn galactic disk. Those relatively easy objects pose an intriguing question: How many other galaxies could I find amid the denser regions of the Milky Way?

Ernie Ostuno's article from the summer 1990 issue of *Deep Sky* magazine, "Galaxies Along the Summer Milky Way," served as inspiration for my survey. I also used *Sky Safari* and José Torres's TriAtlas C charts (**https://is.gd/triatlas**) to find targets amid the star clouds and clusters that litter the galactic plane. I ultimately confined my search to the Summer Triangle, the region defined by the stars Vega, Deneb, and Altair; otherwise, the number of potential targets would be overwhelming.

Armed with my observing list, a 20-inch f/5 Dobsonian, and dark Oregon skies, I spent the summer of 2023 combing through Milky Way star fields looking for extragalactic smudges. For my observations I started at 180× (using a 14-mm TeleVue Delos eyepiece yielding a 24′ true field of view), bumping up to 363× (7-mm TeleVue Nagler, 14′ true field) when the seeing allowed. The project pushed my observing skills, equipment, and sky conditions — not to mention my patience and stamina! — to the limit. For every object I felt confident enough to take notes on, another defied every attempt to extract it from the gray sky background.

Notes from the Lyre

Lyra has the largest number of accessible targets — I've plucked a few here. Vega, its brightest star, marks the westernmost corner of the Summer Triangle and makes it the ideal place to begin.

Starting at 4.3-magnitude Delta (δ) Lyrae, I scanned 33′ southeast to land at 13th-magnitude **UGC 11380**. It's one of the more obvious galaxies in my survey that I saw as a 0.8′ × 0.3′ streak oriented north-south (the table on page 60 has cataloged values). The galaxy has a small, somewhat elongated core, which can be difficult to perceive due to the 6.7-magnitude star that lies 10′ south-southeast. Careful observation revealed that the galaxy's core is marginally offset toward its southern end.

MCG +6-41-24 sits 1.2° northeast of Delta Lyrae and 16′ south-southwest of the 5.9-magnitude double star HD 176318. In my eyepiece the galaxy was an ill-defined 0.3′ smudge, though not particularly difficult, and had a core that appeared slightly brighter. Unlike many of the galaxies in my survey, it took high magnification (363×) quite well. A 14.5-magnitude star sits just off the galaxy's northwestern edge. At magnitude 12.6, MCG +6-41-24 is the brightest object in a large field of tiny galaxies, only one of which is brighter than 16th magnitude.

Moving 2.3° southwest of the 8.4-magnitude globular cluster M56 brings us to **UGC 11404**, a roundish, 0.7′ glow with an embedded 13th-magnitude star masquerading as a nucleus. The 13.2-magnitude galaxy first appeared as a diffuse fuzz around the star, almost like a small planetary nebula. At 363×, I detected a tiny core just north of the star.

Head to the border with Cygnus to locate 5th-magnitude 4 Cygni, then slew 2° southwest to find the 13.5-magnitude spiral **UGC 11426**. Although this galaxy appears elongated in photographs, I saw it as a round, 0.3′-diameter smudge at the eyepiece, with a weakly defined core. A 9.8-magnitude star lies a bit more than 1′ south of UGC 11426, disrupting the view — using averted vision will help. This is another object that takes higher magnification well.

Let's conclude our visit to Lyra's galaxies with the most interesting of them all, **NGC 6745**, the Bird's Head galaxy. Lying 2.8° northwest of 4.4-magnitude Eta (η) Lyrae, NGC 6745 is a 14th-magnitude colliding system, severely distorted from the gravitational interaction of multiple galaxies. At low power, the Bird's Head resembled Hubble's Variable Nebula or (to my eyes) a banana. I saw the southern end as ragged and indistinct, but the central region was notably brighter. Although I didn't detect a nucleus, I did note a *stellaring* (a bright knot) near the galaxy's northern end. In my eyepiece, the whole object was 1.3′ long and 0.5′ wide at the southern end and tapered to a sharper, brighter "stem" at the northern end (cataloged as galaxy PGC 200362). At 363×, the northern two-thirds of the Bird's Head looked lumpy. At this magnification, I detected three discrete objects: a large, oval component in the center and smaller ones at the northern and southern ends.

Moving to the Swan

Cygnus — at least the part of the constellation that lies within the Summer Triangle — has fewer detectable galaxies than Lyra, due to the greater density of obscuring Milky Way gas and dust. Nonetheless, there *are* galaxies to be found here along the galactic plane, if one searches carefully among the multitudes of stars. And, in fact, I observed more noteworthy galaxies in Cygnus than I did in Lyra!

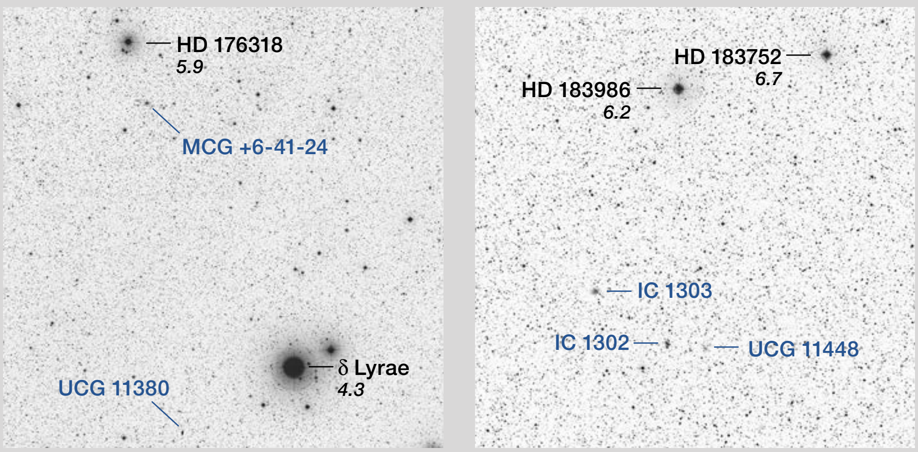
Our first stop in the celestial Swan is a trio of faint fuzzies. **IC 1302** lies 1.3° north-northwest of the 4.7-magnitude star 8 Cygni. It's the brightest of the three objects, appearing as a fairly well-defined 0.7′ × 0.5′ glow elongated northeast-southwest. I could discern a barely brighter core within the galaxy's halo, but I didn't note a nucleus, even at 363×. A 12.4-magnitude star lies outside the halo to the south, while a 14th-magnitude star sits along the northern edge.

From IC 1302, slew 4′ west to arrive at **UGC 11448**, a difficult haze only 0.3′ × 0.2′ in size, bracketed on the northeast and southeast by a pair of 15th-magnitude stars. I saw a faint, small core or substellar nucleus at 181×; at 363×, a pair of 16th-magnitude stars (one on the galaxy's northwestern edge, one on the southwestern) joined the 15th-magnitude stars to form a diamond, imprisoning the dim glow of the galaxy within.

The trio's third member, **IC 1303**, dwells 9′ northeast of IC 1302. The largest of the trio (that I see at 0.8′ in diameter), IC 1303 is brighter than UGC 11448 but is equally diffuse. A tiny triangle of stars of magnitudes 13, 14, and 15 lies 1.2′ west of the galaxy. I didn't discern any central concentration in IC 1303, even at 363×, and the higher power made the galaxy fade into the darker background.

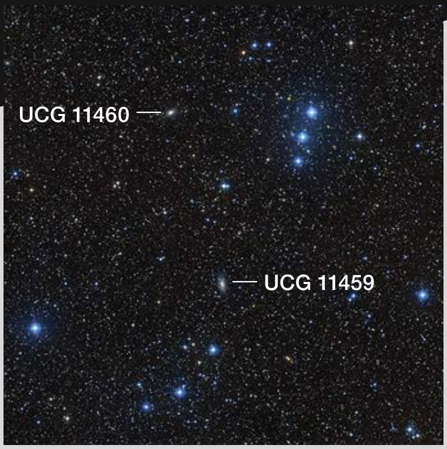
A bit less than 1° northwest of the striking, 7th-magnitude open cluster NGC 6819 lies the phantasmic spiral galaxy **UGC 11459**. A north-south smear of 1.0′ × 0.5′, this 13.4-magnitude galaxy offers little in the way of detail, even at 363×. Scan 19′ north-northeast of UGC 11459 to find, at magnitude 12.9, the brighter and more concentrated **UGC 11460**. Half the size of its larger companion, UGC 11460 extends east-west and contains both a small, brighter core and a faint nonstellar nucleus. To better study these galaxies, you'll have to nudge a row of 8th-magnitude field stars out of the field. The stellar trio stretches north-northeast to south-southwest some 13′ west of UGC 11460.

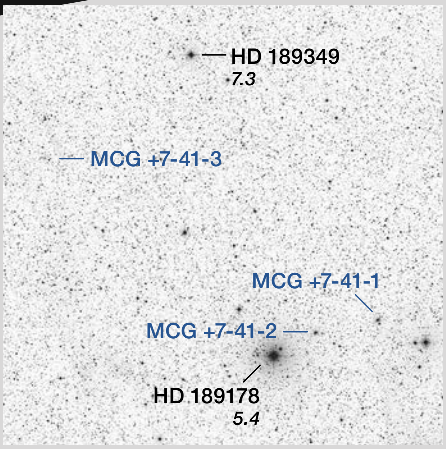
You'll find our next pair of Cygnus galaxies, **MCG +7-41-1** and **MCG +7-41-2**, about halfway from the previous pair to Gamma (γ) Cygni (Sadr). MCG +7-41-1 glows at magnitude 13.5 about 6′ northeast of a 7.3-magnitude star. The galaxy appeared to be 0.5′ in diameter and



▲ **GALAXIES OF THE LYRE AND THE SWAN** (*Left*) You can use Delta Lyrae to navigate to two of the objects described here. MCG +6-41-24 is the brightest in a field of tiny, faint galaxies, while UGC 11380 is one of the more-obvious targets within the Summer Triangle. (*Right*) After star-hopping north-northwest of 8 Cgyni, you can then use the two stars shown to locate the IC 1302 trio.

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





▲ **FAINT FUZZIES** (*Left*) A short line of 7th- and 8th-magnitude stars serves as a signpost for the Cygnus galaxies UCG 11460 and UCG 11459. (*Right*) To find your way to these faint MCG galaxies, slew some 5° west of 2.2-magnitude Gamma Cygni (Sadr). MCG +7-41-3 is the optical counterpart of the radio galaxy, Cygnus A.

wasn't particularly well-defined. Outside the south-southwestern edge of its halo is a distracting 11.6-magnitude star. I noted a small, fairly abrupt core to the galaxy, and high magnification revealed a faint star embedded on the southeastern edge of the core. MCG +7-41-2 hovers 7′ east-southeast of MCG +7-41-1. Smaller (at 0.3′ diameter), with a compact, somewhat-bright core and a very faint stellar nucleus, MCG +7-41-2 also has a distracting star (of 14th magnitude) just on the southeastern edge of its halo.

The last of our Cygnus galaxies is the best known: **MCG +7-41-3**, a barely-there speck in a busy starfield, 36′ northeast of MCG +7-41-2. Yet, this tiny, attenuated glow is the optical component of one of the mightiest radio sources in the sky, the elliptical galaxy Cygnus A. It hosts a supermassive black hole and might even have a *second* supermassive black hole orbiting the first.

Visually, MCG +7-41-3 is no bigger than 10″, a difficult smudge with a tiny core that's just bright enough to attract attention in the star-strewn field. A 14.3-magnitude star lies due east of the galaxy, just outside its tenuous halo, while a 13.2-magnitude star is positioned 0.5′ west-southwest. A 1.2′-long splash of 12th- and 13th-magnitude stars sits 4.3′ north of Cygnus A, providing a useful signpost for locating this difficult, fascinating object. Every galaxy, no matter how underwhelming, has a tale to tell, and Cygnus A's still-developing story adds a layer of fascination to its modest visual presentation.

Given large enough optics and good sky conditions, galaxies can be found most anywhere you look for them! The objects within the Summer Triangle may not be showpieces, but, with that caveat in mind, an intrepid deep-sky observer can spend an entire season tracking down these and many other galaxies glowing stubbornly through the spiral arms of our own Milky Way — something I may very well be doing myself this summer. Stay tuned.

■ **ANDY EDELEN** has moved from the dark skies of Oregon to the East Coast. You can follow his deep-sky adventures at **unfrozencavemanastronomer.wordpress.com**.

Some Summer Triangle Galaxies

Object	Type	Surface Brightness	Mag	Size/Sep	RA	Dec.
UGC 11380	Spiral/Lyra	12.5	12.8	1.5′ × 0.6′	18^h 56.9^m	+36° 37′
MCG +6-41-24	Elliptical	12.7	12.6	1.1′ × 0.9′	18^h 57.6^m	+38° 00′
UGC 11404	Spiral	14.0	13.2	1.9′ × 1.3′	19^h 07.1^m	+29° 00′
UGC 11426	Spiral	12.6	13.5	0.8′ × 0.6′	19^h 18.4^m	+34° 50′
NGC 6745	Spiral	13.1	13.9	1.1′ × 0.5′	19^h 01.7^m	+40° 45′
IC 1302	Spiral/Cygnus	12.4	13.4	0.9′ × 0.5′	19^h 30.9^m	+35° 47′
UGC 11448	Spiral	14.5	14.9	1.1′ × 0.7′	19^h 30.6^m	+35° 47′
IC 1303	Spiral	13.7	14.3	1.1′ × 0.6′	19^h 31.5^m	+35° 53′
UGC 11459	Spiral	14.1	13.4	2.0′ × 1.1′	19^h 37.4^m	+40° 42′
UGC 11460	Spiral	12.0	12.9	1.0′ × 0.5′	19^h 37.9^m	+41° 01′
MCG +7-41-1	Elliptical	13.4	13.5	1.2′ × 0.7′	19^h 56.2^m	+40° 26′
MCG +7-41-2	Elliptical	—	15.1	0.4′ × 0.4′	19^h 56.8^m	+40° 25′
MCG +7-41-3	Spiral	—	15.0	0.5′ × 0.5′	19^h 59.5^m	+40° 44′

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.

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

◀ LIGHT-DUTY GO-TO

Sky-Watcher now offers a lightweight equatorial Go-To mount for observers and imagers alike. The EQ-AL55i ($845) is a dual-axis equatorial mount designed to carry payloads of about 10 kilograms (22 pounds). Its stainless-steel legs extend from 114 to 147 centimeters (45 to 58 inches) with a footprint of 114 cm. The mount includes built-in Wi-Fi and Bluetooth to connect your phone or tablet and is controlled with the *SynScan* app for iOS and Android devices. The EQ-AL55i accepts Vixen-style dovetail mounting bars and its counterweight shaft can be moved to a secondary position to permit use at low latitudes. An illuminated polar alignment scope, DC power cable, 1.8-kg and 3.5-kg counterweights are included with purchase.

Sky-Watcher USA
475 Alaska Ave., Torrance, CA 90503
310-803-5953; skywatcherusa.com

◀ DELOS ADDITION

Tele Vue adds a new model to its popular Delos eyepiece series. The 2-inch Delos 24-mm eyepiece provides a 72° apparent field of view and achieves full-field sharpness with virtually no field distortion. The eyepiece provides 22 millimeters of eye relief, particularly helpful for observers who require eyeglasses. It also features an extendable, twist-lock eye guard to help position your eye to the correct distance while blocking contrast-robbing stray light. The 24-mm Delos is parfocal with all other oculars in the series, as well as Tele Vue's 1¼-inch Plössl, Panoptic, and Nagler eyepieces when paired with Tele Vue's Hi-Hat 1¼-inch to 2-inch adapter. Each purchase includes protective lens caps. Prices yet to be determined.

Tele Vue Optics
32 Elkay Dr., Chester, NY 10918
845-469-4551; televue.com

◀ TRUE APOCHROMATS

Astro-Physics celebrates its 50th year in business with the announcement of two new large refractors: The 190mm f/6 StarFire CS and the 155mm f/6 StarFire CS. These 3-element "Christen Superachromats" are designed to virtually eliminate spherochromatism. The 190-mm (7.5-inch) weighs 17.7 kilograms (39 pounds) while the 155-mm tips the scale at 10.9 kg. Both telescopes are fully baffled to block stray light and all air-to-glass surfaces are multicoated to ensure maximum light transmission. Each comes with a 3.5-inch-format, rack-and-pinion Astro-Physics focuser with Starlight Instruments FeatherTouch 9:1 Micro dual-speed mechanism. A 3-element field-flattener comes with each scope, both providing a 64-mm corrected image circle. Machined aluminum tube rings and visual adapters are included with purchase. Prices yet to be determined.

Astro-Physics
11250 Forest Hills Rd., Machesney Park, IL 61115
Phone: 815-282-1513; astro-physics.com

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

How to Clean Your Optics

All reflective optics eventually need cleaning. Here's how to safely do the job.


After cleaning with distilled water and mild soap, the mirror should be left to dry resting on its edge so that the remaining water runs off its surface.

It's a well-known fact that if your desire is to resolve tiny details in anything in the night sky from albedo features on Mars to star-forming regions in distant galaxies, you need a good-sized primary mirror. For visual observers, that typically means a large reflector, typically a truss-tube Dobsonian. Astrophotographers might follow the lead of professional observatories and opt for a large Cassegrain instead.

The drawback of any reflector is that its optics are exposed to the environment, and inevitably accumulate dust, soot, and other potentially harmful contaminants. Eventually, you will have to clean your scope's optics to maintain its performance. But removing dirt from an aluminum coating is a delicate matter.

Today, there are several commonly used methods for cleaning reflective optics. I've cleaned numerous mirrors myself using a variety of techniques up to and including the CO_2 gas method often used by professionals. Each is helpful, though some are more effective than others depending on your particular optics and observing environment. Let's review your options.

To Clean or Not

The biggest decision when caring for your optics is determining whether they actually need to be cleaned at all — it's best to err on the side of caution. Mirror coatings are fairly delicate (particularly those without an additional, protective layer), and it only takes one overzealous cleaning to scratch through the coatings and even gouge the glass itself.

Dust and smudges on your optics are bad because they absorb and scatter light, which reduces contrast, sharpness, and dims the view. But how long can you go before your mirrors need a good bath? While a little dust isn't usually a problem (it doesn't absorb much light), other contaminants, particularly pollen and ash from wildfires, form aggressive organic


▶ **CAREFUL DABBING** The most common mirror-cleaning technique for small to mid-sized mirrors is to lightly dab the surface with soaked cotton balls.

UNLESS OTHERWISE NOTED, ALL IMAGES ARE COURTESY OF THE AUTHOR; GARY SERONIK / *S&T* (2) compounds with moisture that can create discolored spots on mirror coatings, eventually destroying the reflectivity.

When assessing your optics to determine if they need attention, understand that coatings almost always look dirty when viewed from the side or when illuminated by a bright lamp. It's the vertical incidence of light striking the mirror straight on that's most important, so if dust and other contaminants become noticeable with a casual glance, it's probably time for a cleaning.

Dabbing with Cotton

The most common cleaning technique employed by amateurs is to use cotton balls soaked in distilled water. A wet cotton pad can remove dirt from the mirror after it's been generously rinsed. Use circular movements but with a minimal amount of pressure. In my experience, wiping with cotton seems to be quite effective. However, the aluminum layer can be microscopically scratched by the particles adhering to the cotton as it moves across the mirror surface.

Alternatively, you can simply dab at adhering particles with moistened medical absorbent cotton to loosen and remove dirt. However, the effectiveness of this method is limited to particles that loosely cling to the mirror. After dabbing, some cotton residue may remain on the mirror's surface. To remove this, let it dry and gently sweep these areas with an optical cloth. I used to use this method for cleaning small optics. (See page 36 in the March 2019 issue for a detailed description of this process.) These days, I feel that it should only be used when the mirror is completely immersed in a water bath or has a constant flow of water across its surface.

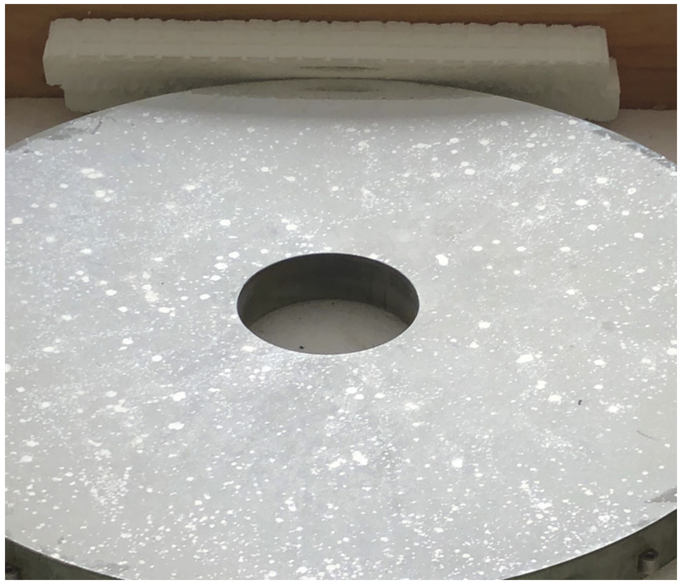
Immersion Washing

Another efficient cleaning method is to wash the mirror while it's fully immersed in water. Using this routine, we were able make the 80-centimeter (31.5-inch) primary mirror at Waldbröl Observatory relatively clean. We first soaked it for several hours in water with a few drops of a cleaning liquid (typically Ivory or Dawn dishwashing soap) and then sprayed it with a jet of water. While the mirror is still under water, you can try to remove any remaining dirt by dabbing cotton on problem areas, but be sure to avoid wiping the cotton over the mirror to avoid creating fine scratches called sleeks. Finally, rinse the mirror with distilled water and place it upright on a soft towel so that the water can run off. This routine also worked well for a 12½-inch mirror I cleaned a few years ago.

Larger optics can also benefit from the immersion-cleaning procedure. For example, the telescope technicians wash the 2-meter mirror at the Wendelstein Observatory in the Bavarian Alps in Germany annually using a two-stage process. They begin by removing the mirror and soaking it in distilled water with a soap solution then adding diluted isopropyl alcohol.

The 1.12-meter mirror at the Expo Observatory in Melle, Germany, on the other hand, must be cleaned while installed, though it's still possible to fully immerse its coatings. They simply pour water onto the primary with the telescope aimed exactly at the zenith, and the shallow curve of the mirror acts like a very shallow bowl. After soaking, they dab a cotton swab over the mirror surface before draining the liquid. The scope is then tipped to pour out the water and mopped up.

Whether either washing method is suitable for your telescope depends on your situation. A big advantage of the



▲ **BATH TIME** *Top:* Eventually, every telescope with reflective optics needs cleaning. The best approach depends on several factors including the mirror's size, weight, whether it has a protective overcoat, and what type of contaminants are present. This image shows the 0.8-meter primary mirror of the Waldbröl Observatory in Waldbröl-Schnörringen, Germany, awaiting cleaning.

▲ **A THOROUGH RINSE** *Bottom:* Following a period of soaking in warm, soapy water, the primary mirror is sprayed down to remove as much loose dust as possible before drying.

latter is that the mirror doesn't require removal — which is extremely desirable for large, heavy mirrors. Unfortunately, this process only works with Newtonian reflectors that don't have a central hole like those found in Cassegrains. For perforated mirrors, you'll need to take extra measures to prevent water from draining though the central hole.

Dusting and Gas

In principle, dusting with pure-cotton optical cloths is a very effective way to remove loose contaminants and can lengthen the life of your mirror's coatings. At the Karl Schwarzschild Observatory in Tautenburg, Germany, the 2-meter primary mirror is lightly brushed with optical cloths every 14 days. This roughly doubles the service life of the mirror, extending the period between recoating to between 6 to 8 years.

While this technique is easy to perform, it requires careful attention. A new piece of fabric is used for each dusting pass, and washed cloths are only usable after laundering with liquid detergent in a washing machine exclusively used for optical cloths. However, much like dabbing with absorbent cotton, this approach won't remove sticky dirt.

Using carbon dioxide (CO_2) gas is a well-established optics-cleaning technique among professionals.

A spray nozzle with an adjustable valve is connected to a gas cylinder containing liquid CO_2, which is blown over the mirror. As it's released from the cylinder, the liquid instantly expands into a gaseous state, and cools adiabatically to become a blast of CO_2 snow. These frigid snowflakes then collide with the dust particles, making them contract abruptly due to the sudden temperature drop and causing them to detach from the mirror's surface. The gentle pressure of the CO_2 snow then pushes the particles off the coating without having to physically touch the optical surface. The CO_2 flakes and dust don't scratch the mirror coating because they glide over the surface on a gas cushion that sublimates from the snowflakes. The method is easy to do and gentle enough to be performed repeatedly until the mirror requires a new coating, which is why it's used at professional observatories.

Yet, CO_2 cleaning isn't always the best approach, depending on conditions at the telescope's location. Professional observatories are usually located at relatively dry sites at high elevations and in deserts, where the main contaminant is

▼ **FRIGID BLAST** A telescope technician at the Very Large Telescope at Paranal Observatory in Chile sprays the 8.2-meter primary mirror of the UT1 telescope (Antu) with carbon dioxide (CO_2) gas.

YURI BELETSKY

▲ **STEAM TREATMENT** A new alternative to CO_2 gas cleaning, technicians at the Isaac Newton Group of Telescopes use steam to remove contaminants from the William Herschel Telescope's 4.2-meter mirror.

▼ **A GOOD DUSTING** *Left:* Telescope mirrors located in dry environments can be kept clean with regular, gentle dusting using optical-quality cloths. A technician dusts the 2-meter primary mirror at the Karl Schwarzschild Observatory with a cotton cloth.

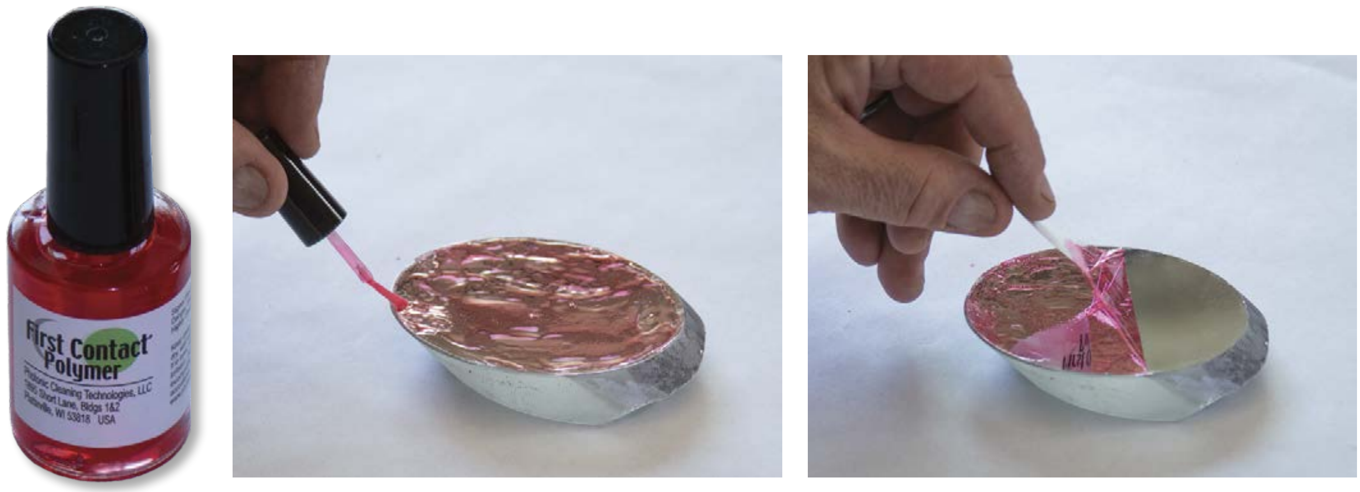
▼ **A COMBINING APPROACHES** *Right:* Waldbröl Observatory's 0.8-meter primary mirror undergoes steam cleaning and careful dabbing with cotton before a final rinse.

dust with little or no humidity. The situation is usually different for your telescope.

Most amateur telescopes reside in typically more humid environments such as the owner's home or backyard observatory, and the scope travels to dark-sky locations. The optics not only get their fair share of settling dust, pollen, and other contaminants, but the stuff is stuck onto the surface due to the effects of humidity. When this happens, a CO_2 blast isn't effective.

A study at the Isaac Newton Group of Telescopes at the La Palma Observatory in the Canary Islands estimates the improvement in reflectivity at around 2% after a CO_2 cleaning, while telescope technicians at the McDonald Observatory in Texas note the 11-meter Hobby-Eberly Telescope experiences "considerable improvement" in reflectivity following a CO_2 treatment. Because large professional reflectors require recoating on a regular basis, it's safe to assume that the soiling of the mirror is only slowed down with regular cleaning rather than arrested completely.

Another impediment to this technique is that CO_2 mirror-cleaning equipment is rather expensive — in the range of $3,000. That doesn't make it very attractive for home use. On online forums, some amateurs have suggested utilizing CO_2 fire extinguishers to clean mirrors. However, this



▲ **CHEMICAL PEEL** *Left:* A very effective mirror-cleaning method is to apply a quick-drying polymer, such as collodion or other specialized products like First Contact Polymer designed specifically for telescope coatings. *Middle:* The liquid polymer is brushed or sprayed on to the mirror's surface in a well-ventilated area. *Right:* in a few minutes, the polymer dries and is removed with tape for a result that's often better than with other methods.

SEAN WALKER / *S&T* (3)

is risky because there's no guarantee that the gas in such extinguishers is clean and free of unwanted particles. Last but not least, it's very important to note that CO_2 cleaning can only be performed in well-ventilated areas due to the very real risk of suffocation!

Steam Cleaning

Another spray-cleaning method has gained traction in professional observatories in recent years. Technicians at La Palma have begun treating the optics with steam, which produces an opposite temperature effect to the cold CO_2 treatment.

This approach begins with moistening the mirror with soapy steam. The soap vapor, heated to 35°C, removes large dust particles. Like the temperature shock with CO_2, the warm steam meeting the colder mirror loosens most particles. Before the mirror is dried, the soap is removed from the surface with steam created from distilled water (as steam can carry particles with it). Finally, to achieve the same results as washing, the optics are dabbed with natural sponge or swabs.

Compared to simple washing, the water-vapor method uses significantly less water and is easily controlled with towels. The results are comparable with conventional washing, but without having to remove the mirror. The observatory uses industrial steam cleaners, but you can use household steam cleaners. Technicians found that it takes a lot of effort to damage the coatings with this technique — they applied the steam stream continuously a few centimeters away from the optical surface for 20 minutes, causing the mirror coating to slightly deteriorate. According to their analysis, steam provides a better result than $C0_2$ cleaning and has become the method of choice for the 2.5-meter Isaac Newton Telescope and the 4.2-meter William Herschel Telescope.

Polymer Peel

Another cleaning method utilizes a mixture of various chemically inactive polymers or liquid plastics such as collodion. In contrast to the methods described above, the liquid polymer is applied directly to the mirror surface, where it then hardens when the solvent evaporates and forms a flexible film. This film is then peeled from the mirror along with the accumulated dust. Collodion is highly flammable and contains the chemical compound ether, so it should be used in a well-ventilated area. A similar, less hazardous polymer called First Contact is available from Photonic Cleaning Technologies (**photoniccleaning.com**). It was developed specifically for cleaning telescope optics.

On the one hand, the material is ideal for removing adhering particles. On the other hand, it can also remove mirror coatings that have poor adhesion qualities, resulting in the need for a complete recoating. The manufacturer recommends testing the polymer on an unused section of the mirror — an area covered by retaining clips or in the shadow of the secondary mirror.

Unlike CO_2, the polymer film also dissolves grease and other materials glued to the coatings by humidity. Incidentally, the polymer also protects the optics against dirt and damage during transportation, so you could apply it before taking your scope to a dark-sky site and then peel it off before observing.

The Choice Is Yours

Ultimately, there is no ideal way to clean mirrors. The best method depends on the type and degree of soiling, and what kind of telescope you have. Each method presented here is meant to maximize the reflectivity and extend the life of your mirror's coatings. Regular maintenance slows the accumulation of particulates on the mirror surface. Find the cleaning technique you're most comfortable with and keep your optics in their best condition.

■ **THOMAS EVERSBERG** is an astrophysicist with the German Space Agency specializing in optics.

Sky-Watcher's Wave 150i Mount

We look at the company's first strain-wave telescope mount.

Sky-Watcher Wave 150i Strainwave Mount

U.S. Price*: $2,495
Carbon-Fiber Tripod: $425
skywatcherusa.com

What We Like

Drive axes can be disengaged to balance load

Built-in cable management

What We Don't Like

Nonstandard power connectors

Awkward placement of pass-through connectors

**Prices subject to change*

STRAIN-WAVE GEARS seem to be the hottest trend in telescope mounts these days. Manufacturers are riding a wave of demand for high-capacity, compact, lightweight models that won't break your back during setup or require cumbersome counterweights. Sky-Watcher recently joined the club with two models: the Wave 100i and the Wave 150i Strainwave Mounts. They provided us with the larger model — the 150i — for this review.

First Impressions

The mount arrived in a foam-lined case and weighs in at just 5.8 kilograms (13 pounds, which makes it extremely portable. The 150i accepts both Losmandy D-format and Vixen-style dovetail mounting plates (which Sky-Watcher refers to as a D/V saddle). Its weight capacity is 15 kg and with the addition of an optional counterweight and shaft, 25 kg. The mount comfortably handles a variety of payloads. I successfully tested it using several telescopes ranging from a Takahashi FS-60CB up to a Sky-Watcher Esprit 150-mm f/7 refractor.

The 150i is sold "à la carte." Sky-Watcher shipped our test sample with the optional Wave Counterweight Kit ($125), the Wave Carbon-Fiber Tripod ($425), and the Wave Carbon Fiber Tripod Extension Tube ($185). The unit comes with a 12-volt DC power car adapter, though no AC power brick is included.

▲ The Wave 150i Strainwave Mount is a versatile unit that operates in both equatorial and alt-azimuth modes.

▶ The mount is shipped in a hard-sided case with foam insert that accommodates the head, an optional counterweight shaft, and has space for additional accessories.

The mount operates in either alt-azimuth or equatorial modes. I found the alt-azimuth configuration offered a quick and easy setup for both visual observing and images of the Moon and Sun. Equatorial mode, on the other hand, is ideal for long-exposure astrophotography and planetary imaging. The mount also includes homing sensors on both axes — a welcome surprise that proved helpful during polar alignment, as discussed later.

An excellent feature in the 150i — and, I believe, unique among current strain-wave models — is the ability to loosen both axes to allow free movement of the mount to carefully balance the payload. Locking knobs on each axis engage the gears after balancing. Although strain-wave drives are designed to virtually eliminate the need for counterweights, load balance is important for heavier setups. Just because the mount can handle an

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imbalanced load doesn't eliminate the risk of your entire setup tipping over! Using counterweights and properly balancing your scope is always advisable, and with particularly heavy loads, I consider it *mandatory*. There's one knob just above the control panel that engages the polar axis and two knobs on the front and back ends of the D/V saddle that engage the declination drive.

Sky-Watcher also thoughtfully incorporated power-loss axis braking into the 150i to prevent your telescope from potentially colliding with the tripod or pier if the if the mount becomes unplugged or your battery runs down.

The Wave Carbon-Fiber Tripod performed adequately with my 60- and 92-mm telescopes but was insufficient for supporting my 6-inch refractor or larger instruments safely. Even with its legs fully extended, it doesn't provide a wide enough footprint to ensure the entire assembly wouldn't tip over while slewing across the sky. This was especially the case when using the mount in equatorial mode without counterweights. To address this, I preferred to attach the 150i to a Starfield Optics Tri-Pier 1000 which offered solid support.

Passthroughs and Control

Another welcome feature of the 150i is its integrated cable management, allowing users to run USB and power through the mount for tidier, snag-free setups. While internal electrical routing is always desirable, Sky-Watcher's implementation has a few quirks of which to be aware.

▲ The input panel located just below the right ascension locking knob contains several passthrough ports and inputs. From left to right, these are the 2.5-mm passthrough port to power your attached accessories, a USB 3.0 passthrough (erroneously labeled USB HUB), the 2.1-mm jack to power the mount itself, the RJ-45 hand-control input, and a USB-B jack to connect an external computer. The green aluminum knobs are for adjusting the altitude and azimuth axes during polar alignment.

A panel with several ports is located at the base of the mount. The ports are labeled (from left to right) PWR TO HUB, intended for through-the-mount power distribution to other accessories; PWR 12V which provides electricity to the mount itself; HAND CNTRL, which is an RJ-45 connection that accepts an optional SynScan hand paddle; and a USB-B input. An additional port labeled USB HUB is at bottom left.

The mount's power input uses the industry standard 2.1-mm format socket. In contrast, the PWR TO HUB port at the base, as well as the two PWR OUT sockets on the saddle plate utilize less-common 2.5-mm formats. Nearly every astronomy accessory on the market uses 2.1-mm plugs, so using this passthrough will require purchasing some additional adapters or converter cables. When asked about this choice, Sky-Watcher explained that the 2.5-mm plug provides better "electrical characteristics," presumably related to higher current capacity. Given that most users will inevitably require adapters to work with this size, the advantage seems questionable. I was able to purchase the necessary, inexpensive adapters online.

Another quirk of the electronics panel is the USB HUB, which is slightly mislabeled. This USB-A port simply passes through the mount, connecting directly to a second USB-A port on the saddle plate. However, that doesn't make this a USB hub as only a single connection is supported. The user manual instead correctly refers to it as an AUX USB port.

▲ *Left:* Telescopes connect to the 150i via a dual-format saddle that accepts both Losmandy D- and Vixen-style dovetail bars. Unlike other strain-wave mounts, the 150i lets you disengage its drives to allow balancing a mounted instrument. Two locking knobs located on the front and back of the saddle can be removed to disengage the declination axis, while the large green knob seen at right is for the right ascension axis. *Right:* On the east side of the D/V saddle is the autoguiding port and the USB 3.0 and 2.5-mm power passthrough ports. The two declination locking knobs are visible on the left and right.

Regardless of its name, it operates at USB 3.0 speeds. When I tested it with a high-speed Player One Astronomy planetary camera, I experienced no problems nor lost frames, making it a convenient option for tidy cable management even for planetary imagers.

A significant shortcoming of the through-the-mount cable system is the location of the power and accessory connectors along the bottom panel. All the ports face the same direction as the altitude (or declination) axis. Consequently, any telescope with a lengthy dovetail bar potentially extends directly over the panel and could interfere with the cables. That's why I strongly urge users to purchase several 90° cable adapters to avoid potential damage to the wires, or worse, the mount's electronics when slewing around the sky.

You can control the 150i in several ways. While a SynScan hand paddle isn't included, users can download Sky-Watcher's *SynScan* or *SynScan Pro* mobile apps for free from the Apple and Android app stores. This allows you to use your smartphone or tablet device to wirelessly connect over both Wi-Fi and Bluetooth. Connecting via Wi-Fi was similar to most every mount by selecting the mount name in your device's

▲ Users should be aware that cables plugged into the control panel can interfere with movement of the declination axis, particularly with scopes fitted with long dovetail mounting bars.

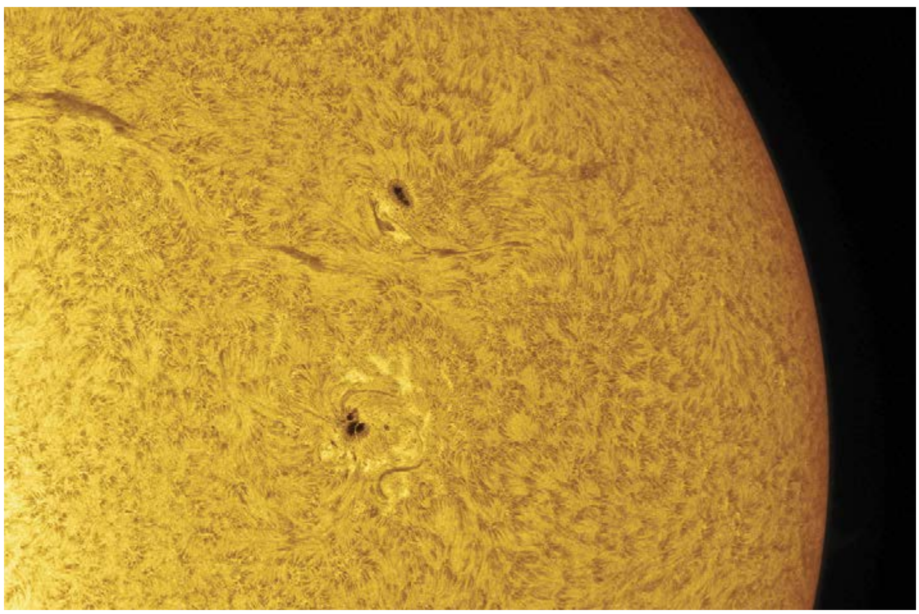
Wi-Fi options. Setting up Bluetooth control was easier than I anticipated. Simply select BLE in the *SynScan* app's settings and it automatically detects and connects to the mount. I noticed no operational difference between Bluetooth and Wi-Fi, except that my phone could remain connected to my home Wi-Fi network (and the internet) while operating the mount. This quickly became my preferred way of operating the mount with my iPhone.

I also controlled the mount through the hand-control port and an EQMOD cable to connect an ASI-Air as well as a computer running *TheSky Imaging Edition* software. Both methods worked seamlessly for astrophotography. Guiding with the ASI-Air was smooth and trouble-free. I was able to guide without any problems using a Player One camera as an autoguider and its 6-pin cable plugged into the ST-4 port located on the front of the dovetail plate.

Performance Under the Stars

The 150i has rekindled my appreciation for the simplicity and joy of alt-azimuth mounts. In this configuration, the Sky-Watcher unit is remarkably quick and easy to set up for visual astronomy, and very sturdy. I can be outside observing in about five minutes. Alignment is simple — all that I needed to do is point the scope north, perform a 1-star alignment, and I was ready to observe. For solar imaging in the morning, it's equally convenient. I can capture a stream of solar images and still wrap things up before my workday begins.

Setting up equatorially takes a little more effort. I was initially surprised that the mount doesn't include a polar-alignment scope. But I quickly recalled the 150i has helpful homing sensors. A



▲ Solar observing and imaging with the 150i was especially easy in alt-azimuth mode. Simply set the mount down with the scope pointed north, make sure your solar filter is in place, then align on the Sun. The author used the 92-mm scope and Player One Apollo-M camera seen at left to image two active regions and filaments seen at right.

mount equipped this way always knows the position of its axes if it starts at its calibration points. You can use this to polar-align the mount with a very simple procedure. Begin by ensuring the date, time, and location entered in your controller are accurate, and that the mount is level with its polar axis roughly aimed north. Next, initialize the mount and "home" it. Slew to a bright star not too high in the sky in the scope's eyepiece then center it by shifting the mount's position with the altitude and azimuth polar-alignment adjustments (not the hand control). This usually gets you to within less than a degree of the pole, and close enough to sync and perform guided imaging. This routine is a tremendous boon to me and enables me to get aligned and imaging really fast each night.

Of course, the 150i also works with traditional polar-alignment methods, as well as with third-party aids like QHY's PoleMaster device.

As noted earlier, the 150i needs to be homed before use. This commands it to slew to a predetermined position, where the internal homing sensors calibrate the exact orientation of both axes based on the time and location. This procedure must be performed before starting an observing or imaging session. Using the SynScan hand controller, you're automatically prompted to home the unit as soon as you turn the power on. However, when operating the 150i with the *SynScan* mobile app instead, you need to navigate to the Advanced Utilities menu and select Auto Home. The app doesn't automatically prompt you to perform this action, so if you skip it, you'll experience poor pointing accuracy. I've suggested to Sky-Watcher that they implement such a prompt so new users unfamiliar with the homing process will be aware of this critical step.

Weight Limits and Periodic Error

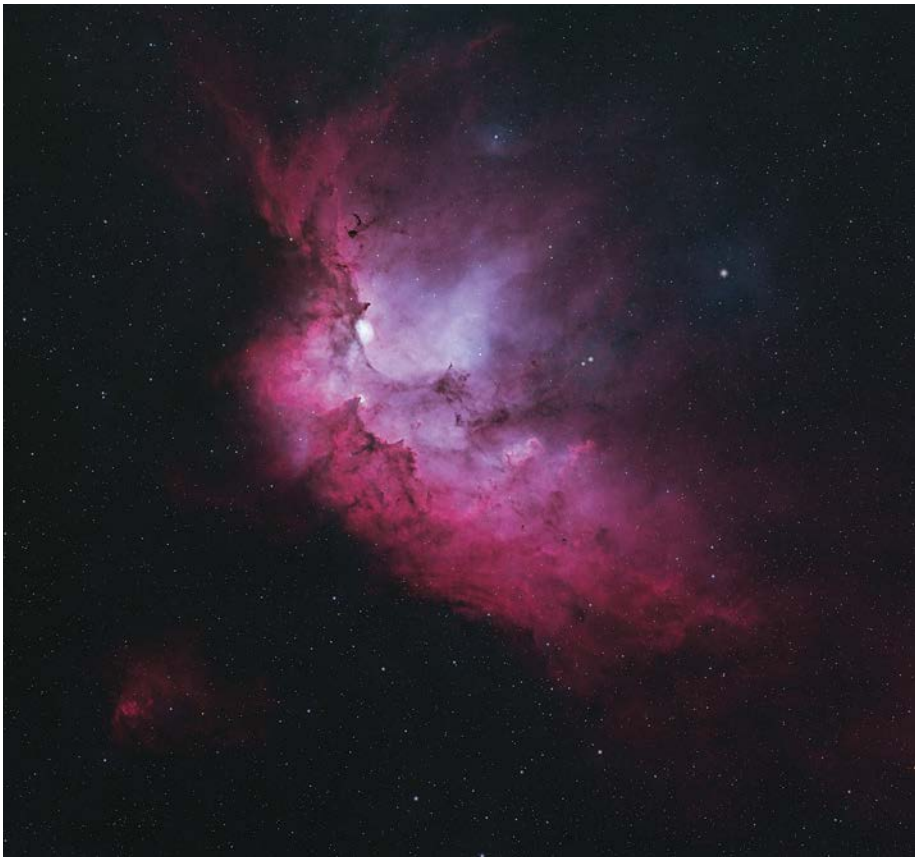
Strain-wave gears are remarkable for their exceptional load-bearing ability — exactly why they've become so popular for use in telescope mounts. Enthusiasts also appreciate their ability

▲ Although an option, the author highly recommends purchasing the counterweight kit if you have a long or heavy telescope that approaches the weight limit of the mount.

to function without counterweights, though as I previously cautioned, there is a risk of doing so. Still, it's important to recognize there are practical limits. I found a 6-inch f/7 refractor to be at the very upper limit of the 150i's capacity. The long refractor creates a substantial moment arm that created some slight play in the declination axis. While this was manageable with autoguiding, I wouldn't recommend pushing the mount beyond this point.

I also mounted my 21-kg Celestron EdgeHD 14 as a stress test. Admittedly, the weight of this scope bordered on the abusive. Even after adding extra counterweight, I couldn't achieve proper balance. I also discovered that a weak power supply was insufficient to slew this heavy load, resulting in frequent stalls. Switching from the 1.0-amp sup-

▲ The author's Sky-Watcher Esprit 150ED refractor pushed the Wave 150i to its limits, though it performed admirably when a second counterweight was added. The supplied tripod didn't safely support the scope, so the author used a Starfield Optics Tri-Pier 1000 instead.



▲ This 9-hour, color composite of NGC 7380, the Wizard Nebula in Cygnus, is a testament to the 150i's imaging capabilities. The 6-inch refractor shown on page 71 captured this photo.

▲ *Left:* Despite being close to the maximum weight capacity of the 150i, the mount held this Celestron EdgeHD 14-inch OTA, though it required extra counterweights and a sturdier tripod than the one provided by Sky-Watcher. *Right:* Even without using counterweights, Sky-Watcher's 180-mm Maksutov-Cassegrain was a comfortable match for the 150i when configured with the optional tripod and tripod extension.

ply to one delivering 2.5 amps resolved the issues entirely. Sky-Watcher recommends at least a 2.0-amp power supply, and my tests bear this out. Despite the intimidating appearance of such a large scope on the 150i, I did use this configuration occasionally for visual observing and some imaging.

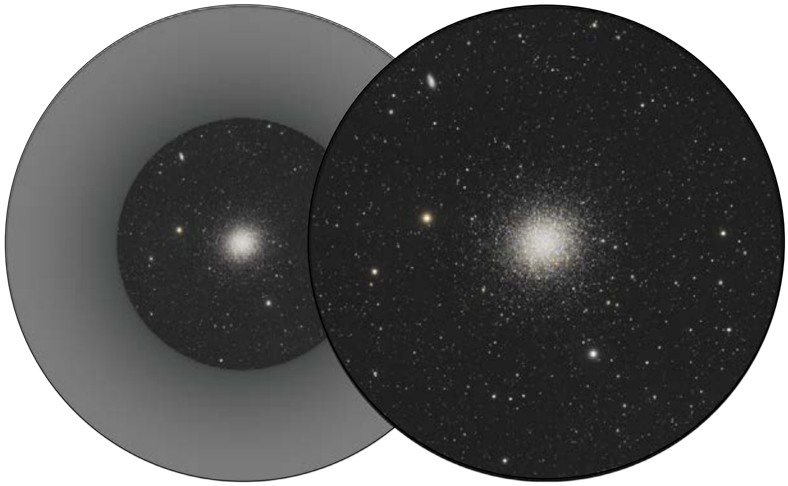
Final Observations

A pleasant surprise was that the periodic error of the 150i was noticeably lower than earlier generations of strain-wave mounts I've tested. With careful polar alignment, I often achieved unguided exposures of up to 20 seconds at an image-scale of roughly 1.5 arcseconds per pixel. When guiding 2- or 3-second exposures, the RMS typically stayed within 0.1 to 0.15 pixels, which is close to the center of the pixel. To get a rough sense of the mount's periodic error, I offset its alignment from the pole by several degrees and recorded several long exposures in order to see the wobble of its right-ascension gear. While the amplitude of the error was relatively large (I measured 18 arcseconds), its gentle, slow nature made it easy to correct with autoguiding.

Overall, the Sky-Watcher Wave 150i strain-wave mount is a versatile, highly portable option offering numerous advanced features tailored for both visual observers and astrophotographers. Its compact size, dual-mode operation, and user-friendly setup make it an excellent choice for quick observing sessions or lucky imaging, while its manageable periodic error allows for effective guided astrophotography. Although adapters are required to overcome a few quirks, the benefits of this mount greatly outweigh the minor inconveniences. For astronomers seeking portability without compromising payload capacity or performance, the Wave 150i is a compelling option.

■ Contributing Editor **RICHARD WRIGHT** started observing with a department-store telescope more than 40 years ago. He couldn't be more pleased with how much telescope mounts have evolved since then.

What is Apparent Field?



▲ **EQUAL BUT DIFFERENT** These simulated eyepiece views of the Hercules globular cluster M13 show the difference apparent field can make. The true fields in both cases are the same, but the right-hand eyepiece produces greater magnification, allowing for a more detailed rendering of the cluster.

TELESCOPES AND THEIR accessories can seem like an intimidating minefield of specifications and formulas. Take eyepieces, for example. They're characterized by several numbers, but let's look at one specification that often creates confusion: *apparent field*.

Much of the difficulty arises from seeing two terms that sound similar: *true field* (also known as *field of view*) and *apparent field*. Both are measured in degrees, yet mean different things. "True field" refers to how much sky you can see in a single view, whether that's with your eyes alone, with binoculars, or in a telescope. Typically, a small telescope used at low power yields 1° or more. "Apparent field," on the other hand, represents how much a telescope or binocular eyepiece *appears* to show you.

Let's explore the concept further with the world's simplest (and most useless) telescope — a cardboard paper-towel tube. Looking into it, the opening at the end spans about 8° — that is, the bright circle at the bottom of the tube occupies about 8° of your eye's visual field. You can say that the tube's "apparent field" is 8°. But what is its "true field?" Because our pretend telescope is a 1× device, its true field is the same as its apparent field: 8°. This leads us to a nifty formula. To calculate *true field*, you simply divide the *apparent field* by the *magnification*. In this case, 8° divided by 1× gives us an apparent field of 8°.

Let's look at a real telescope to see how this all works. Suppose we have an 8-inch f/5 Dobsonian, which has a focal length of around 1,000 millimeters (39 inches). We've decided to use it with a 25-mm Plössl eyepiece with an apparent field of around 50° — that is, when you hold it up to your eye (without a telescope), the circle of light you see occupies about 50° of your visual field. Now, place that eyepiece in the telescope focuser and you get a magnification of 40× since magnification is the telescope's focal length divided by that of the eyepiece (*S&T:* Jul. 2024, p. 74). Because the apparent field is baked into the eyepiece's design, it remains 50° no matter what scope you use it with. So, what is its true field when combined with our 8-inch Dob? Using our formula from earlier, it's the apparent field (50°) divided by the magnification (40×), which gives us a true field of 1.25°.

Now here's where things get interesting. Different eyepiece designs have different apparent fields, with some exotic formulations even exceeding 100°! But why would you want that? First, the "porthole into space" sensation you get is simply amazing. But there's also a practical reason an expansive apparent field is desirable. To appreciate why, you first have to understand the role magnification plays in rendering an object visible. Simply put, the greater the magnification, the better the resolution (allowing you to see more detail) and the darker the background sky, which helps make dim threshold targets stand out better. The downside to boosting the magnification is that — all other things being equal — the size of the true field decreases. A small field of view makes aiming your scope trickier; it also means that some large, extended deep-sky objects might spill out of the field. But what if you could combine the benefits of high magnification with a wide true field? That's essentially the appeal of eyepieces with large apparent fields.

Returning to our 8-inch f/5 telescope, a 20-mm Plössl with a 50° apparent field and a 12-mm Nagler-type eyepiece with an 82° apparent field both yield a 1° true field with this instrument. The difference is the Plössl is working at 50× and the Nagler at 83×! That extra magnification means the view in the Nagler will be more detailed and have a significantly darker background sky. In some cases, this could be the difference between seeing an object or not.

It takes a little research to discover the apparent field of a given eyepiece design and focal length. Thankfully, most manufacturers are pretty good about providing such information. A quick online search will usually turn up what you want. You'll also quickly discover that the greater an eyepiece's apparent field, the more it usually costs. But if you choose carefully, you may find that you can do 80% of your observing with just two eyepieces. This is definitely a situation where quality is more important than quantity! ■

S&T ILLUSTRATION, SOURCE: M13: RON BRECHER

The Sheldon High Maryscope

Old meets young in a high-school astronomy club.

◀ The Sheldon High astronomy club with their newly finished telescope.

LIKE MOST HOME-BUILT telescopes, this one started with a mirror. It wasn't just any mirror, though. This mirror has some history. Ninety-six years of history, in fact. It was made by Mary Hill Mikesell, a U.S. Naval Observatory astronomer, in 1929.

How did it wind up in a high school in Eugene, Oregon? Well, Mary was married to another USNO astronomer Alfred Mikesell. Alfred was instrumental in scouting out the USNO's western campus in Flagstaff, Arizona. (He's also known for riding a balloon into the stratosphere to see if stars would stop twinkling when he passed through the tropopause, which they did.) Mary and Alfred divorced in 1971, and Alfred moved to Oregon when he retired, bringing along a box of random astronomy equipment.

Alfred joined my astronomy club in the early 2000s. When he died in 2008, his family donated most of his equipment to the club, including the box containing Mary's mirror.

It's an unusual size — 8.3 inches in diameter and only an inch thick (which was thought to be thin at the time, when a thickness ratio of 1:6 was considered essential). It's made of regular green glass, what we would call float or plate glass nowadays. Mary had ground and polished it to f/6.6 (55-inch focal length) and had partially parabolized it, but she hadn't finished the parabola, so I touched it up and had the mirror coated.

Then the mirror sat in storage for more than a decade, waiting for someone to build a scope around it.

Enter Halleigh Travis and Ellen Poulsen, principal instigators of the Sheldon High School Astronomy Club. They decided that it would be fun to make a telescope, but didn't have the time to grind a mirror and finish the scope before graduating. So the Eugene Astronomical Society donated Mary's mirror to the Sheldon club.

The club already had a Dobsonian scope, so they had an example to follow, but they also took inspiration from John Dobson's classic design (*S&T:* April 2020, p. 36). They built the rocker box and tube box pretty much to his specifications, even using a phonograph record for the azimuth bearing.

Several challenges arose along the way. Club members bought plywood circles for the altitude bearings, but the diameter proved too large so they had to cut them down with a jigsaw. That left the circles slightly out of round, so they compensated with thick felt padding lining the entire U-shaped bearing races. That evened out the bumps and gave them smooth altitude motion.

The primary and secondary mirror mounts also required some innovation. For the primary cell, they copied the design of their commercial Dobsonian, which used a three-lobed base with spring-loaded bolts running through it for collimation. They glued the bolts directly to the mirror back, running the bolts through large blocks of wood to increase the glue's surface area. The arms

▲ The 96-year-old mirror finally found a home in the Sheldon High astronomy club's telescope. Ellen Poulsen drills a hole for the mirror mount while Halleigh Travis looks on.

THE SHELDON CLUB AND MIRROR MOUNT: ELLEN POULSEN (2); DRILLING: JERRY OLTION

▲ Halleigh and Ellen share the excitement of first light through the scope.

were a bit short, though, to wedge tightly in the cardboard tube. So, they had to shim the ends with thick felt, then carefully drive screws through the tube and felt into the ends of the plywood arms in order to hold the cell in place.

The secondary would make Dobson proud. They didn't use his cedar-shingle design, but instead came up with one that's just as simple: They mounted the secondary on a block of wood and ran ¼-inch dowels outward from the block to the walls of the tube. Like the primary cell, the ends of the dowels are padded with thick felt, making the secondary spider snug enough to stay put. Collimation is done just like the original Dobsonians, by nudging the ends of the dowels around inside the tube.

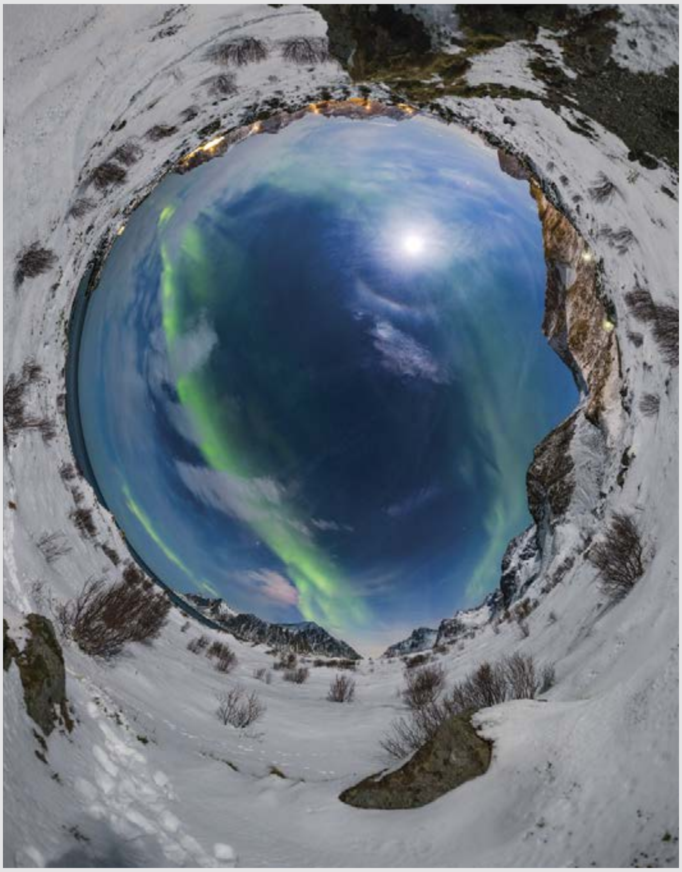
They used a commercial 1¼-inch focuser from the same box of random parts that the mirror came in. Mary's original focuser? We don't know.

I had the pleasure of being with Halleigh and Ellen for first light, moments after they finished mounting the primary and secondary and collimating the mirrors. It was midday, so we looked at a neighbor's treetop and were pleased to see a crisp view even at high (300×) power.

The club members decided to memorialize Mary's mirror in a big way, naming their creation the "Maryscope" in bold letters along the tube. Mary Mikesell's mirror has finally found a home after nearly a century, and another generation of telescope makers has made a great beginning.

JERRY OLTION

■ Contributing Editor **JERRY OLTION** is delighted to see another generation take up amateur telescope making.



◁△ LOOK UP

Ondrej Králik

This image series captures the skies above seven locations across Europe under various conditions. Two record very different auroral displays — shimmering green curtains *(facing page, top left)* and tall, red aurorae with a stable auroral red arc *(this page, top right)*. The remaining five show the Milky Way at various times of the year, with both green and orange airglow coloring the horizon, particularly in the images on the right side of the facing page. Several also show our home galaxy with an encroaching arc of yellowish light pollution washing out the horizon, though both Comet Tsuchinshan-ATLAS (C/2023 A3) and the zodiacal light still manage to penetrate its glowing veil *(top left and left, respectively)*.

DETAILS: *24-mm and 35-mm lenses. Each picture is a mosaic of even exposures recorded at f/1.4.*

SOUTHERN COMET

César Briceño

Comet ATLAS (C/2024 G3) sported several long, curved dust tails with faint striations on January 24th as seen above Andacollo, Chile.

DETAILS: *Canon EOS RP camera and Samyang 85-mm lens. Total exposure: Stack of 10 frames each 30 seconds long at f/2.8, ISO 1600.*

◁ TRICLIPSE

Philippe Moussette

This composite image recorded from Quebec City, Quebec, depicts the Moon at the beginning, the midpoint, and end of the total phase of the lunar eclipse on March 14th.

DETAILS: *Canon EOS R3 camera and RF 600-mm lens. Composite of 3 exposures each less than a second at f/4, ISO 400.*

▽ AURORAL CURTAINS

Chirag Upreti

Green auroral bands stretched across the skies above Lodingen, Norway, on the evening of March 23rd. The activity was so bright it was reflected in the river below.

DETAILS: *Sony α7R III camera and 14-to-24-mm lens. Total exposure: 4 seconds at f/2.5, ISO 6400.*

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An Exercise in Futility? Maybe Not

The author finds joy in observing at the bottom of his sky.

WHEN I LOOK UP at the stars at night, I feel like I own them. I know every constellation by heart and can find the brightest deep-sky objects in binoculars with ease. And when I see a constellation beginning to rise in the east, I know it's only a matter of time before I'll be aiming my binoculars and telescopes at it.

However, I mostly find myself looking toward my southern horizon while out at night. I've always been entranced by what lies above and below it. When I see stars that form parts of such "exotic" constellations as Phoenix, Horologium, and Carina, I feel transported to a foreign land in which I'm privy to someone else's constellations.

You see, I've lived my entire life right around latitude 36° north, which means 10% of the sky stays permanently below my southern horizon. That doesn't sound like a lot, but it doesn't include *atmospheric extinction,* which is a measure of air mass. In essence, what this means is that to observe objects that are at an altitude of 11°, we're probing them through approximately five times more of Earth's atmosphere compared to targets that are directly overhead. You might even hear your fellow observer lament the fact that unless an object gets higher in the sky than 10°, it's an "exercise in futility."

However, I've never let that stop me. I might be crazy, but when I look at a star atlas, I know I've still got a whisper of a chance as long as my intended target lies north of declination –54°. I can't help myself. It's the ultimate challenge. Not only is it harder to find objects because fewer guide stars are visible, but also the lower you aim, the less time you have to catch sight of them before they either vanish behind a distant hill or simply set! Plus, you need those rarest of nights in which a strong cold front has cleared the sky and yet left nary a twinkle to the stars.

NGC 4945 is resplendent in this image obtained with the 2.2-meter telescope of the European Southern Observatory's La Silla facility. One of several elusive low-altitude targets, the author finally managed to snag it in his 6-inch reflector.

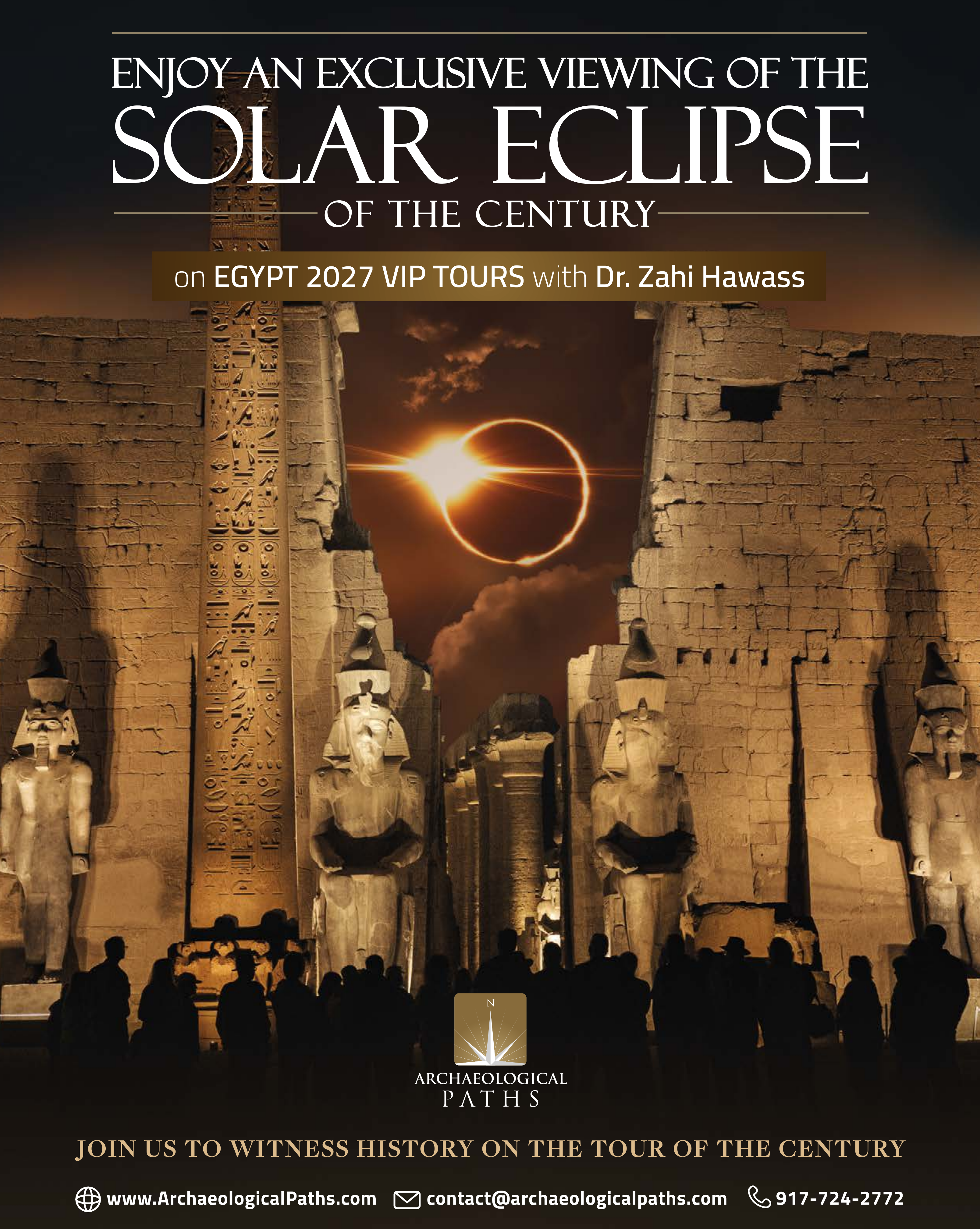
Some of my most disappointing failures — yet at the same time my most cherished successes — involve observing southerly objects. I can still recall how cold it was hiking up a neighbor's hill on a February night more than a decade ago and failing to see Canopus in Carina. But I also haven't forgotten the excitement of seeing the globular cluster Omega Centauri for the first time naked-eye from a corner of a field on our farm, or the globular cluster NGC 6352 in Ara with handheld 12×60 binoculars.

Last spring, I spotted the galaxy NGC 4945 for the first time after years of failed attempts. At magnitude 8.6, it's the second-brightest galaxy in Centaurus, but this large, nearly edge-on southern beauty never gets higher than 4.5° for me and had eluded even my 16-inch reflector. I finally achieved success when I traveled with my 6-inch to a friend's place 85 miles to the west of my home. While his skies are brighter overhead, his southern sky is darker because he lives just north of the Buffalo National River — the only International Dark Sky Park in Arkansas. I was almost in disbelief when, after so many failed attempts, I was now able to see the core of the galaxy as a small, very faint, and diffuse glow!

I do hope to observe the splendors of the southern sky in all their glory from the Southern Hemisphere one day. But until then, I'm not going to stop savoring the glimpses that my latitude affords.

■ Can you guess where Contributing Editor **SCOTT HARRINGTON** aimed his telescope at this year's Texas Star Party?

ESO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