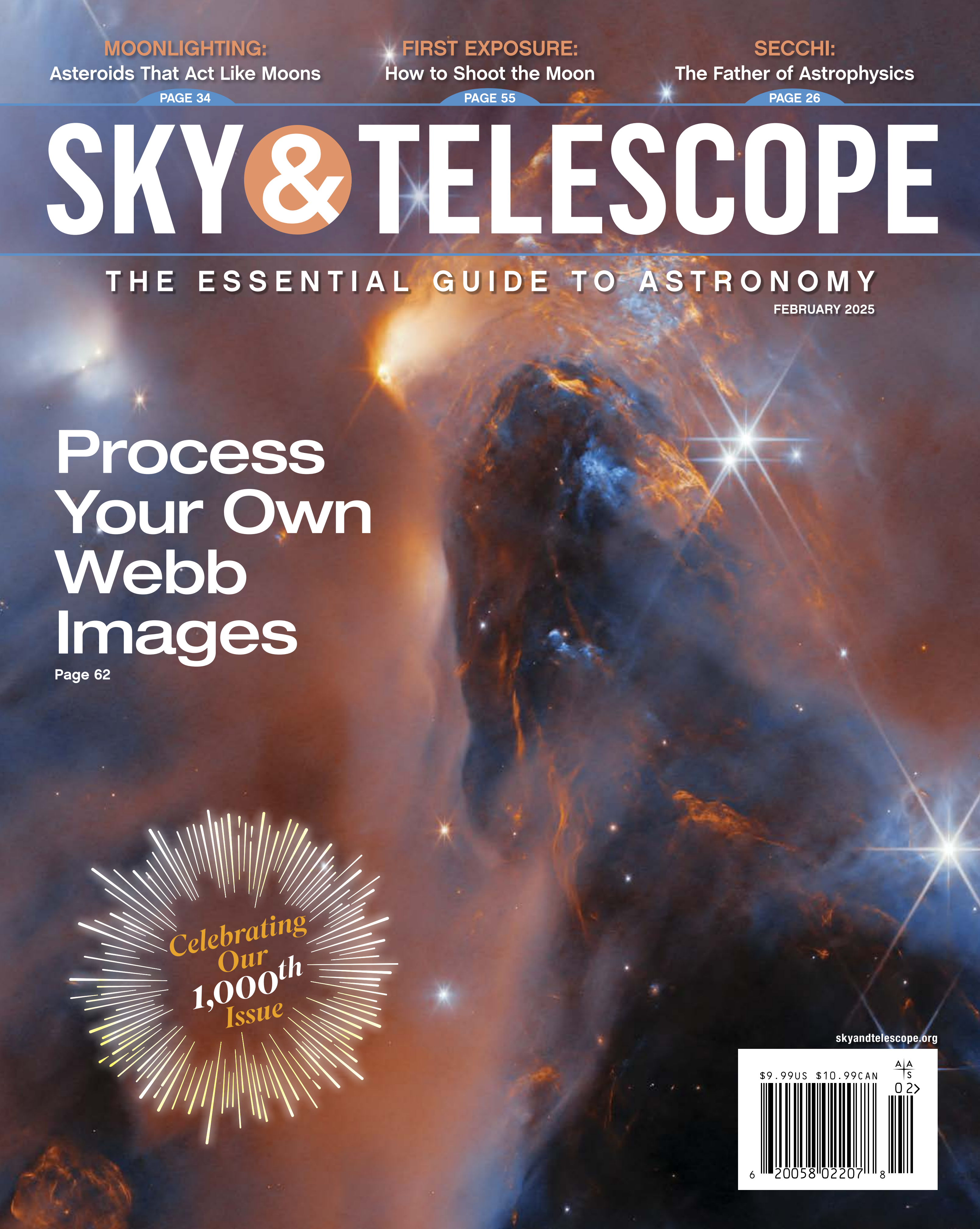

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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

FEBRUARY 2025

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ON THE COVER

Infrared image of reflection nebula NGC 1333, in Perseus

ESA / WEBB, NASA & CSA, A. SCHOLZ, K. MUZIC, A. LANGEVELD, R. JAYAWARDHANA

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Slewing to the New

THE AMERICAN ASTRONOMICAL SOCIETY'S acquisition of *Sky & Telescope* in 2019 forged a dynamic bond between professional and amateur astronomy. Which is why I'm particularly delighted to present Diana Hannikainen as the next editor in chief of this magazine, because she is pro-am personified.

Many readers know Diana as our Observing Editor, which she has been since 2017. (That post will become a new editorial position, to be announced soon.) But few may know that she spent many years as a professional astronomer.

Diana earned her PhD in high-energy astrophysics at the University of Helsinki, Finland, in collaboration with the University of Sydney, Australia. As a postdoc at the University of Southampton, UK, she furthered her doctoral research studying the multi-wavelength properties of *microquasars*, binary systems that contain a star and a stellar-mass black hole that shoots plasma jets.

From 2002 to 2008, Diana was a Fellow of the Academy of Finland at the University of Helsinki, and from 2008 to 2010 she served as a senior researcher at Metsähovi Radio Observatory. In her research in high-energy astrophysics, she was lead author or coauthor on more than 60 refereed papers and mentored multiple students.

▲ *S&T*'s new editor in chief, Diana Hannikainen

SEAN WALKER / S&T

In the early 2010s, she and her husband, Philip, moved to Florida, and this is when Diana pivoted back to the amateur side of things, in which she'd been involved before her university days. She became an active member of the Astronomical Society of the Palm Beaches and edited its newsletter. This post deeply immersed her in the amateur community, an ideal segue to her role as *S&T*'s Observing Editor.

In our January 2021 issue, Diana inaugurated Pro-Am Conjunction, a bimonthly column that perfectly blends her two areas of expertise. Altogether, in her seven years here she has honed a broad skill set across all areas of our business, which perfectly equips her for her new role as editor in chief.

It feels fitting that I'm passing the baton with *S&T*'s 1,000th issue. For any monthly magazine to reach 1,000 consecutive issues is rare, as former Editor in Chief Rick Fienberg explains on page 84. For an overview of all that *S&T* has witnessed since its first issue in 1941, see our timeline on pages 12–13.

I'm extremely proud to have been a part of roughly 12% of those 1,000 issues over the past decade. It's a bittersweet moment, for I'll miss working with such a talented coterie of staff and contributors — as well as on such a legendary brand and the ever-fascinating subjects it covers. It's been a hugely fulfilling 10 years for me, and I will avidly watch *S&T*'s progress in the coming years.

Peter

Editor in Chief

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The Essential Guide to Astronomy

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ART, DESIGN & DIGITAL
Creative Director Terri Dubé
Technical Illustrator Beatriz Inglessis
Illustrator Leah Tiscione
Web Developer & Digital Content Producer
Scilla Bennett

ADVERTISING
Director of Strategic Partnerships Rod Nenner
ads@skyandtelescope.org

Editorial Correspondence
(including permissions, partnerships, and content licensing): *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA. Phone: 617-500-6793. E-mail: editors@skyandtelescope.org. Website: skyandtelescope.org. Unsolicited proposals, manuscripts, photographs, and electronic images are welcome, but a stamped, self-addressed envelope must be provided to guarantee their return; see our guidelines for contributors at skyandtelescope.org.

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▲ Three generations of astrophotographers captured the aurora on May 11th from (left to right) Princeton, Minnesota; Fountain Hills, Arizona; and Duluth, Minnesota.

MICHEAL ROBERTSON AND FAMILY (3)

Three Generations

I was browsing through *S&T*'s website today and remembered that a few months ago I tried to post some aurora photos. Alone, none of the photos was very remarkable, but I had pestered my son who lives in Duluth, Minnesota, and my father who lives in Fountain Hills, Arizona, to try to see the northern lights on the same night. So I was delighted when we each (grandfather, son, and grandson) were able to share photos of aurorae from the same night in May from Duluth, central Minnesota, and Arizona. A silly but fun accomplishment! We were each excited to share in the moment.

I'm a complete amateur with amateur equipment, an iPhone! But in the last year, I started uploading most of my aurora videos to an old YouTube channel (**youtube.com/@aurora_borealis_100**). While seeing aurorae in Minnesota is not rare, it's not common because they're so unpredictable. But with numerous aurora apps and access to real-time data, I have learned that if a person makes an effort, seeing aurorae in Minnesota can become common (at least during an active solar cycle).

Michael Robertson • Princeton, Minnesota

Remote Concerns

Ron Brecher's excellent article "Going Remote" (*S&T:* Sep. 2024, p. 60) is a wonderful introduction to setting up remote operations for astrophotography. I have remotely operated three telescopes at the Grasslands Observatory for almost 10 years. I live in Tucson, Arizona, and the observatory is 1¼-hour drive southeast of Tucson.

Brecher covered all the bases except for one important consideration. What if something goes wrong in the middle of the night? In my somewhat inept hands, plenty has gone wrong over the years, necessitating more than one "midnight run" down to the observatory.

If the remote observatory is in the backyard, one can simply walk out and fix things. But if you are out of town or if the observatory is out of town, what then? It is important to have some kind of backup plan.

Either get in the car and drive to the observatory or have someone available to go to the observatory to at least shut it safely from the weather. Harder problems can be solved later, once the equipment is safe. Give remote a try — it's splendid — but have a backup plan.

Tim Hunter
Tucson, Arizona

Ron Brecher replies*: Thanks for bringing this up. It's important to have a person at your remote-imaging location who can resolve things quickly when things go awry. The telescope hosting services that I've worked with all have a person local to the observatory who can step in when necessary. When I travel, my family or a neighbor can take care of anything I can't address remotely.*

Another useful form of "backup" is an uninterruptible power supply (UPS) for your imaging equipment and Wi-Fi modem and router. This will keep your imaging run going through a brief outage, and you'll be able to shut things down in an orderly fashion if necessary.

A Stellar Disappearing Act

"A Black Hole Without a Supernova?" by Colin Stuart (*S&T:* Sep. 2024, p. 9) reminded me of the following story. At the end of the 17th century, John Flamsteed noticed a star in the neck of Hercules and designated it as number 55 Herculis. Almost a century passed until, on October 10, 1781, and April 11, 1782, William Herschel saw Flamsteed's object as a red star near 54 Her (**https://is.gd/55Herculis**). But on May 24, 1791, he noted its complete invisibility even in his famous telescopes. Since then, no one has seen this star again, and even SIMBAD refuses to answer a request for this star. Although experts assumed that it was a typo in the coordinates of 54 Her, Herschel saw both objects simultaneously. Hence, the missing star may have been real, and now there's hope that this historical mystery can be solved.

Oleksiy V. Arkhypov
Kharkiv, Ukraine

Orbital Discussion

In "A Black Hole Without a Supernova?," Colin Stuart writes "In this system, an O-class star some 25 times more massive than the Sun orbits a black hole that tips the scales at 10 solar masses. Surprisingly, the massive star in VFTS 243 maintains an almost perfectly circular orbit around the system's black hole."

If the star is two and a half times the mass of the black hole, wouldn't the black hole orbit around VFTS 243's star rather than the star orbiting the black hole? Given their mass difference, the system barycenter must be closer to the star than it is to the black hole, and, depending on the distance between the two, it might actually lie inside the star itself.

Mark Holland
Nashua, New Hampshire

Monica Young replies: *You're right, it's not quite correct to say that the star orbits the black hole. Given their roughly equal masses (within a factor of 2), the barycenter probably lies in between them, so the more accurate phrasing would have been to say that the star and black hole mutually orbit their center of mass. From an observational perspective, though, the black hole isn't seen at all, and so it's the orbit of the star that they're measuring.*

Size Matters

I was just reading Howard Banich's "A Deep Dive into Stephan's Quintet" (*S&T:* Sep. 2024, p. 28), and I was curious what size telescope he used to create his sketches. I'll be using my 18-inch UC Obsession Dobsonian.

I wanted to say hello and let Howard Banich know what an awesome article he wrote about Stephan's Quintet (Hickson Compact Group 92). While I've been working through a list of planetary nebulae, the area in which this grouping falls is directly in my primary viewing area, so I shouldn't have any issue getting to it.

Richard Kroh
Brick Township, New Jersey

Howard Banich replies: *The sketches of Stephan's Quintet in my article were drawn by myself and my friend Uwe Glahn. For the sketch on page 32, I used my 30-inch f/2.73 Newtonian, and for the sketch on page 33, Uwe used his 27-inch Dobsonian and a friend's 36-inch Dobsonian for his drawing. Uwe made the sketch on page 31 using his 8-inch telescope.*

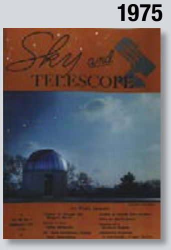
If you're observing from a relatively dark site, you should be able to see all the member galaxies of Stephan's Quintet with your 18-inch Dobsonian, although they are subtle. Good luck, and I'm so glad you enjoyed my article.

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

◖ February 1950

Oort Cloud "Dr. J. H. Oort has presented a new and comprehensive theory of the comets. . . . Oort found that there is a decided maximum of frequency among comets having a major axis of the order of about 150,000 [astronomical units, and he] believes that they must be members of the solar system because they share the motion of the sun through interstellar space. . . .

"It is only necessary to suppose that within the outer cloud the number of comets is very great, perhaps one hundred billion. In that case there will always be new comets perturbed by stellar attractions in such a way that they may reach the small inner sphere and become visible from the earth."

At Leiden Observatory, Adrianus van Woerkom, had shown analytically how Jupiter's gravity can turn in-bound comets into those of short period. The reality of Oort's unseen cloud is now firmly accepted.

◖ February 1975

Distance Scale "Ever since the 200-inch Hale telescope began operating in 1949, one of its main tasks has been the revision of the distance scale of the galaxies. [To this end] Allan Sandage and G. A. Tammann of Hale Observatories have determined very carefully by six methods the distance of Messier 101, a large late-type supergiant spiral in Ursa Major. . . . Within a few degrees of M101 are five other much fainter galaxies that are evidently low-luminosity companions . . .

"Weighing all the evidence, the Hale astronomers [find a] distance of 7.2 ± 1 million parsecs . . . The average redshift for the M101 group is 402 kilometers per second. If this is divided by the distance, a new estimate of Hubble's constant is obtained as 55.5 kilometers per second per million parsecs. Thus, Messier 101 is now known to be over 10 times more remote than [Edwin] Hubble's pioneer value in 1936."

Recent studies put the elusive Hubble constant near 70.

◖ February 2000

Gobbled Galaxy? "The globular star cluster Omega Centauri may be the nucleus of a small galaxy that has merged with the Milky Way, say Young-Wook Lee (Yonsei University, South Korea) and five colleagues in the November 4, 1999, issue of *Nature*. Lee's team imaged the 4th-magnitude, ½°-wide globular (our galaxy's most massive and luminous one) with a 0.9-meter reflector on Chile's Cerro Tololo. The scientists then plotted a color-magnitude diagram for 50,000 of the cluster's stars. Doing so revealed that Omega Centauri's stars formed not all at once but over a 2-billion-year period punctuated by several discrete starbirth events. This proves that whatever preceded the cluster was massive enough to retain gas even when its first generation of stars exploded as supernovae."

SOLAR SYSTEM

Europa Clipper Launches for Jupiter's Icy Moon

THE EUROPA CLIPPER mission lifted off aboard an expendable Falcon Heavy rocket on October 14th, headed for Jupiter's icy moon Europa. The goal: to explore the moon's subsurface ocean.

The rocket used all its oomph to set the spacecraft on its way, with no fuel reserved for return and reuse. (The two side boosters bear the scorch marks of previous service, though, including the launch of the Psyche mission in 2023.)

Following launch, the spacecraft unfurled its gargantuan solar arrays, which were accordion-folded for stowing in the rocket. Fully extended, they make the spacecraft more than 30 meters (100 feet) wide.

The spacecraft is now headed for Mars, which will provide a gravity assist this February. On the way, the team will be checking out systems and instruments as well as deploying the 8.5-meter boom for the magnetometer. Also set to deploy are four antennae, each 2.6 meters long, for a crucial tool for exploring subsurface environs.

The spacecraft will return to Earth for a second gravity assist in December 2026, which will send it on to intercept Jupiter on April 11, 2030. The spacecraft will fly by Ganymede as it conducts a six-hour burn of the main engines to settle into orbit around the giant planet. That orbit will include 49 flybys of Europa, plus seven flybys of Ganymede and nine of Callisto.

The nine science instruments onboard will help answer questions about the thickness and structure of the moon's crust and ocean interior. One of these, Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON), will even penetrate as much as 30 km (18 miles) into Europa's icy shell. They'll investigate the composition of the ocean, crust, atmosphere, and space environment around Europa, determining how salty the ocean is, whether liquid from the ocean works its way up to the surface, or if surface material can be recycled into the ocean. The instruments will also study the surface to unravel the stories that landforms can tell about past and present activity. At mission end, Europa Clipper will prevent contamination of Europa by crashing into Ganymede.

Juno, currently exploring Jupiter, is not expected to survive until Europa Clipper's arrival, but the European Space Agency's Jupiter Icy Moons Explorer (Juice) orbiter will join NASA's spacecraft in July 2031 (*S&T:* Aug. 2023, p. 11). While Juice will focus on Ganymede, joint operations will help assess whether life could now exist within Europa and Ganymede's oceans and what environments exist that could support life. Importantly, though, neither mission is designed to actually search for life.

For now, the mission team can breathe in relief that their spacecraft — the largest ever sent on an interplanetary mission — has made it to space. Go Europa Clipper!

■ **EMILY LAKDAWALLA**

Europa Clipper lifted off from Cape Canaveral atop a Falcon Heavy rocket on October 14th.

KIRBY KAHLER

IN BRIEF

Two years ago, NASA's Double Asteroid Redirect Test (DART) mission intentionally ran into the asteroid moonlet Dimorphos at 15,000 mph (6.6 km/s). Now, a new mission is headed to the scene of the collision to show us a detailed view of the aftermath. A SpaceX Falcon 9 rocket lifted off from Cape Canaveral Space Force Station on October 7th with the European Space Agency's Hera mission. Hera will pass Mars this March, taking the opportunity to test its instruments as it flies by the tiny Martian moon Deimos. Hera will arrive at 65803 Didymos on December 14, 2026, entering orbit around the binary pair and examining DART's impact crater on Dimorphos. The mission will also measure changes in the asteroids' mutual orbit, refining observations made from the ground and from Earth orbit. Hera carries a suite of instruments, including two cameras, a spectral imager, an infrared imager provided by Japan's space agency, and an altimeter. The spacecraft also includes a radio science experiment, which will measure the asteroids' mass distributions by their slight gravitational pulls. Two CubeSats hitching a ride on Hera will carry out complementary observations and perhaps even soft-land on Dimorphos. Hera will end its days on the surface of larger Didymos.

■ **DAVID DICKINSON**

EXOPLANET

Barnard's Star Has a Planet

ASTRONOMERS HAVE FOUND a planet orbiting Barnard's Star, just six light-years away — a find that settles years of controversial claims.

▲ Artist's illustration of a sub-Earth-mass planet around Barnard's Star

In the October *Astronomy & Astrophysics*, Jonay González Hernández (Institute of Astrophysics of the Canaries, Spain) and colleagues announce the discovery of a world smaller than Earth circling Barnard's Star in a little more than 3 days. It has at least half the mass of Venus, but probably less than Earth's mass. The planet orbits its star 20 times closer than Mercury orbits the Sun, so even though Barnard's Star is cooler than the Sun, the planet's surface is hot, around 400K (260°F).

The team also found hints of other small planets with orbital periods of 2.3, 4.1, and 6.7 days; the latter world would be just at the inner boundary of the habitable zone. Those hints warrant further observations.

The first claim of planets around Barnard's Star dates back to 1963, though it was later discredited. Then, in 2018, Ignasi Ribas (then at the Institute of Space Sciences, Spain) and colleagues claimed to have found another planet, this time on a wide, 233-day orbit around Barnard's Star. But two other groups contested that find (*S&T:* Sept. 2021, p. 8).

González's claim is made all the stronger by the sharper tool at his team's disposal: the fiber-fed, high-resolution Echelle Spectrograph for Rocky Exoplanets and Stable Spectroscopic Observations (ESPRESSO) at the Very Large Telescope in Chile. ESPRESSO enables the measurement of gravitational tugs as tiny as 10 cm/s on the star, equivalent to Earth's pull on the Sun. The astronomers avoided contamination from starspots and other stellar activity by focusing their attention on timescales shorter than the rotation of Barnard's Star.

The researchers also searched for a 233-day signal but didn't find anything. "It seems quite improbable that the planet candidate we claimed in 2018 is indeed there," Ribas acknowledges. He adds praise for the advance in technology this discovery symbolizes: "The ESPRESSO instrument is significantly superior in terms of precision to any of the spectrometers we used in our 2018 paper. I would qualify [the proposed planet] as a solid detection."

■ **JAN HATTENBACH**

Read more at https://is.gd/Barnardb.

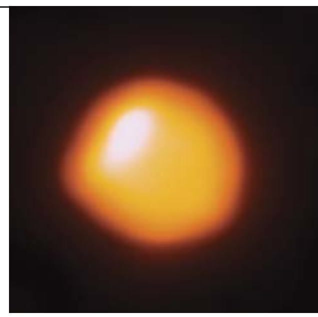
STARS

Betelgeuse Has a Companion

ASTRONOMERS MIGHT HAVE discovered a companion star orbiting around Betelgeuse, explaining one way the star regularly brightens and dims.

The red supergiant star pulsates violently in a pattern that repeats roughly every 400 days. A second pattern of variation with unknown cause lasts about 2,000 days. This second pattern also appeared as early as 1908 in measurements of the star's *radial velocity*, its motions toward and away from Earth. Even then, astronomers speculated that an unseen companion might be pulling the gravitational strings.

Now, a team led by Morgan MacLeod (Center for Astrophysics, Harvard & Smithsonian) has analyzed a century's worth of data, including measurements of Betelgeuse's radial velocity, brightness, and its position on the sky (*astrometry*). From these data, the researchers conclude Betelgeuse might have what they whimsically refer to as "a little friend" in a paper posted on the arXiv preprint server.



◀ This radio image of Betelgeuse reveals the star's hot atmosphere but can't make out a potential companion.

To explain the data, the companion would need to be less massive than the Sun and would take 2,110 days to orbit Betelgeuse from a distance equivalent to the giant star's width. (Betelgeuse is roughly as wide as Jupiter is far from the Sun.) Besides being much fainter than the red supergiant, the smaller companion would also have about the same temperature, so Betelgeuse would outshine it at all wavelengths.

"It was very surprising," says MacLeod. "It's kind of hidden right there in plain sight."

The team predicts that the companion is spiraling inward, with Betelgeuse swallowing it in just 10,000 years.

René Oudmaijer (University of Leeds, UK), who wasn't on the team, calls the results "compelling." But, she cautions, "the companion itself is not directly detected, so there's still room for doubt."

Yet there may be a chance to detect the companion directly: The Nancy Grace Roman Space Telescope, due to launch in two years, may have the high contrast and angular resolution needed to image the smaller star if it exists. Doing so would settle the century-old debate once and for all.

■ **COLIN STUART**

BARNARD B: ESO / M. KORNMESSER; BETELGEUSE: ALMA (ESO / NAOJ / NRAO) / E. O'GORMAN / P. KERVELLA

STARS

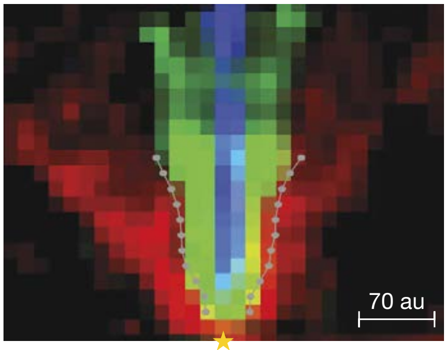
Webb Telescope Images Planet-Shaping Winds

IMAGES FROM the James Webb Space Telescope have revealed winds blowing from gaseous disks around young stars, paving the way for improved models of planet formation.

An infant star begins its life swaddled in dusty gas and encircled by a *protoplanetary disk*. The disk both feeds the star and grows planets, but it also powers winds that escape the system. Now, Webb has imaged structured streams of gas blowing away from the protoplanetary disks around four young stars, with findings published October 4th in *Nature Astronomy*.

Astronomers have proposed that, if magnetic fields are involved, winds would form a nested structure, with a fast, narrow jet flowing from the center of the disk, surrounded by several broader and slower-moving outflows.

Ilaria Pascucci (University of Arizona) led a team that pointed Webb at stars 450 light-years away in the Taurus star-forming region. They selected four stars between 1 and 2 million years old whose protoplanetary disks appear edge-on when observed from Earth, partially obscuring the young stars' brilliant light. They then used Webb's near-infrared spectrograph to look for signatures from molecules and atoms in the area above and below the disks, using those signals to reconstruct an image of the wind. In all four cases, the nested structure echoes the prediction of the magnetic scenario.



Ionized iron
Molecular oxygen
Carbon monoxide (radio)
Trace carbon monoxide

▲ The Webb telescope shows a nested structure in the wind coming from a young star (yellow star). Previously, only carbon monoxide (red) had been detected at radio wavelengths.

"The work confirms what a huge body of work has been pointing to for . . . the last 10 years," says Emma Whelan (Maynooth University, Ireland), who wasn't involved in the study.

The image shows that the nested winds arise from the disks' inner 15 astronomical units, affecting the availability of material for planet formation.

The ubiquity of such disk winds remains to be seen. Pascucci and her colleagues plan to search for winds around additional stars, especially those with very low masses, which represent the bulk of the stellar population in the Milky Way.

■ **JURE JAPELJ**

SOLAR SYSTEM

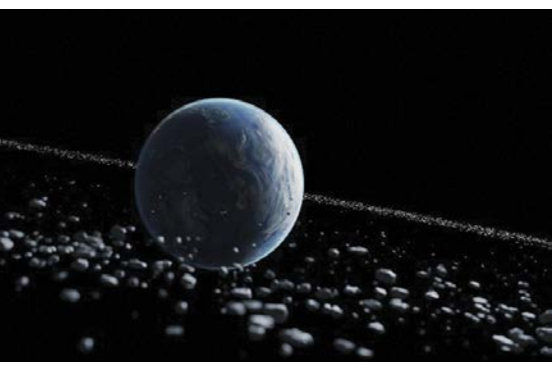
Did Earth Once Have a Ring?

A CLUSTERING OF ancient impact craters suggests a temporary ring surrounded Earth hundreds of millions of years ago, astronomers claim.

Andrew Tomkins (Monash University, Australia) deduced the ring's existence from a curious trend: For a window of time in Earth's past, all known impacts happened to land near the equator. This 40-million-year window started about 466 million years ago, in the middle of the Ordovician Period.

There are 21 known impact craters dating back to this time period. Given the constant shifting of Earth's crust, the researchers used six different models of plate tectonics to map the exact location of those craters, all of which showed that at least part of all 21 craters falls within 30 degrees of the ancient equator. The distribution isn't likely to be random; rather, such an arrangement is more reasonable if the impactors came from an orbit around Earth, Tomkins's team concludes in the November 15th *Earth and Planetary Science Letters*.

There's little precedence for rings around small worlds, but it's not zero. Two bodies much smaller than Earth have multiple rings of unknown origin: the Centaurs 10199 Chariklo (*S&T:* July 2017, p. 14) and 2060 Chiron (*S&T:* Apr. 2024, p. 11).



◀ This artist's impression shows the ring that might have circled ancient Earth, which would have contained larger chunks that might fall to impact our planet as well as smaller grains.

Tomkins thinks Earth's ancient ring could have formed after an asteroid some 10 kilometers (6 miles) wide broke apart after passing too close to Earth. Its debris remained gravitationally bound, and big chunks fell to Earth to form craters, while dust and smaller debris stayed in orbit as a ring that might have lasted millions of years. The ring might even have triggered global cooling, perhaps contributing to an ice age and mass extinction that occurred near the end of the Ordovician Period, the team speculates.

"His idea is testable," says Birger Schmitz (Lund University, Sweden), who was not involved in Tomkins's research. While the recent study approached the Ordovician from the perspective of large impactors, Schmitz notes one could look for a comparable equatorial clustering in submillimeter-size micrometeorites that date back to that long-ago era. If scientists were to find such a similar trend, it would help support Tomkins's hypothesis.

■ **JEFF HECHT**

IMAGE OF DISK WIND: BEATRIZ INGLESSIS / *S&T*; SOURCE: PASCUCCI ET AL. / *NATURE ASTRONOMY* 2024 / MPIA; ANCIENT RING: OLIVER HULL

OBITUARY

Beverly Turner Lynds, 1929–2024

AMERICAN ASTRONOMER Beverly T. Lynds has died, passing peacefully on October 5, 2024, at 95 years old.

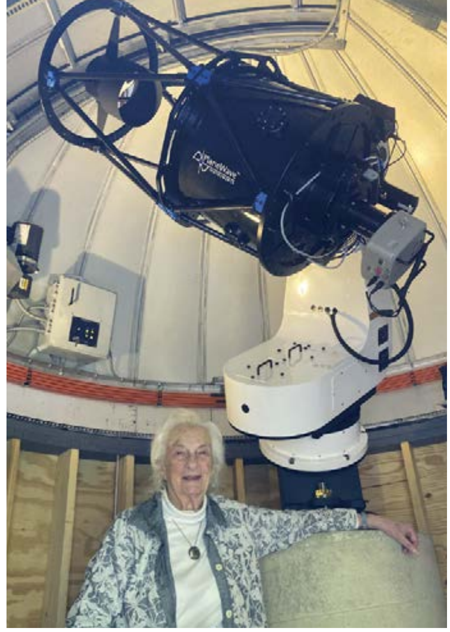
Beverly Turner was born on August 19, 1929, in Shreveport, Louisiana, and attended Centenary College. She applied to four graduate astronomy programs and was admitted to three. However, shortly after she accepted a position at the University of Chicago, the offer was withdrawn because they'd discovered that she was a female graduate student.

To gain more experience in astronomy, she went to Lick Observatory, where she assisted Nicholas Mayall and George Herbig. She was subsequently admitted to the graduate program at the University of California, Berkeley, and earned her PhD in 1955. She married fellow astronomy graduate student C. Roger Lynds in 1954.

In 1959, the Lynds relocated briefly to the National Radio Astronomy Observatory in Green Bank, West Virginia. Director Otto Struve hired Beverly to build the observatory's astronomy library, and when she ordered a copy of the First Palomar Observatory Sky Survey, she was taken with how clearly dark nebulae showed up on the plates. So she began to compile a catalog of these clouds of dust and gas that, due to advances in technology, would far surpass E. E. Barnard's list published in 1927. She spent countless hours tracing nebulae, measuring their areas, recording their coordinates, and estimating their darkness on a scale of 1 to 6.

Lynds published the 1,802 dark nebulae in the *Astrophysical Journal Supplement* in 1962, a landmark listing on par with the Messier, New General, Index, and Sharpless catalogs. She repeated this process with emission and reflection nebulae as well as with supernova remnants, publishing a catalog of bright nebulae in 1965. She went on to study the connection between bright and dark nebulae in other galaxies, and C. C. Lin found her work supportive of his density wave theory for the formation of galaxies' spiral arms.

After retirement, Lynds devoted much of her time to science education and reducing racial and gender disparities. She served as a Shapley Lecturer for the American Astronomical Society, and, in 2013, received the Education and Outreach Award from the University Corporation for Atmospheric Research. Lynds is survived by her daughter, Susan Elizabeth.



▲ Beverly Turner Lynds poses with the author's telescope at his home observatory.

■ RODNEY POMMIER

To read more about Lynds' life, visit https://is.gd/BeverlyTurnerLynds.

IN BRIEF

The Solar Cycle Is Peaking

Scientists from NASA, the National Oceanic and Atmospheric Administration (NOAA), and the international Solar Cycle Prediction Panel announced the latest status of the Sun's activity on October 15th, confirming that we are in the most active part of the current solar cycle. The exact peak is due in the next year or so. The current Solar Cycle 25 is stronger than the last one, and recent solar storms have even had impacts on the farming industry. However, it's still not as strong as activity seen in the 1950s. "Solar Cycle 25 is shaping up to be a relatively small cycle," says panel co-chair Lisa Upton (Southwest Research Institute). Such cycles are more likely to have double or even triple peaks, which makes it more difficult to say for certain whether maximum has occurred. "We need to be past the maximum by at least six months to a year before we can be sure which month is the peak," she adds. What's more certain is that extreme space weather events will continue for the next year or so, with large numbers of sunspots, flares, and coronal mass ejections — and perhaps also more expansive aurorae.

■ COLIN STUART

Read more about the impacts at https://is.gd/solarcycle25.

Amateur Observatory Destroyed in Wildfire

The historic Clinton B. Ford Observatory, once used for variable star observations, has fallen to wildfires. Beginning on September 8th, the Bridge Fire spread from the San Gabriel Mountains across the Los Angeles and San Bernardino counties, felling 81 structures and injuring 8 people. Another casualty was the historic Ford Observatory, which was nestled within the same mountains where the fire originated. Until recently operated for recreational use by the Los Angeles Astronomical Society (LAAS), the observatory was once an asset to the American Association of Variable Star Observers (AAVSO). Donating his 18-inch Newtonian reflector, AAVSO member Claude Carpenter joined with six other amateur astronomers — including Clinton B. Ford, who financed the project — to build the observatory in 1965. Obtaining a special permit from the U.S. Forest Service, the group placed the observatory on the eastern end of Table Mountain at 7,500 feet elevation. Unfortunately, the secluded spot that made the Ford Observatory a superb observing site was also the cause of its downfall. "There was no chance of response by firefighters to this remote location," says LAAS president Darrell Dooley. The fast-moving wildfire took out the entire observatory; however, all of the residents of nearby Wrightwood were able to evacuate, and firefighters saved 99% of the residences.

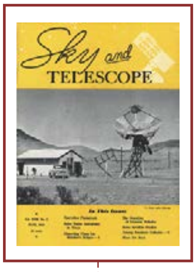
■ ARIELLE FROMMER

See before and after photos at https://is.gd/clintonfordobservatory.

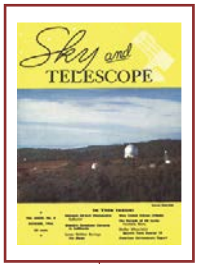
RODNEY POMMIER

November 1941
First issue

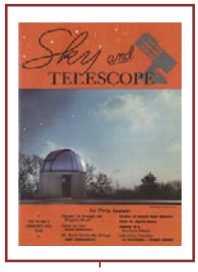
February 1950
100th issue



June 1958
200th issue



October 1966
300th issue



February 1975
400th issue

June 1983
500th issue

Celebrating

1942 Solar radio emission detected

1947 Astronomical League incorporated

1949 200-inch Hale Telescope sees first light

1956 John Dobson builds his first telescope

1957 First artificial satellite, Sputnik, launched

1958 NASA established

1962 First interplanetary flyby (Mariner 2, Venus)

1963 Quasars identified as distant active galaxies

1965 Cosmic microwave background discovered

1969 Apollo 11 astronauts land on the Moon

1970 Celestron introduces 8-inch Schmidt-Cassegrain telescope

Discovery of dark matter in galaxies

1971 First spacecraft to orbit another planet (Mariner 9, Mars)

1975 First CCD camera

1976 Comet West at its best

1977 Voyager 1 & 2 launch to the outer planets

1978 *Burnham's Celestial Handbook* published

1981 First Space Shuttle launch

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Sky & Telescope's first issue appeared in November 1941. Every month since, we've published content that brings the sky and skygazers together, covering developments in professional and amateur astronomy for more than 80 years. We've seen the discovery of black holes and pulsars, the development of novel telescope designs, the revolution of digital cameras replacing film, and robotic exploration of every planet — not to mention human exploration of the Moon. Some unforgettable comets and meteor storms graced our skies, too. What marvels will the future bring?

October 1991
600th issue

February 2000
700th issue

June 2008
800th issue

October 2016
900th issue

February 2025
1,000th issue

1,000 Issues

1987
First naked-eye supernova in 400 years

1988
International Dark-Sky Association founded

1989
Neptune flyby completes Voyagers' Grand Tour

1990
Hubble Space Telescope launched

1994
Comet Shoemaker-Levy 9 hits Jupiter

1995
First exoplanet discovered around a Sun-like star

1998
Dark energy: cosmic expansion found to accelerate

2005
Huygens probe lands on Titan

2006
First comet samples brought to Earth

2007
Fast radio bursts discovered

2012
Voyager 1 enters interstellar space

2015
First detection of gravitational waves

New Horizons Pluto flyby

2017
First interstellar asteroid discovered

2019
First image of a super-massive black hole

Smart imaging tele-scopes debut

2022
DART alters the orbit of an asteroid

2023
Active volcanism found on Venus

The vast majority of black holes elude detection. Gaia has recently found three of these invisible objects and will soon discover more.

The first black hole ever found, Cygnus X-1, epitomizes the standard view of a stellar-mass black hole: Gas from an orbiting star spirals around the dark object and heats up dramatically, emitting a plethora of X-rays. This powerful radiation is the black hole's "siren song" in the words of the Canadian rock band Rush, which in 1977 wrote a 10-minute song about a journey to Cygnus X-1.

But for every black hole that boldly broadcasts its presence via X-rays, countless others keep things on the down-low. In fact, the entire Milky Way Galaxy has only an estimated 1,000 black holes like Cygnus X-1 — versus roughly 100 million X-ray-quiet black holes.

Now the European Space Agency's Gaia spacecraft is starting to find the quiet ones. "Gaia is a total game-changer," says Kareem El-Badry (Caltech), whose team recently used the spacecraft to locate two previously unknown black holes in our galaxy. Launched in 2013 to measure the distances and motions of luminous stars, Gaia isn't the first to find a quiet black hole, but El-Badry estimates the spacecraft will eventually uncover dozens more.

"It's wonderful that we have a new population [of black holes] detected by a completely new method," says Avi Loeb (Harvard University), who was not involved in the recent discoveries. "The precision is quite remarkable."

Indeed: Observations published in the January 2024 *Publications of the Astronomical Society of the Pacific* nailed down the mass of Gaia's first black hole to about 1% — far better than the mass determination of any other stellar-mass black hole in the universe.

Such precision results from the spacecraft's exquisite measurements coupled with the work of Johannes Kepler four centuries ago. Although his three laws originally pertained to the planets orbiting the Sun, they also describe how one star orbits another — even if one of them is a black hole.

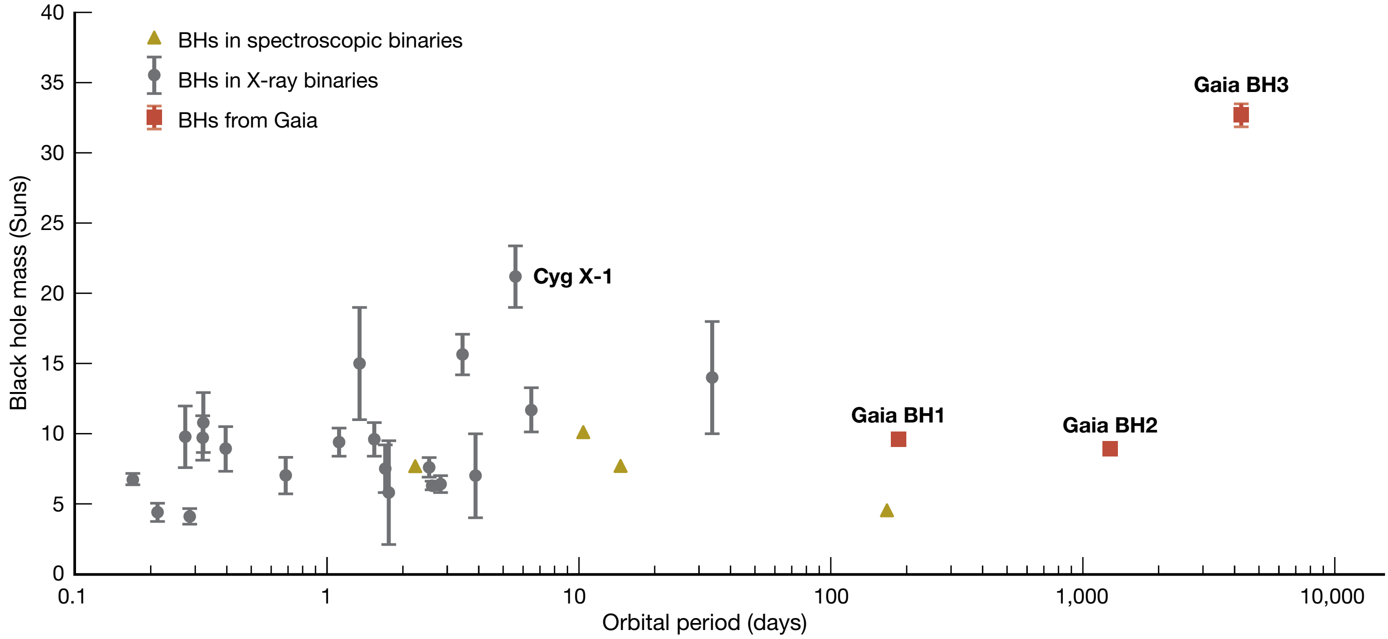
In particular, Kepler's third law allows astronomers to measure stellar masses. It states that the greater the combined mass of the two stars, the faster they whip around each other for a given separation. Measuring their orbital period and mean separation therefore reveals their total mass.

If a luminous star orbits a black hole, the star appears to be going around nothing at all. By measuring the star's changing position on the plane of the sky, Gaia sees this orbit projected onto that plane. Meanwhile, ground-based observations of the Doppler shifts in the luminous star's spectrum reveal the star's motion along our line of sight (its *radial*

GAIA SKY / ESA / MPL 2.0

▶ **GAIA'S FIRST BLACK HOLE** This visualization shows Gaia BH1 with its companion, a yellow main-sequence star. The black hole warps nearby space, causing light rays that pass through the space to bend around the black hole's location.

Gaia Begins a Black Hole REVOLUTION



▲ **GAIA OUTLIERS** Based on their masses and the orbital periods of their stars, the three Gaia black holes (red squares) stand out from other black holes that astronomers have found in binary systems. Black holes in X-ray binaries reveal themselves by the radiation from the gas they're accreting from their neighboring stars. Spectroscopic binaries are those in which the members are too far apart for the black hole to accrete gas; they're only detectable by the star's changing radial velocity.

velocity), which is perpendicular to the plane of the sky. Thus, astronomers know the exact tilt of the binary's orbit in space — necessary for a mass measurement — and can ascertain the black hole's precise mass.

This measurement enables them to determine whether the dark object is actually a black hole. A black hole forms when a massive star dies. The death may occur as the star explodes in a supernova, or the explosion may fail, in which case the star simply *im*plodes. Most supernova explosions leave behind neutron stars rather than black holes, but neutron stars can have no more than about 3 solar masses. So if Gaia and Kepler's third law reveal a luminous star orbiting a dark object that exceeds this mass threshold, the object must be a black hole.

Gaia BH1: The Black Hole Versus the Blizzard

On June 13, 2022, when Gaia scientists put out the spacecraft's third data release, El-Badry and his colleagues already had telescopes lined up in both the Northern and Southern Hemispheres to track any luminous star that seemed to be orbiting an invisible object.

But Gaia observes more than 1 billion stars. "Even if the data are very good, you expect things to go wrong in some cases," El-Badry says. "And so when you're looking for something rare, you usually assume that most will be dominated by false positives." In fact, one by one, most of the few suspicious objects in the Gaia data proved to be nothing special.

At first that also seemed to be true for a yellow sun in the constellation Ophiuchus bearing the unmemorable name Gaia DR3 4373465352415301632. The star shines between the Local Arm and the Sagittarius Arm, the next spiral arm toward the galactic center from our own.

The Gaia data suggested the star was going around something dark every half a year. "Initially we thought there was a very good chance it's wrong," El-Badry says, because a period that's an exact fraction of an Earth year could arise from some elementary error.

As it happened, the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) in China had recorded the yellow star's radial velocity twice, in 2017 and again in 2019. Both times the velocity was similar and resembled what Gaia itself had measured for the star. "It looked like it hadn't moved very much, so we thought, 'Ah, it's probably a dud,'" El-Badry says. After all, if the star was really bound to a black hole, then the star would have to move quickly to keep from falling in. So its radial velocity should always be changing as the star zooms one way and then another in its orbit.

The Magellan Clay telescope in Chile then observed the star on July 6, 2022, finding a much higher velocity. "So then we really started to think: 'OK, maybe it's real,'" El-Badry says.

But trouble lay ahead: July in Chile is winter, and a blizzard closed down the observatory.

The next measurement, made elsewhere more than three weeks later, indicated that the star was racing around something no one could see.

"With every additional velocity measurement we got, we became more convinced that it had to be a black hole," he says. The star had fooled them because, by pure chance, it had been at nearly the same position in its orbit during each earlier observation, explaining why the velocity was about the same and why the star didn't seem to be orbiting anything.

The dark object and the yellow star are about as far apart as the Sun and Mars. But the luminous star races around its dark partner about three times faster than Mars moves. Just as Mars is much less massive than the Sun, the yellow star is much less massive than the dark object it's racing around, so the star's speed primarily reflects the dark object's great mass.

For a given separation, Kepler's third law says that the binary's total mass goes as the square of the orbital velocity. Because the yellow star is moving three times faster than Mars, the dark object must be about $3^2 = 3 \times 3 = 9$ times as massive as the Sun. Such a massive invisible object can only be a black hole. Despite the exotic partner, the star itself is a *G*-type, main-sequence star like the Sun, converting hydrogen into helium at its center.

The astronomers renamed the system Gaia BH1, the "BH" standing for "black hole." With a distance of 1,560 light-years, it is the closest known black hole to Earth. "There are probably something like a million other black holes that are even closer," El-Badry says. "They're just hard to find."

That's because the vast majority of black holes are probably single, he says, even though massive stars are usually born with at least one stellar partner. But if a massive star explodes, the supernova can cast off so much material that gravity no longer keeps the companion star in orbit, and the surviving star sails off on its own. And even if the massive star merely implodes, the collapse can kick the freshly formed black hole away from its mate, because the implosion is usually asymmetric.

Meanwhile, El-Badry's team was on the trail of a second black hole. This time the obstacle was not snow but sun — or rather, *the* Sun.

Gaia BH2: The Black Hole Versus the Sun

The second black hole also has 9 solar masses. But its companion is an orange giant like Pollux, the brightest star in Gemini, rather than a yellow main-sequence star like the Sun. The binary is 3,800 light-years from Earth in the Milky Way's Sagittarius Arm.

The orange star shines in the southern constellation Centaurus, which the Sun blots out for several months every year. El-Badry's team managed to observe the star just once, on August 22, 2022, before the Sun intruded. For the next three months, the Sun blocked the view. By the time the star re-emerged, it was early December.

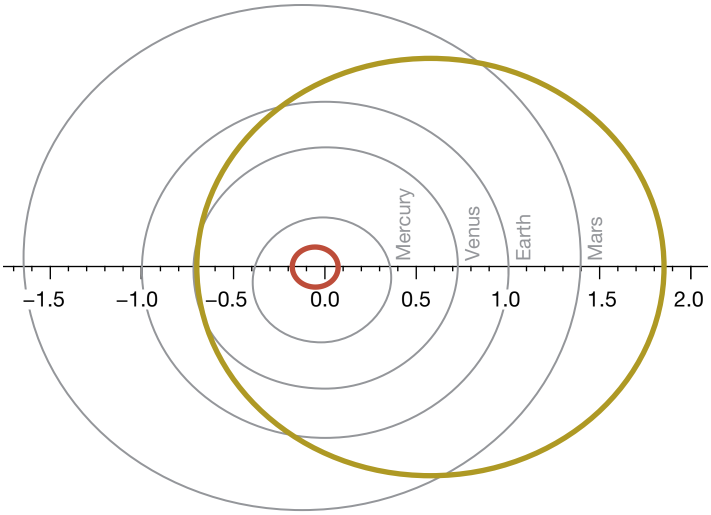
"We were lucky," El-Badry says. The star happened to be near its closest point to the black hole and so was moving fastest, à la Kepler's second law. The star's radial velocity therefore changed measurably every night, quickly confirming the Gaia orbit. The astronomers announced the discovery in early 2023. Since then, he says, "the star continues to do what Gaia says it will."

In X-ray-emitting binaries, the black hole and luminous star must be close together so that gas can spill from one to the other. Gaia-detected black holes are exactly the opposite: The two partners must be so far apart that the luminous star traces out an orbit large enough for Gaia to see the star's motion. In Gaia BH2, the black hole and orange giant are as far apart as the Sun and Jupiter. But whereas Jupiter requires 12 years to orbit the Sun, the black hole's great gravity forces the orange giant to revolve around it in just 3.5 years.

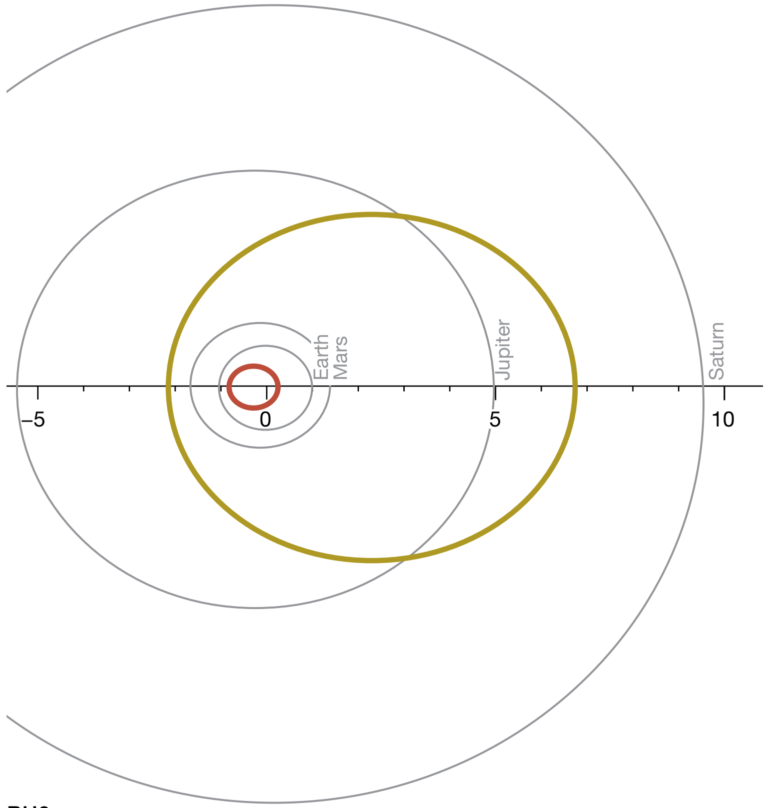
El-Badry says that 100 million years ago, Gaia BH2 resembled Gaia BH1, because the giant was then a main-sequence star. The giant is about as massive as the Sun and so was spectral type *F* or *G* while on the main sequence. Even

Black Hole Data

	Gaia BH1	Gaia BH2	Gaia BH3
Gaia DR3 Name	4373465352415301632	5870569352746779008	4318465066420528000
Constellation	Ophiuchus	Centaurus	Aquila
Distance (light-years)	1,560	3,800	1,930
Black hole mass (Suns)	9.3	8.9	33
Companion star mass (Suns)	0.93	1.1	0.76
Companion star type	Yellow main-sequence	Orange giant	Yellow giant
Star diameter (Suns)	1	8	5
Orbital period	185 days	3.5 years	11.6 years
Mean separation (au)	1.4	5.0	16.5
Orbital eccentricity	0.43	0.52	0.73
Iron abundance	65% solar	60% solar	0.3% solar
Population	Thin disk	Thin disk	Halo
Superlative	Nearest known black hole	Farthest Gaia black hole	Widest binary orbit with a stellar-mass black hole



BH1



BH2

now the giant is fairly small as such stars go, with a diameter only 8 times the Sun's, indicating that the star has not yet expanded much.

But the star does have one quirk: a large amount of what astronomers call *alpha elements*, such as oxygen, magnesium, and silicon. The star isn't massive enough to have forged these elements itself — such elements are created in massive stars (like the one that made the black hole) and shoot into space when the stars explode. However, the system's orbit is wide enough that the star shouldn't have intercepted much supernova ejecta when its companion collapsed into a black hole.

Perhaps the supernova spewed material in a jet that happened to hit the surviving star. Or perhaps the alpha-rich material whirled around the system and eventually settled onto the star.

A Black Hole Mass Gap?

The first two Gaia black holes are remarkably similar, each with 9 solar masses. Furthermore, Gaia has had no problem finding new white dwarf stars and neutron stars with much lower masses, between 1 and 2 solar masses, orbiting other stars. But the spacecraft has failed to detect any dark companions between 2 and 9 solar masses.

"That's suggestive," Loeb says, and El-Badry agrees. Perhaps most stellar-mass black holes are about 9 times as massive as the Sun, and the lowest-mass black holes are rare. Black holes in X-ray-emitting binaries as well as black-hole binaries that merge into single black holes also point to a possible paucity of the smallest black holes (*S&T:* June 2022, p. 12). But both scientists note the obvious: Two Gaia-detected black holes hardly constitute a large sample.

Both black holes share another trait. They belong to the Milky Way's *thin disk* population, which includes the Sun and most of its neighbors. Thin-disk stars shine near the galaxy's plane and range in age from stellar newborns to stars some 8 billion years old (*S&T:* Aug. 2023, p. 34).

But the third black hole system, Gaia BH3, is radically different. It's the first black hole ever found in the galactic halo and the largest known stellar-mass black hole in the galaxy.

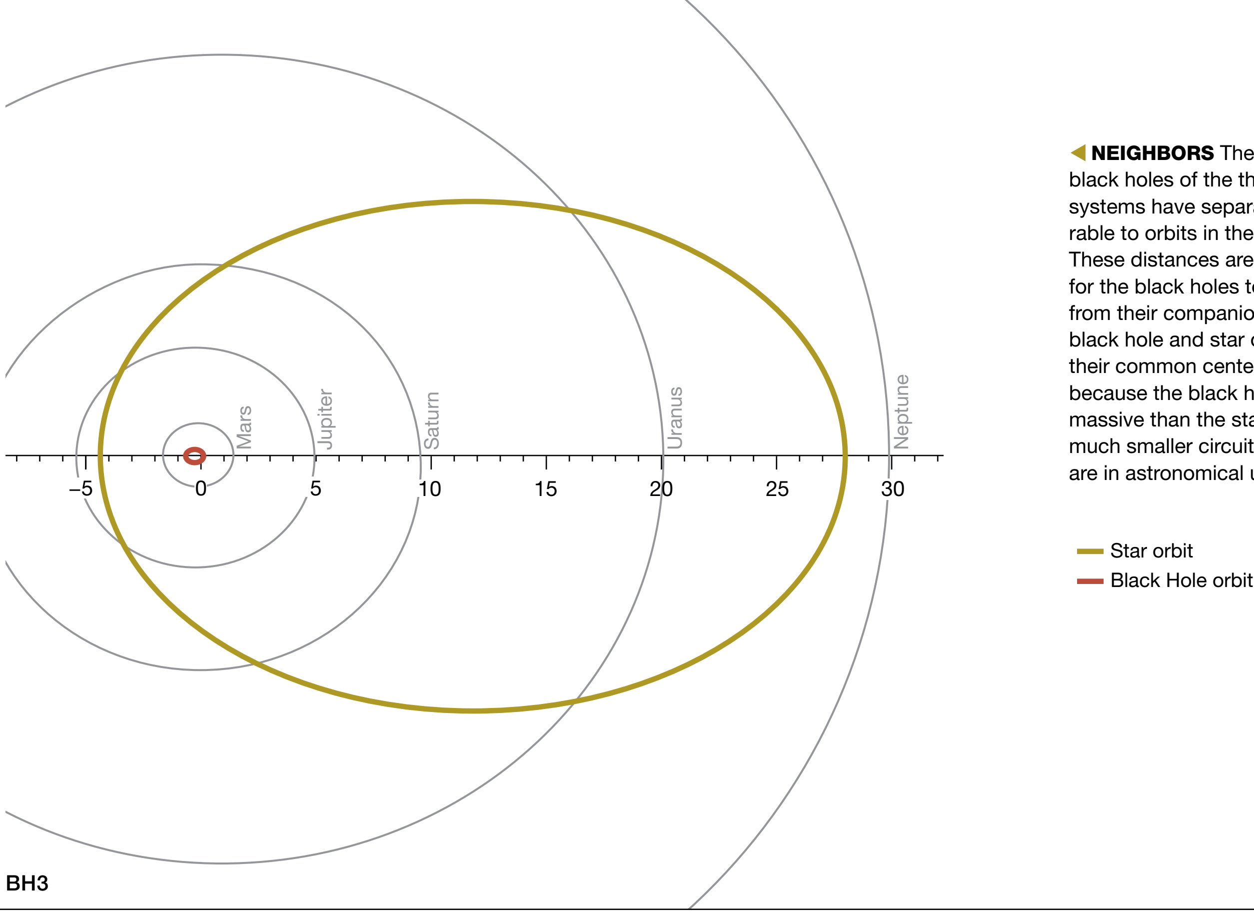
ALPHA ELEMENT

A chemical element with an even atomic number that arises mostly in short-lived, massive stars: oxygen, neon, magnesium, silicon, sulfur, argon, calcium, and titanium. Astronomers call them alpha elements because the dominant isotopes of all but titanium consist of stuck-together helium-4 nuclei, which are also known as *alpha particles*.

Gaia BH3: From the Edge of Time

In July 2023, Pasquale Panuzzo (Paris Observatory) was examining unreleased Gaia data. He was looking at what he calls "binary fake solutions" — stars that seemed to be orbiting massive dark objects only because of undetected errors.

But one of the fakes wasn't fake at all. "This one was real," he says. "And then we realized that it was the largest stellar black hole." Its mass — 33 times that of the Sun — easily tops the 21 solar masses of the galaxy's previous champ, Cygnus X-1. A yellow giant star orbits the black hole every



NEIGHBORS The stars and black holes of the three Gaia systems have separations comparable to orbits in the solar system. These distances are too far apart for the black holes to siphon gas from their companion stars. The black hole and star orbit around their common center of mass, but because the black hole is more massive than the star, it traces a much smaller circuit. Distances are in astronomical units.

11.6 years. On average the two are slightly closer together than are the Sun and Uranus, according to work published in the June 2024 *Astronomy and Astrophysics*.

Located in the constellation Aquila, Gaia BH3 is plunging through the Milky Way's disk from the *halo*, the vast region of ancient stars that surrounds our galaxy's disk like a cloud. Gaia BH3 goes around the galaxy's center backward, opposite the direction of the Sun, which marks the system as a halo member. So, too, does the yellow giant's dearth of heavier elements. Its iron-to-hydrogen ratio is only 0.3% that of the Sun — low even by halo standards. That indicates the star formed long ago, before other stars had much time to enrich space with metals.

"This gives us a hint that these very massive stellar-mass black holes were made early in the universe," Loeb says. The first black hole merger, detected in 2015, astonished astronomers because its black holes were so large, bearing 36 and 31 solar masses — similar to the 33-solar-mass black hole in Gaia BH3. Loeb suspects that the merged black hole system belongs to the halo of its galaxy, too.

Says Panuzzo, "We have — finally — an equivalent in our galaxy that we can study, because it's so nearby." Gaia BH3's distance from Earth is 1,930 light-years.

Low metallicity explains how the galactic halo can hatch such a heavy black hole — for two reasons. First, metal-poor gas can spawn especially large stars. Second, metal-poor stars have weaker winds than their metal-rich counterparts and therefore lose less mass during their lives. So it's not surprising that some halo stars could form a black hole as massive as the one in Gaia BH3.

Coming Gravitational Attractions

The new discovery occurred because Panuzzo was working on Gaia's fourth data release, due out in 2026. El-Badry predicts this release will yield dozens of quiet black holes. Most will probably be in the Milky Way's disk, but some may belong to the halo. Their masses will be especially intriguing.

Meanwhile, astronomers ponder the chief mystery that the Gaia black holes pose: How did the companion star manage to survive the drama that preceded the black hole's birth? Late in life, the massive star that became the black hole should have swollen into a red supergiant like Antares or Betelgeuse, engulfing its partner. Yet the partner endures.

Theories abound. Perhaps the massive star blew away its envelope, staying blue and compact, and never became a red supergiant, so it never swallowed its companion. Or perhaps the black hole and companion originally formed in separate binaries inside a star cluster, then exchanged partners and paired up at their current separation. Although the star cluster later dispersed, the couple survives. Gaia BH3 even belongs to a stellar stream, named ED-2, which is the likely remnant of a small globular star cluster that disintegrated.

The Gaia spacecraft is clearly revolutionizing our study of stellar-mass black holes in the Milky Way. With dozens of new black hole discoveries on the horizon, the future looks bright for astronomers who seek the universe's darkest objects.

Contributing Editor **KEN CROSWELL** is an astronomer, author, and poet. He earned his PhD for studying the halo of the Milky Way Galaxy.

ILLUMINATED CLOUDS by Brian Ventrudo

Winter's Best Reflection Nebulae

Point your telescope at some of the prettiest sights in the night sky.

Tips for Observing Winter Reflection Nebulae

The winter sky offers numerous reflection nebulae, but seeing these objects requires extra care during your observing sessions. Here are a few tips on how to view these celestial gems.

Clean Your Optics.

Scattered light from dust and dirt on your objective and eyepieces creates a glow around brighter stars that resembles reflection nebulae. Clean your eyepieces and use a dust-removal tool to loosen debris from your objective.

Fight Dew and Condensation.

Use a dew heater or dew shield for your optics, if possible. If you're having problems with condensation on the eye lens of your eyepiece on cold nights, keep one eyepiece in your pocket to gently warm it and swap your eyepieces during your observing session.

In 1912, the industrious astronomer Vesto Slipher turned the 24-inch refractor at Lowell Observatory (Arizona), mounted with a state-of-the-art spectrograph, towards the Pleiades to capture the spectrum of the faint nebula around the star Merope. He expected to find an emission spectrum, spiked with lines from ionized oxygen and hydrogen like those astronomers had observed in objects such as the Orion Nebula. Instead, his data showed a continuous spectrum from the Merope Nebula that matched that of the star itself. Slipher suggested, correctly, that the nebula emitted no light of its own and instead simply reflected starlight. We now understand such reflection nebulae arise when interstellar clouds of fine grains of dust scatter light from the relatively young stars embedded within. This process — *Rayleigh scattering* — preferentially scatters blue light, which renders these nebulae a striking color in photographs.

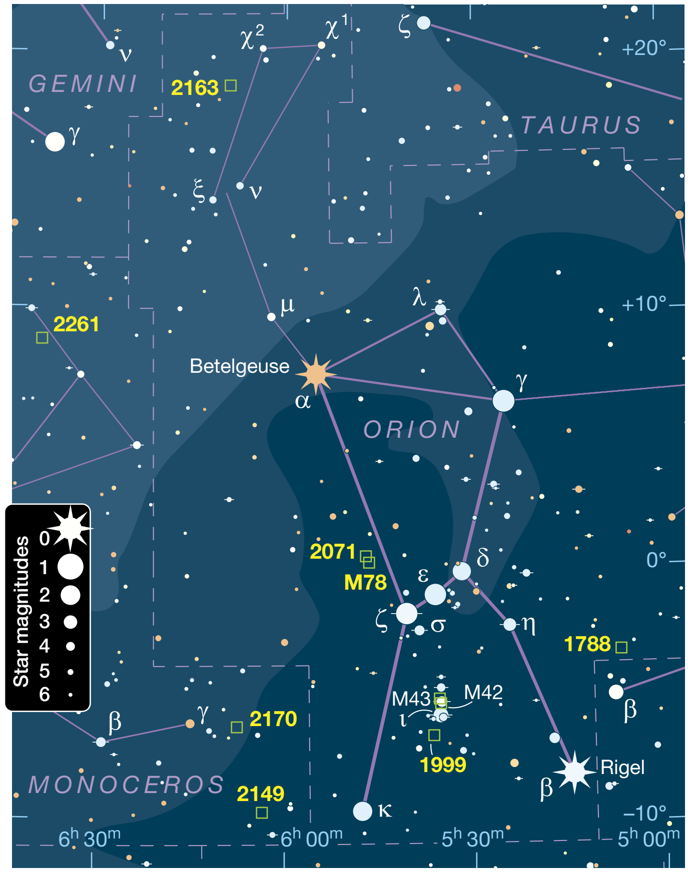
Astronomical catalogs now list more than 1,200 reflection nebulae. Winter brings many into view, and though observing them requires patience and deliberation, each year I enjoy testing my eyesight (and cold tolerance) on a few brighter specimens. I also muse on how the same process that makes our sky blue also yields shimmering patches of ethereal blue-white light reflected by rarefied clouds of dust light-years across.

To see reflection nebulae — which visually appear whitish-grey — I rely on my 10-inch f/4.7 Dobsonian, which is what I used for the targets described here (unless otherwise noted). The aperture helps, but I don't usually use nebula filters since they offer limited benefits with these broadband objects. I observe in Bortle 3–4 or darker skies on nights of high transparency (see the sidebar below for tips on how to better observe reflection nebulae). For this tour, I selected nebulae that have an overwhelmingly reflective component and excluded objects such as the Orion Nebula that are primarily emission nebulae.

Tiny Blisters of Nebulosity in Orion

Let's begin in Orion with **M78**, the brightest of several reflection nebulae in a large complex. Located 2.5° north-northeast of 1.8-magnitude Zeta (ζ) Orionis (Alnitak), M78 is a good test of sky conditions. If you can't see it, you're not likely to see the rest of the nebulae on this tour until you find darker or clearer skies. About 8′ long, M78 surrounds two stars of magnitudes 10.4 and 10.8 that resemble a ghostly set of eyes. With a 24-mm Panoptic eyepiece delivering 50×, M78 looks distinctly fan-shaped, like a comet that splays to the southeast. In a 13-mm Ethos at 92×, the nebula appears split into two uneven parts by an arc of darkness with a thinner curved section to the northwest. The northern edge appears sharply defined, while the southern limb fades to darkness.

◀ **GEMS IN THE SKY** Many brand-new star clusters emerge from dusty cocoons, but at 100 million years old, the stars of the Pleiades pushed away the remains of its birth cloud through radiation pressure long ago. The nebulosity we see in this image results from the cluster serendipitously passing through interstellar dust.



▲ **WINTER'S HUNTER** Many of the targets on this tour of reflection nebulae lie in one of the night sky's most iconic constellations, Orion, and in its neighbor Monoceros, the celestial Unicorn.

PLEIADES: MASIL IMAGING TEAM; CLOTH ICON: BLAN-K / SHUTTERSTOCK.COM; WATER DROPLETS ICON: ZAUR RAHIMOV / SHUTTERSTOCK.COM; NO CLOUDS & EYE ICONS: VVQ / SHUTTERSTOCK.COM; FILTERS ICON: TERRI DUBÉ / *S&T*; TEMPERATURE ICON: ICONICVECTORS / SHUTTERSTOCK.COM

Sky Conditions. A dark (Bortle 4 or darker), transparent, and moonless sky is essential for observing reflection nebulae.

Averted Vision. Move the center of your gaze away from the nebula to expose the most sensitive part of your retina.

Filters. Some observers see slight contrast improvement using wideband "deep sky" light-pollution filters. Some do not. See what works for you.

Warmth. Above all, stay as warm as possible! You'll see more if you're comfortable.

About 15′ north-northeast of M78 lies a pair of 10th-magnitude stars that shine as frosty beacons in the dark Orion B molecular cloud, which is about 1,300 light-years away. The eastern star (HD 290861) appears enveloped in the small, featureless, round haze of 8th-magnitude **NGC 2071**. The nebula spans nearly the same angular diameter as M78, but its lower surface brightness makes it appear smaller.

Now, locate the 2.8-magnitude star Iota (ι) Orionis in Orion's Sword and look 50′ south-southeast to find tiny **NGC 1999**, a dust cloud reflecting light from the 11th-magnitude star V380 Orionis. At 50×, I see the star embedded in a faint nebula that renders it slightly fuzzy. The little haze spans only 2′. Higher magnification reveals a striking dark "keyhole" structure at the center of the object. I could spot the keyhole — barely — at 133× in binoviewers in my 10-inch at the 2017 Winter Star Party in the Florida Keys. With averted vision it looks like a dark donut hole that pops in and out of view just southwest of V380 Orionis. At that magnification, I get a hint of wispy structure at the nebula's outer edges. At 133× and above, I see no other field stars, which accentuates the nebula's ghostly appearance. Astronomers once thought the keyhole was a *Bok globule*, a dense blob

◀ **COSMIC KEYHOLE** A tiny reflection nebula south of M42, NGC 1999 harbors a thick and dark dust cloud that resembles a hole in space. Careful observation will reveal its remarkable shape, reminiscent of a keyhole, which is much easier to discern in images.

PART OF A LARGER COMPLEX M78 ranks as one of the brightest reflection nebulae and a favorite of observers and imagers. It's one of many patches of nebulosity that adorn the otherwise dark molecular clouds in and around Orion.

M78: BERNHARD HUBL; NGC 1999: ALSON WONG of cold, dark gas where new stars form — but it's really just a region in space devoid of gas or dust. How it formed remains a mystery (see, e.g., *S&T:* Feb. 2022, p. 57).

Our next target, **NGC 1788**, lies in southwestern Orion about 1.7° northwest of 2.8-magnitude Beta (β) Eridani in a star-forming region on the edge of the Orion Molecular Cloud. The stars illuminating the nebula are just a million years old and still ensconced in the remnants of a dusty cocoon. At 50×, NGC 1788 resembles a fuzzy star. Averted vision coaxes an elliptical nebulosity about 5′ long into view oriented northwest to southeast, but with little other detail. At 92× I start to see a few knots. Tenth-magnitude HD 293815 shines as the brightest star of an unresolvable cluster at the heart of the nebula. More magnification offered diminishing returns.

Now to **NGC 2163**, an appealing little nebula among the stars of the Hunter's upraised club about 1.7° southeast of 4.6-magnitude Chi^2 (χ^2) Orionis. This 11th-magnitude nebula spreads north-south from a central 11.3-magnitude star and resembles a tiny celestial butterfly at higher magnification. At 50× I see no signs of the nebula. At 92× the star looks elongated, and at 185× I see hints of the nebula's bipolar lobes. The northernmost lobe is clearly brighter, which gives NGC 2163 the appearance of a tiny comet. About 3′ long, this nebula isn't an easy object but it's worth the effort.

▲ **VARIABLE FAN** The subject of one of Edwin Hubble's first research papers, NGC 2261 resembles a flickering flame set aglow by the star R Monocerotis (the magnitude of which varies between 10.7 and 13.2). Time-lapse images show changes in the nebula's brightness and structure, which can occur in as little as a few weeks.

Variability and More in Monoceros

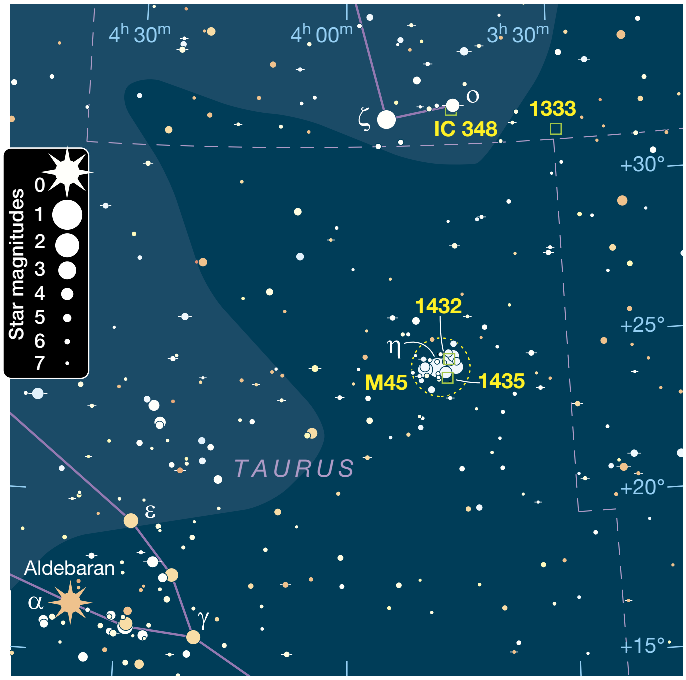
Monoceros harbors cometary reflection nebula **NGC 2261**, also known as Hubble's Variable Nebula. It sits about 1.2° south-southwest of 4.7-magnitude 15 Monocerotis, the brightest star in the superb Christmas Tree Cluster (cataloged as NGC 2264 along with the Cone Nebula). Eleventh-magnitude R Monocerotis anchors the nebula at its southeastern point. John Mellish, an unpaid observer at Yerkes Observatory, first suspected the nebula's variability in 1915, while Edwin Hubble, then a graduate student at the University of Chicago, confirmed it in 1916. NGC 2261 shines by the light of R Monocerotis, itself a variable star and in a newly minted binary system enshrouded in nebulosity — but the nebula's variability is unrelated to the star's. Instead, R Monocerotis and its accretion disk rotate, dragging matter from the surrounding dusty envelope and ejecting it in two directions (toward and away from us). Occasionally, some of that ejected material passes in front of the star, dimming it. At 50×, I see R Monocerotis and a 10.5-magnitude star 2′ to its northeast, which gives the appearance of a wide double. It's only when I use averted vision that I get a hint of this striking nebula curving north-northwest away from the star. At 150× I see a well-defined fan shape, like a flickering candle, extending 2′ to 3′ from R Monocerotis, while 185× brings out bright edges and traces of structure in the nebula's interior.

Before we leave Monoceros, let's examine two more highlights. **NGC 2149** lies on the edge of the Orion-Eridanus Superbubble, a clearing in the interstellar medium

▲ **SMALL BUT SPLENDID** Tiny, fan-shaped NGC 2149 lies on the edge of the Orion-Eridanus Superbubble, a structure of overlapping shock fronts that were likely formed by supernovae from young stars in the Orion OB1 association.

that formed when half a dozen stars in and around Orion exploded as supernovae in the last 10 to 15 million years. The shock waves stimulated new star formation, and NGC 2149 is a conspicuous result. This minute nebula lies nearly 4° east of 2.1-magnitude Kappa (κ) Orionis (Saiph) in a pleasing star field between a pair of 11th-magnitude stars. At 92×,

NGC 2261: MAKIS PALAIOLOGOU / STEFAN BINNEWIES / FRANK SACKENHEIM / CAPELLA OBSERVATORY; NGC 2149: GARY IMM



▲ **SHIMMERING CLUSTER** Head to northwestern Taurus for the Pleiades and then scan north into Perseus for two delightful nebulae.

I see a small fan about 3′ wide that opens eastward. To the west it falls off suddenly. A 12th-magnitude star lies near the nebula's western side. Images of the nebula show a tiny, dark blob on its western side, but I can't see it.

While it's only 3.5° to the north-northeast of NGC 2149 and 1.5° west of 4.0-magnitude Gamma (γ) Monocerotis, **NGC 2170** inhabits the more distant Monoceros R2 molecular cloud. It lies 2,900 light-years away, twice as far as NGC 2149. At 92× and 150× I see it as a frosty and uniform circle about 2′ across with a partially obscured 10th-magnitude central star.

The Dusty Nebulosity of the Pleiades

Now, at last, let's turn our attention to the **Pleiades** (M45). On nights of excellent transparency, faint nebulosity appears around many of the cluster's bright stars. To ensure you're not seeing the effect of condensation on your optics, nudge your scope towards the neighboring Hyades star cluster. If you see nebulosity there, too (where none exists), it might be time to fire up a dew heater. Perhaps uniquely, the Pleiades' nebulosity results from the cluster passing through an unrelated cloud of interstellar dust.

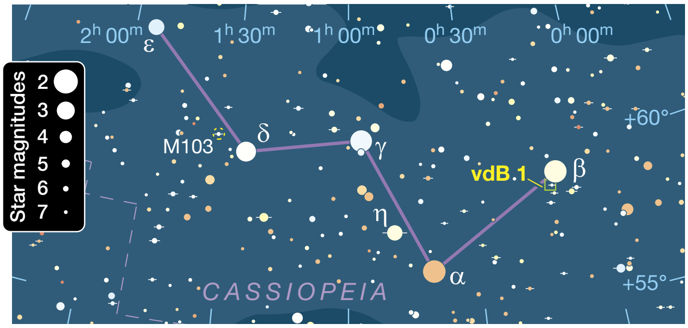
The brightest nebulosity (where Slipher measured his spectra more than a century ago) lies south of 4.2-magnitude Merope in the form of **NGC 1435**. First seen by German astronomer Wilhelm Tempel in 1859 with a 4-inch telescope, this patch extends nearly 0.5° and is within reach of 10×50 binoculars in ideal conditions. I've seen it in a 66-mm refractor. In my 10-inch at 50×, I detect a tapered fan of faint light arcing southward from Merope with evidence of delicate structure and striations. Unlike other reflection nebulae, this one looks better to me with a wideband deep-sky filter, and I saw more detail after placing Merope just outside the field of view.

Before you leave the Pleiades, try for **NGC 1432** surrounding the 3.9-magnitude star Maia. At 50×, the reflection nebula appears round and largely featureless and less distinct than its brighter, hazy neighbor.

Winter's Finest Reflection Nebulae

Object	Constellation	Magnitude	Size	RA	Dec.
M78	Orion	8.0	8′ × 6′	$05^h\ 46.7^m$	+00° 05′
NGC 2071	Orion	8.3	7′ × 5′	$05^h\ 47.1^m$	+00° 18′
NGC 1999	Orion	9.5	2′ × 2′	$05^h\ 36.4^m$	−06° 43′
NGC 1788	Orion	—	5′ × 3′	$05^h\ 06.9^m$	−03° 20′
NGC 2163	Orion	~11	3′ × 2′	$06^h\ 07.8^m$	+18° 39′
NGC 2261	Monoceros	—	3′ × 1′	$06^h\ 39.2^m$	+08° 45′
NGC 2149	Monoceros	—	3′ × 2′	$06^h\ 03.5^m$	−09° 44′
NGC 2170	Monoceros	—	2′ × 2′	$06^h\ 07.5^m$	−06° 24′
M45	Taurus	1.5	120′	$03^h\ 47.5^m$	+24° 06′
NGC 1435	Taurus	—	30′ × 30′	$03^h\ 46.2^m$	+23° 46′
NGC 1432	Taurus	—	26′ × 26′	$03^h\ 45.8^m$	+24° 22′
IC 348	Perseus	7.3	10′	$03^h\ 44.6^m$	+32° 10′
NGC 1333	Perseus	5.7	6′ × 3′	$03^h\ 29.3^m$	+31° 25′
vdB 1	Cassiopeia	—	5′ × 5′	$00^h\ 11.0^m$	+58° 46′
NGC 7023	Cepheus	7.2	10′ × 8′	$21^h\ 01.6^m$	+68° 10′

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.



▲ **IN CASSIOPEIA** You'll visit another recognizable constellation when you search for tiny vdB 1.

▶ **BEACONS IN THE DARK** Just southwest of 2nd-magnitude Beta Cassiopeiae, vdB 1 calls to mind three distant searchlights on a foggy night. This small, nebulous patch bears the name of Canadian astronomer Sidney van den Bergh, who listed it as the first target in his 1966 catalog of 158 reflection nebulae.

BERNHARD HUBL

Wrapping Up with a Quirky Quartet

Let's move northward into Perseus to locate 3.9-magnitude Omicron (o) Persei (Atik) and then scan just to the southeast. There lies **IC 348**, a lovely little cluster of brand-new blue-white stars a bit more than 1,000 light-years away. At 92×, I see perhaps a dozen stars. The most striking is the wide double star Struve 439, which has components of magnitudes 8.8 and 10.3 separated by 23″. Under ideal conditions, at 92× and 150× I see fleeting evidence of interstellar haze around these stars. The designation IC 348 refers to both cluster and nebula, but the nebula itself is also vdB 19 in Canadian astronomer Sidney van den Bergh's 1966 catalog of reflection nebulae.

Just 3.3° west-southwest of Atik we see an easier target in **NGC 1333**, which Contributing Editor Stephen James O'Meara describes in his book *Deep-Sky Companions: Hidden Treasures* as "a simple but beautiful reflection nebula." Eduard Schönfeld discovered it with a 3.1-inch refractor at Bonn Observatory (Germany) in 1858. Despite its brightness (magnitude 5.7) and size (about 6′ × 3′), this object escaped the attention of Charles Messier, Pierre Méchain, and the Herschels. I've detected it and its central 10th-magnitude star with little effort in an 85-mm refractor. In my 10-inch scope, I initially see only the central star and some attendant fuzziness. But averted vision or a tap on the telescope snaps its larger oval shape into view. A magnification of 50× reveals a few 12th-magnitude stars sprinkled around the nebula's outer reaches. At 92×, about 3′ southwest of the central star, I note hints of a smaller bright patch cut off by a puff of dark nebulosity. NGC 1333 is a highly active star-forming region in the Perseus Molecular Cloud, with a cluster of some 150 members within.

Let's conclude with two nebulae along the northern Milky Way. Less than ½° southeast of 2.3-magnitude Beta Cassiopeiae (Caph) lies the tiny patch of nebulosity known as **vdB 1**, which wraps itself around a trio of 8th- and 9th-magnitude stars. At 50×, I see the stars but no nebula. At 92× with averted vision, a uniform fog around the stars reveals itself. The nebula appears slightly brighter around the northeastern star of the trio. I popped in a widefield eyepiece with a 2° field of view, large enough to include Caph in the field, and patiently looked south-southeast for the broad arc of the dark nebula LDN 1265 extending about 0.7°. I see not a single star over its inky surface.

While it's considered an autumn target, **NGC 7023**, the dazzling Iris Nebula, in Cepheus lies almost halfway to the zenith in early evening in January and February. Some 3.5° southwest of 3.2-magnitude Beta Cephei, the nebula shines at magnitude 7.2 and spans 10′ × 8′. A 4-inch telescope shows it easily. In my 10-inch at 50×, with direct vision, I see a round central region enshrouding the brand-new 7.4-magnitude star HD 200775. With averted vision, the nebula balloons in size and reveals an irregular box shape with a faint bar oriented roughly north-south and a slight hook on its southern edge. NGC 7023 is an astrophysicist's paradise, with a central star that has yet to settle onto the main sequence, dynamic molecular gas clouds, and spectroscopic evidence of fine dust grains and complex carbon-based molecules scattering blue-white starlight into the interstellar medium.

While they're not easy to see, reflection nebulae have an undeniable allure. Viewing them increases your visual acuity and skill. They reward patient observation with fleeting glimpses of delicate structure. And these outposts of star formation offer a glimpse into the complex star-making machinery of the Milky Way Galaxy as it turns cold, dark clouds of gas and dust into newly formed stars.

■ Contributing Editor **BRIAN VENTRUDO** is a writer, scientist, and longtime amateur astronomer based in Calgary, Canada. He writes about astronomy and stargazing at his website **CosmicPursuits.com**.

Meet the Father of Astrophysics

Angelo Secchi may be the greatest astronomer you've never heard of.

As with many of the other great cathedrals and basilicas in Rome, the ornate ceiling crowning the Church of Saint Ignatius invites visitors to look up toward the heavens the moment they step inside. A baroque fresco stretches across the nave, depicting the church's namesake surrounded by angels. With its painted pillars and arches, the canvas seems to extend outwards past the true ceiling. And closer to the altar, a large dome sits above it all — or at least, it *appears* to.

The dome is, in fact, an optical illusion created by Andrea Pozzo in the late 1600s in lieu of the physical structure. The 17-meter-wide (56-foot-wide) canvas was painted using a technique called *trompe l'oeil*, a French term that translates to "deceives the eye." And when viewed from the right position, it does just that.

Saint Ignatius is the only one of Rome's largest churches without an actual dome. The painted illusion was intended only to buy time until the architects completed their plans. But the dome was never built. Instead, its very absence allowed one of history's greatest astronomers to look skyward and expand the horizons of astronomy.

A View to the Heavens

In 1853, a Catholic priest and astronomer named Angelo Secchi made use of the pillars that would have carried the weight of the church's dome to instead support a rooftop astronomical observatory. Secchi had recently been appointed director of the observatory at the Roman College — the first school established by the Jesuits — and he sought a replacement for the crumbling tower that held the College's observatory at the time. Above all, he needed stability to facilitate precise measurement, and the church's pillars stood strong.

Although today Secchi is sometimes called the father of modern astrophysics, Brother Guy Consolmagno, current director of the Vatican Observatory, has also described him as "the greatest astronomer you've never heard of." In his

▶ **UNDER AN ILLUSION** When viewed from the right position in the church's nave, Andrea Pozzo's painted dome tricks the eye to appear like a physical structure. This photo taken directly below shows how perspective is used in this illusionistic technique, called trompe l'oeil in French. Pozzo's fresco above the nave, partially visible at the top of this photo, also creates an architectural illusion with painted pillars seemingly extending the space skyward.

lifetime, Secchi studied and contributed to many scientific disciplines, including meteorology, geology, and ocean science — indeed, his name is now most often associated with the *Secchi disk*, a device used to measure the transparency of water. But his true passions were physics and astronomy. For more than 25 years, Secchi worked atop the faux dome conducting research that would serve as the basis for an emerging field that combined the laws of physics and astronomical observations. For Secchi, science and religion did not conflict; rather, the Catholic Church provided a figurative and literal foundation for his pursuits.

Historian Ileana Chinnici first encountered Secchi while researching a different historical figure for her dissertation. “Immediately, I perceived that he was a very remarkable man and scientist,” says Chinnici, who now works as a research astronomer at the Italian National Institute for Astrophysics in Palermo, Italy. Struck by a lack of reliable, unbiased information on Secchi’s life and work, she set out to write a biography.

Several authors, including Chinnici, compare Secchi to perhaps the most iconic Italian astronomer of all, Galileo Galilei. Both made important contributions to modern science and conflicted with ruling authorities during turbulent times. Both also held strong convictions — and had even stronger personalities.

Galileo was instrumental in promoting the scientific method and was ultimately sentenced to house arrest by the Church for teaching the then-heretical notion that Earth orbits the Sun. Similarly, Secchi put the scientific method to work in a life dedicated to research even while facing meager funding, political attacks, and exile from a 19th-century anticlerical Italian regime. As his classics teacher once remarked, Secchi was a man who “could not suffer narrow-mindedness and meanness of heart.”

▲ **A DISCIPLE OF MANY DISCIPLINES** *Left:* Italian Catholic priest Angelo Secchi wasn’t just the father of astrophysics, he also conducted research in magnetism and meteorology, and he invented the eponymous Secchi disk, still used today to measure water transparency.

▲ **ABOVE THE FACADE** *Right:* This illustration dating from 1863 shows the rooftop observatory as it originally appeared. The structures visible here were mostly dismantled after the observatory closed in 1923.

A Church-top Observatory

Secchi was born in 1818 to a middle-class family and had a brother and a sister. He became a Jesuit by age 16, but in 1848 was forced out of Rome during the revolution that sparked the unification of Italy. He bided his time in the UK and even briefly taught in the U.S. before returning to Rome in 1850, where he was appointed observatory director. Secchi sought

PORTRAIT: WIKIMEDIA COMMONS / PUBLIC DOMAIN; ST. IGNATIUS OBSERVATORY: VATICAN OBSERVATORY; SPECTRA: PUBLIC DOMAIN (2)

THE STARS

Type 1: Sirius, Vega, etc.

Type 3: α Herculis, β Pegasi, etc.

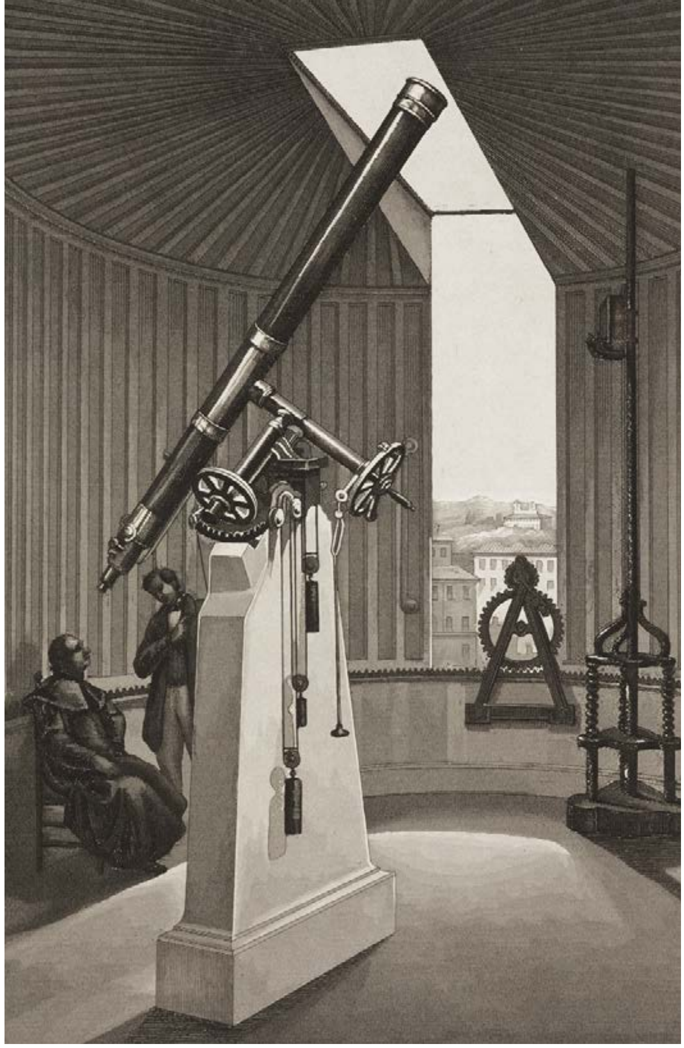
▲ **COLOR COMPOSITION** Angelo Secchi was one of the first to propose a spectral classification system for stars. His scheme included five classes or types, represented by the sample spectra in these images from his 1875 book *Le Soleil*. Two of the five categories are illustrated here. Each type is characterized by its pattern of absorption lines (the black lines in the pictured rainbow spectra).

and received permission to build a new observatory at the Church of Saint Ignatius. The choice of location was both practical and symbolic, reflecting the relationship between science and faith. “For Secchi, scientific activity was another way of praising God,” Chinnici says.

Three top-notch telescopes were eventually installed on the church’s rooftop, located across the Roman College’s campus from the previous observatory. The instruments included the Cauchoix telescope, a 16.9-centimeter (6.7-inch) f/14 refractor with excellent optics that was used for solar observations. Another important instrument was the Merz refractor, which was imported from Germany. At 24.4 centimeters aperture, the telescope was one of the largest available at the time. Both instruments were fitted with a prism, which Secchi used to perform some of the first spectroscopic observations in astronomy. Secchi also transferred a meridian-circle instrument — designed to measure a star’s position as it crosses the meridian — from the old observatory.

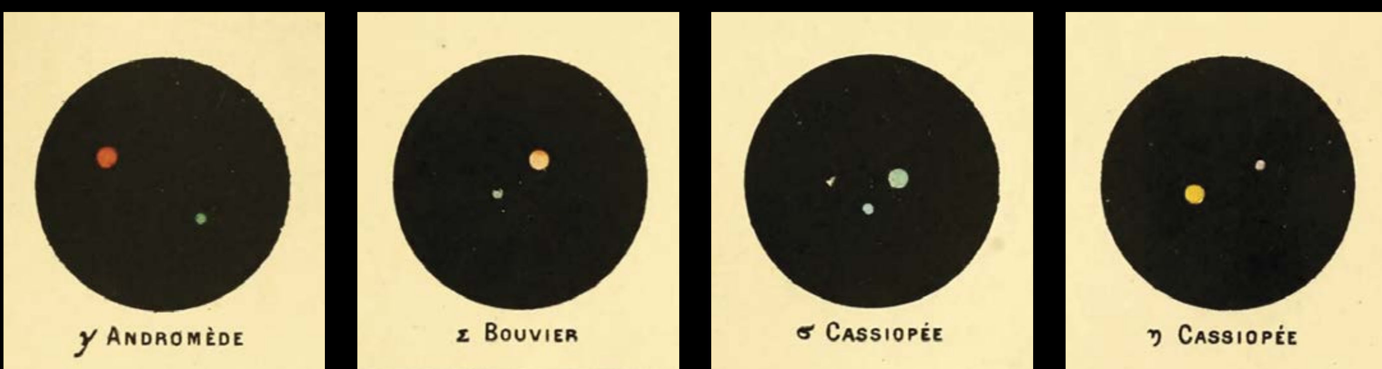
The observatory’s church-top location was very convenient, allowing the Jesuit astronomers to work and worship in the same place. But the idea was not originally Secchi’s, says Marco Spada, an architectural researcher at the University of Suffolk who wrote about the attempts to build Saint Ignatius’s “impossible dome.” One of the church’s original architects, Orazio Grassi, wanted to transform the rooftop into a magnificent solar clock, with an obelisk mounted on the dome as a needle. But the idea never came to fruition. Instead, Secchi transformed Grassi’s ambitious design “into something concrete, something real,” Spada says.

The painted dome inside created a “continuity with the sky,” reflecting the idea that the church is a place for all people to connect with the heavens, Spada notes. “But if you are one of the chaste, a scholar of the Roman College, you can go on top of the church to see the real sky.”



▲ **PRIZE SCOPE** With its 24-cm (9-inch) aperture, the Merz refracting telescope was one of the largest available in the mid-19th century —and Secchi’s favored instrument. The impressive scope was imported from Germany, then moved to the observatory outside of Rome when the Saint Ignatius observatory closed. Unfortunately, the instrument was destroyed in a large fire in 1958.

TELESCOPE: SSPL / UIG / BRIDGEMAN IMAGES; DOUBLE STARS: PUBLIC DOMAIN (4)



▲ **COLORFUL DOUBLES** These illustrations from Angelo Secchi’s 1877 book *Le Stelle* depict several color-contrasting double stars that most readers will be familiar with. Secchi was an avid observer and over the course of seven years compiled data for more than 10,000 binary stars in his effort to revise Friedrich Georg Wilhelm von Struve’s famous catalog of double stars.

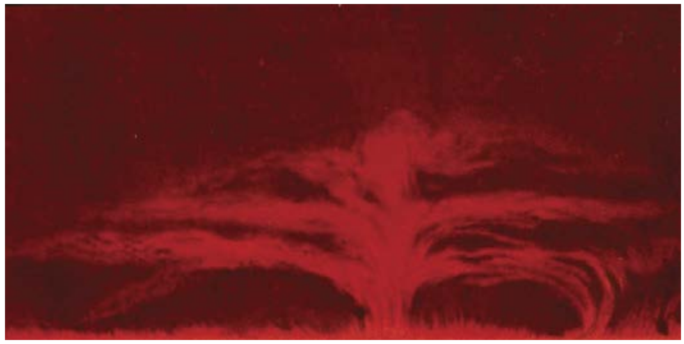
The Father of Astrophysics

Although the 19th century was a time in which science was branching out into multiple specialties, Secchi was a pioneer in many disciplines. “He always tried to find connections between different phenomena,” Chinnici says. For instance, he sought to understand how meteorological events were connected to solar activity, and how chemistry could relate to the stars. Chinnici believes this tendency was largely due to his training in physics. As she notes, “He was not an astronomer, but really an astrophysicist — one of the first astrophysicists.” His background in physics provided a broader view of the natural world.

Up to this point, astronomy was largely a theoretical and mathematical field, focused on the positions and movement of stars. Meanwhile, physics was considered a laboratory science, like chemistry. Secchi was among the first to fuse the two and consider not only how stars move, but also what they might be made of. “He really had this important intuition that the introduction of physics and chemistry in astronomy can give us the opportunity to know the chemical composition of the stars,” says Chinnici.

While the Sun and stars can’t be studied in a laboratory, their spectra can be. *Spectroscopy* — the study of light split into its constituent wavelengths — was an emerging field in Secchi’s time. Physicists were just beginning to understand that light could reveal precisely the material it passed through en route from the source to the observer.

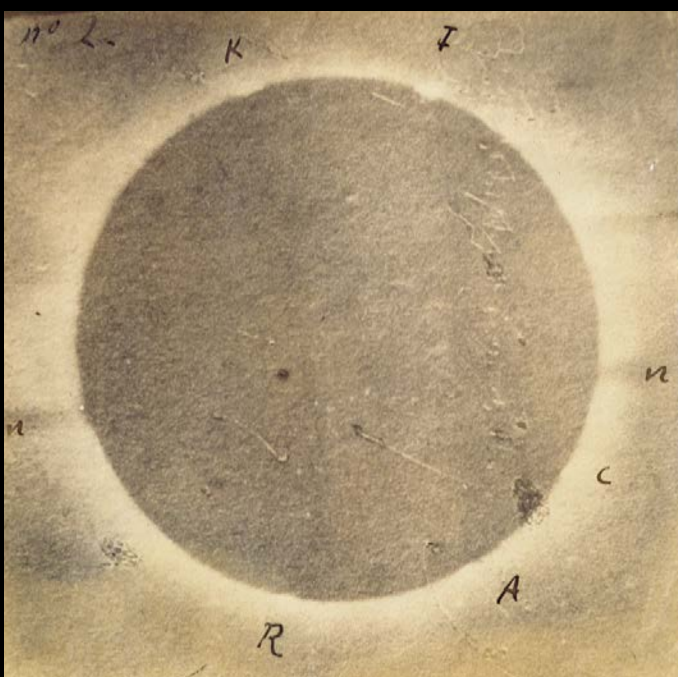
Joseph von Fraunhofer first observed dark lines in the dispersed spectrum of sunlight in 1814, but what these features meant remained a mystery. It wasn’t until 1859 that Gustav Kirchhoff discovered that the lines in the solar spectrum were caused by elements absorbing specific wavelengths of light.



ECLIPSE IMAGES: © ARCHIVES DE L'ACADEMIE DES SCIENCES / © ARCHIVES CHARMET / BRIDGEMAN IMAGES (4); SOLAR PROMINENCES: PUBLIC DOMAIN (2); SUNSPOT ILLUSTRATION: ASTRONOMICAL AND COPERNICAN MUSEUM OF THE INAF ASTRONOMICAL OBSERVATORY OF ROME

THE SUN

▼ **EARLY ECLIPSE PHOTO** These images were taken by Secchi in Spain during the July 1860 solar eclipse — some of the first of their kind. The annotations identify prominences and the corona visible during totality, which provided photographic proof that these features are solar phenomena and not simply optical illusions.



Secchi collected some 4,000 stellar spectra, revealing the compositions of stars. “This was really a breakthrough in astronomy,” says Chinnici. “That was the moment when astronomy became astrophysics.” With these observations, he devised the first spectral classification system, dividing stars into five types based on their absorption and emission lines. The “Secchi classes” are the basis of modern classification systems developed at the Harvard College Observatory years later. Notably, Secchi is also credited with the discovery of carbon stars — his spectral “type IV”.

Sunspots and Solar Physics

In addition to his work in stellar spectroscopy, Secchi was a pioneer in solar physics. Like a moth to a flame, the scientist was drawn to the Sun and was one of the most active solar observers of his time. He was also one of the first to photograph a total solar eclipse.

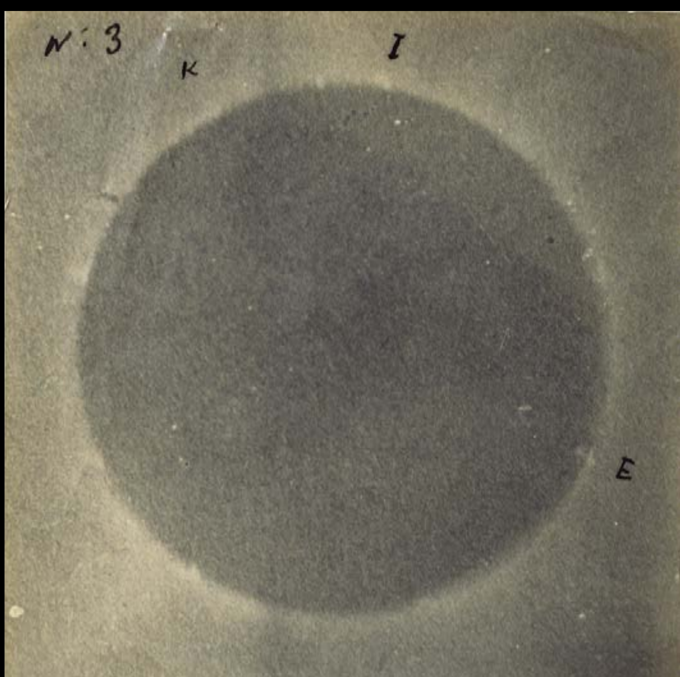
Secchi regularly made drawings of sunspots and prominences, capturing the evolution of each of these features, which helped scientists determine that they are manifestations of solar activity. While scientists now understand that stars are highly active and evolve over their lifetimes, the idea that the Sun follows cyclical patterns was new, says Ilaria Ermolli, a solar physicist at the Italian National Institute for Astrophysics.

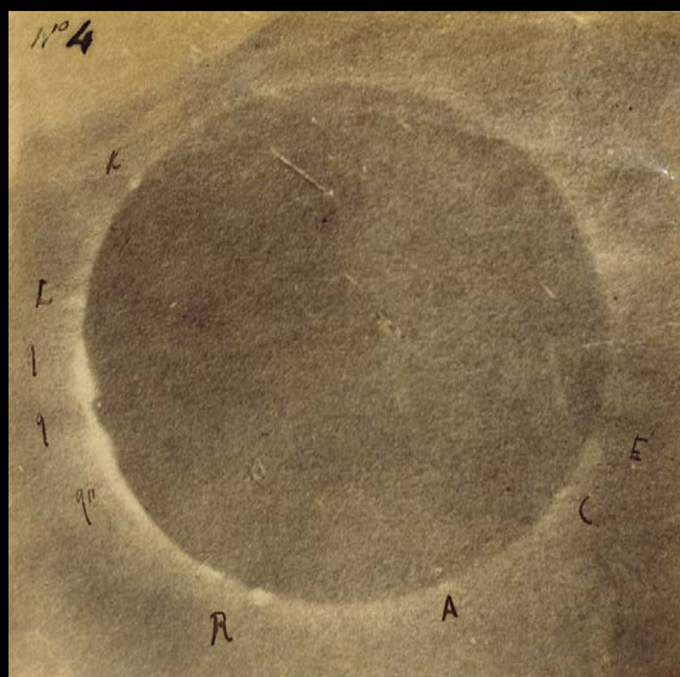
Ermolli is currently leading a project to digitize and analyze Secchi’s hand-drawn observations, in collaboration with colleagues at the Max Plank Institute for Solar System Research and universities in Spain. The project has preserved more than 3,900 drawings from Secchi’s notebooks made over a 20-year period. But these observations aren’t just interesting relics, they also provide valuable historical data that can illuminate patterns over long timescales.

“In order to know the Sun in the past, we must exploit all the data we have,” says Ermolli. As a researcher, she usually works with modern, high-resolution images and sophisticated models of the Sun. But working in a country with a rich scientific archive, she was inspired to make use of the treasure-trove of historical data at her disposal. The project began with photographic materials recording the Sun’s activity, which have been captured since the end of the 19th

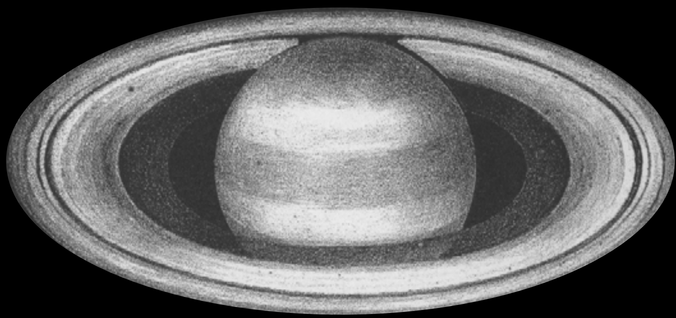
◀ **STRIKING PROMINENCES** Secchi was able to render detailed drawings of solar prominences through spectroscopic techniques. The use of chromolithography allowed for high-quality reproductions in books like *Le Soleil*.

▶ **SKETCHY SECCHI** Compared to those of other observers, Secchi’s drawings have been described as schematic and sketchy. Rather than focusing on individual features, his observations aimed to capture the relationship between individual sunspots.

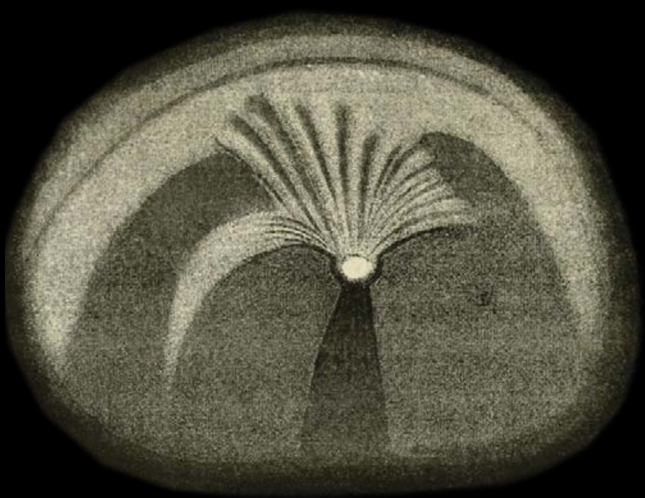




SOLAR SYSTEM SKETCHES



◀ **RING WORLD** In addition to observing the Sun and stars, Secchi kept a keen eye on the Moon and planets, including Saturn, shown here as it appeared in the 9-inch Merz refractor in November 1855.



◀ **SUMMER DELIGHT** This June 30th sketch by Secchi depicts the head of the great comet of 1861. Although he didn't find this particular object, Secchi is credited with the discovery of three comets of his own.

◀ **MAPPING THE RED PLANET** In this color reproduction of one of Secchi's Mars drawings, the Martian surface feature Syrtis Major is prominent. Secchi was the first to describe linear features on the Red Plant as "canali" in his native Italian, which was translated into English as canals.

SATURN SKETCH: VATICAN OBSERVATORY LIBRARY; COMET SKETCH: PUBLIC DOMAIN; MARS SKETCH: DETLEV VAN RAVENSWAAY / SCIENCE PHOTO LIBRARY century. Now, they have started analyzing pre-photographic data. "The Secchi collection is particularly important in this respect," Ermolli says.

To facilitate analysis of the drawings — a labor-intensive process — Ermolli and her colleagues turned to the global community of citizen scientists. The team launched a project called Sunspot Detectives on the Zooniverse online platform (**https://is.gd/sunspotdetectives**), in which users can count the number of sunspots in each drawing. The number and size of the spots indicate the strength of the magnetic field and thus the level of solar activity, Ermolli explains. The project draws on a tradition that Secchi himself participated in by involving the public in scientific practice and providing equipment for amateurs to use.

While Secchi's drawings contain important information, there are challenges to using the data. Unlike photographs, which accurately show details present on the solar disk, drawings reflect the inclinations and abilities of the individuals who made them. "Someone reported them with pencil and ink," Ermolli says. Different observers would take different approaches, for example, by choosing to emphasize individual features or the relationship between sunspots. Compared to his collaborators, Secchi's drawings were rather "schematic and sketchy," notes Ermolli. "But in the end," she adds, "we have to try to exploit all the data we have."

To Ermolli, Secchi's methodology was as important as his discoveries. Embodying the traits of a modern scientist, Secchi was willing to challenge commonly held beliefs and was convinced scientific knowledge should be shared. In addition to moving the Roman College's observatory from its crumbling stone tower, he also tried to abandon the isolation of the scientist's fabled ivory tower. While most astronomers of his time worked alone, he realized the importance of collaboration and a scientific community.

Secchi helped establish a network of observing stations so that a single phenomenon could be recorded in multiple places by several scientists. For example, he and another Jesuit astronomer, Pietro Tacchini, had identical telescopes. This allowed them to directly compare observations recorded at the same time from different locations. "This idea to work in a team was new," says Chinnici. Secchi also believed in the importance of publishing in journals, and he promoted the establishment of the first scientific society devoted specifically to astrophysics.

Unfortunately, however, his outspoken nature often conflicted with this collaborative approach. In fact, his rivals prevented some of his most important work from being translated into English so that it couldn't be read by his contemporaries.

The Cracked Dome

In 1891, a gunpowder magazine left over from the Capture of Rome during the final years of the Italian unification process exploded. Although the calamity occurred far away in the countryside, a powerful shock wave surged through Rome, shattering glass in Saint Paul's Basilica and the windows of the Italian Parliament. At the Church of Saint Ignatius, debris tore open the canvas dome.

▲ **GREAT RUINS** Little remains today of the rooftop observatory Secchi used to explore the night sky. This 2018 photograph shows the site's present condition. The most significant remaining piece of the observatory is the pier that once supported Secchi's prized Merz refractor.

OBSERVATORY REMAINS: BR. ROBERT MACKE SJ.

On the rooftop above the shattered illusion, the observatory was changing, too. More than a decade earlier, in 1878, Secchi died during a tumultuous time. Although the Italian government took possession of the Holy See — the Pope's jurisdiction — in 1870, Secchi as observatory director continued to manage the facility. No longer a papal establishment and not yet Italian, the observatory's status was uncertain and received no financial resources from either government. After Secchi's death, it was confiscated by the Italian state.

The observatory remained open through the end of the century with Secchi's colleague, Tacchini, serving as the new director. But the facility, once among the most advanced of its time, couldn't keep up with changes in the field. In 1889, Secchi's prized Merz refractor was moved to a new facility outside Rome, where it was used as a finder on a larger telescope for decades. And by 1892, photography had largely replaced the kinds of hand-drawn illustrations made at Saint Ignatius. Just as Secchi had moved the observatory from its crumbling tower to attain better data, his successors needed more precise tools to advance the fields of study he had pioneered.

Ultimately, "the success of the observatory was also the curse of the observatory," Spada says. In 1923, the Roman College Observatory merged with another in the city to form the Rome Astronomical Observatory on Monte Mario. It's now the headquarters of the Italian National Institute for Astrophysics.

Meanwhile, the observatory on Saint Ignatius was disassembled and left to decay. Only a few ghost structures remain on the rooftop. "Unfortunately, there is nothing that remembers the glorious time of the observatory," Chinnici says. But inside the church, the illusion that conceals a conspicuously missing dome's absence remains, hinting at the building's hidden history.

■ **GWENDOLYN RAK** holds a master's degree in science journalism from New York University and a bachelor's degree in astrophysics and history from Swarthmore College. She thanks Christopher M. Graney of the Vatican Observatory for his assistance in preparing this article.

Oddbal

▶ **ROLLER COASTER** The asteroid 2020 CD_3 made several loops around Earth between when it was captured in 2017 and when it escaped Earth's pull in 2020. The white ellipse is the Moon's orbit. Thinner lines are farther away from the viewer, and thicker lines are closer. Color indicates distance from Earth (blue dot): Darker segments are closer to Earth, and lighter ones are farther away.

LEAH TISCIONE / S&T; SOURCE: SHANTANU NAIDU / NASA JPL

...l Orbits

Most objects in the solar system follow simple, orderly orbits. But some just go their own way.

OK, time for a pop quiz: How many moons does Earth have? How many does Venus have?

If your answers were one and none, you're correct. But those aren't always the only answers.

For example, if our quiz had been asked in 2019, you could have correctly answered that Earth had two moons. That's because in late 2017, the asteroid 2020 CD_3 had been captured into an Earth-circling orbit (*S&T:* June 2020, p. 12). Shortly after its discovery in February 2020, it was ejected back into a Sun-circling orbit, no longer subject to Earth's gravitation. It will come relatively close to Earth again in 2044, but not close enough to be captured anew.

Scientists have discovered several small bodies in the last couple of decades, like 2020 CD_3, that travel on complex orbits that don't quite fit into the usual categories. There are asteroids that follow exotic paths around the Sun, such as horseshoe and tadpole orbits, and that sometimes become *quasi-moons* or even temporary *mini-moons* of Earth and the other planets. These oddball orbits have revealed that the solar system is a more complicated place than we realized, with quirky, unexpected nooks and crannies of orbital dynamics that are just being uncovered.

Many Mini-Moons

Calculations based on simulated asteroid populations suggest that, on average, at least once a year Earth is temporarily accompanied by a mini-moon — an asteroid captured into Earth orbit. The asteroid may remain for months or years before being perturbed by close approaches with the Moon or Earth and cast back out into a Sun-circling orbit.

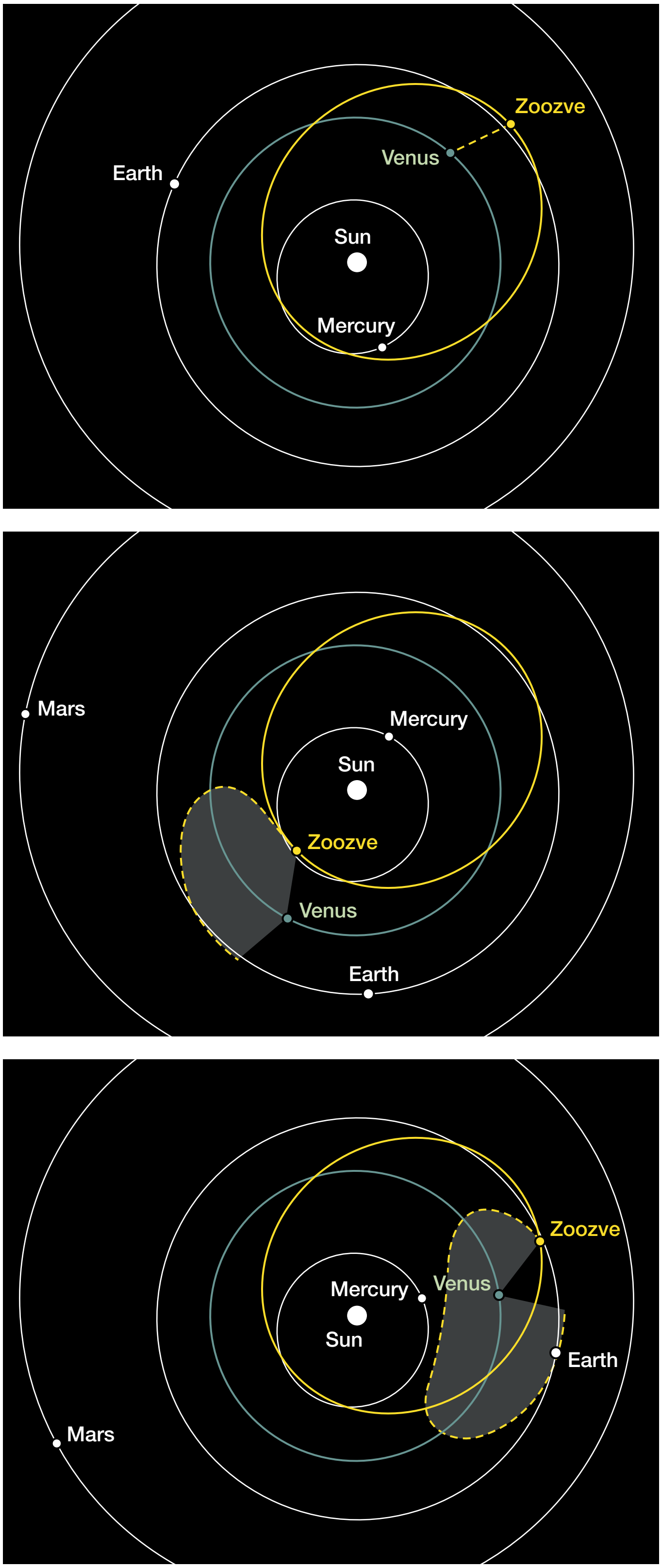
Such mini-moon orbits had been predicted as early as 1913, but despite these objects' typically very close distances (maybe a few times the distance to the Moon), none was discovered for sure until the 21st century. That's because the objects on these orbits tend to be small, faint, and close to the Sun as seen from Earth.

The first one positively identified as a natural object was asteroid 2006 RH_{120}, estimated to be just 3 meters (10 feet) across. Discovered in 2006, it remained in Earth orbit for a year, from July 2006 to July 2007, then returned to heliocentric orbit. But it remains in resonance with Earth, having essentially the same orbital period around the Sun as Earth does. It travels on an orbit slightly tilted from ours.

The object will come back to visit us again in 2028, when it will pass close to Earth at an astonishingly slow relative velocity of 140 m/s (300 mph) — less than the speed of a commercial jet. By way of comparison, meteoroids typically strike Earth at more than 12 km/s (27,000 mph). The asteroid's slow velocity during this approach makes it a tempting target for a close-up visit by a spacecraft.

Fake Out
Among the artificial objects mistaken for mini-moons are rocket stages from lunar missions and the European Gaia spacecraft.

Since 2006 RH_{120}, astronomers have found at least two other mini-moons. They've also found things masquerading as mini-moons. Sometimes, when a new object is sighted by astronomers in an apparent orbit around Earth, observers may initially suspect it's a natural object, only to discover it's a long-lost rocket booster. That happened in 2017, for example, when researchers found an object on a geocentric orbit and gave it a provisional asteroidal designation — then later learned it was the leftover booster stage from China's Chang'e 2 mission to the Moon, which had launched in 2010 (*S&T:* June 2022, p. 11). Several other suspected asteroidal companions in Earth's orbit have similarly turned out to be old rockets, in one case a few decades old. And the first potential mini-moon ever identified, designated 1991 VG, remains ambiguous; it could be either an asteroid or space junk.



▲ **VENUS'S QUASI-MOON** The asteroid Zoozve (aka 2002 VE_{68}) follows an elongated orbit around the Sun. But it never strays far from Venus, and as seen from Venus's surface, the object appears to orbit the planet. The shaded region traces the asteroid's position with respect to Venus over several months. Watch a video: **https://is.gd/zoozvepath**.

LEAH TISCIONE / *S&T*, SOURCE: PAUL WIEGERT / UNIV. OF WESTERN ONTARIO

Quasi-Moons

Mini-moons are only one example of oddly behaving asteroids. At least one astronomer more than a century ago predicted another category of strange orbits: quasi-moons.

Quasi-moons appear to orbit a planet, as seen from the planet's perspective. But in reality, if we could look down on the solar system from above, we'd see that they orbit the Sun. These asteroids stay in the vicinity of the planet, and their orbital periods are almost exactly the same as the planet's. But sometimes the asteroid is closer to the Sun than the planet is, and sometimes it's farther out. As the asteroid's position wobbles around, the object appears to trace a loop around the planet.

Astronomers found the first quasi-moon in 2002, but they didn't identify it as a quasi-moon until 2004. That object is an asteroid originally designated as 2002 VE_{68} and appears to orbit Venus, as seen from that planet. The International Astronomical Union formally renamed the asteroid as Zoozve in 2024 after inspiration by a typo: The designer of a solar system poster for children misread the numeric designation and added an object named Zoozve to the illustration.

Zoozve is now by far the most stable quasi-moon known. Simulations of its orbit run forward and backward by Seppo Mikkola (University of Turku, Finland) and others show that it has been in this quasi-moon orbit for about 7,000 years and will remain so for about 500 more before being ejected. After that, its trajectory is hard to predict, but the asteroid could approach Earth and be captured as a mini-moon or quasi-moon, or maybe even impact our planet.

Astronomers have now found at least seven quasi-moons around Earth, with a few more claimed but still uncertain. The most stable of these is Kamoʻoalewa (a Hawaiian word sometimes translated to mean an object that oscillates up and down in the sky), which was originally designated as asteroid 2016 HO_3. Unlike most other quasi-moons, whose orbits tend to be unstable, Kamoʻoalewa has been in this orbit for almost 100 years and could remain there for centuries to come, according to calculations by Paul Chodas (NASA Jet Propulsion Laboratory).

"It's in that state for hundreds of years, but it can flip out if the timing is right," Chodas says. "It's a very delicate situation." Eventually, a relatively close encounter with Earth, the Moon, or another planet will perturb Kamoʻoalewa's orbit just enough that it will no longer appear to orbit Earth at all.

Unlike mini-moons, which really do orbit Earth, albeit only as brief visitors, quasi-moons are only minimally affected by the planet. "Quasi-moons are much farther away from Earth and they are orbiting the Sun, and Earth's gravity is just a slight effect that holds them near Earth — or near [another] planet — so that it doesn't wander all the way around the planet's orbit," Chodas says.

Recently, a team of astronomers published an analysis showing that it's likely that Kamoʻoalewa is actually a chunk of the Moon that was blasted away by the impact that produced the lunar crater Giordano Bruno. If true, this would be the first time such an object could be linked directly to its parent object.

Erik Asphaug (University of Arizona) was part of the team that carried out that analysis and says the connection between the Moon and Kamoʻoalewa is compelling. First, spectral analysis shows that the asteroid's composition is a close match to lunar regolith. Second, its orbit closely matches orbits of material ejected in simulations of such an impact. And Giordano Bruno is the only lunar crater that is large enough and recent enough to have produced a fragment of that size that would still be around, he says. "If we are sure Kamoʻoalewa is a lunar fragment, then G. Bruno is the only possible source crater that we know of."

That could make it a very enticing object for exploration, he says. If their interpretation is right, then "it is the first example of a massive object that has been ejected from the surface of a planetary body." As such, it may provide clues about how meteoritic material is transferred between planets. That's especially interesting in relation to material ejected from Mars, which may carry information about past geological or even biological processes.

Not everyone is convinced of the connection between this asteroid and that crater, though. Alan Harris (Space Science Institute) says the velocity of the asteroid relative to Earth, at more than 5 km/s, is higher than expected for lunar ejecta. A more likely origin would be the inner asteroid belt. In addition, he says, scientists estimate that Giordano Bruno formed millions of years ago, far longer than this asteroid has been in its present orbit. "I'd rate the claimed association with the crater Giordano Bruno (or any lunar crater) as pure speculation."

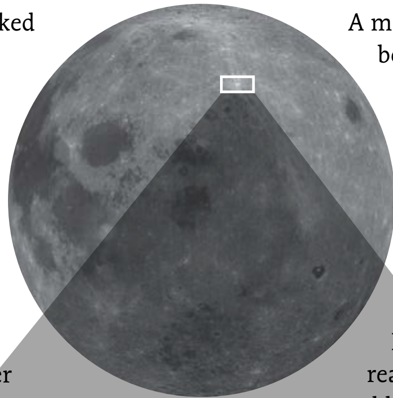
Astronomer Paul Wiegert (University of Western Ontario) is more open to the idea. "I think it's a plausible hypothesis," he says. But whether or not that specific association is real, he says, "that kind of phenomenon certainly could be contributing to the population of quasi-moons around Earth."

And if so, they could be more easily accessible than the surface of the Moon itself, having much smaller gravitational fields and thus requiring little acceleration to depart from. "The presence of lunar ejecta, parts of the Moon in orbit around the Earth, might make it easier to collect samples and bring them back for study," he says. "I think these kinds of objects could be very interesting scientifically because they provide a bit of a new window into the history of the Moon, and by extension [of] Earth."

China is taking the bait: Its Tianwen 2 mission, set to launch in 2025, will visit Kamoʻoalewa and collect samples to return to Earth for study.

Horseshoe Orbits

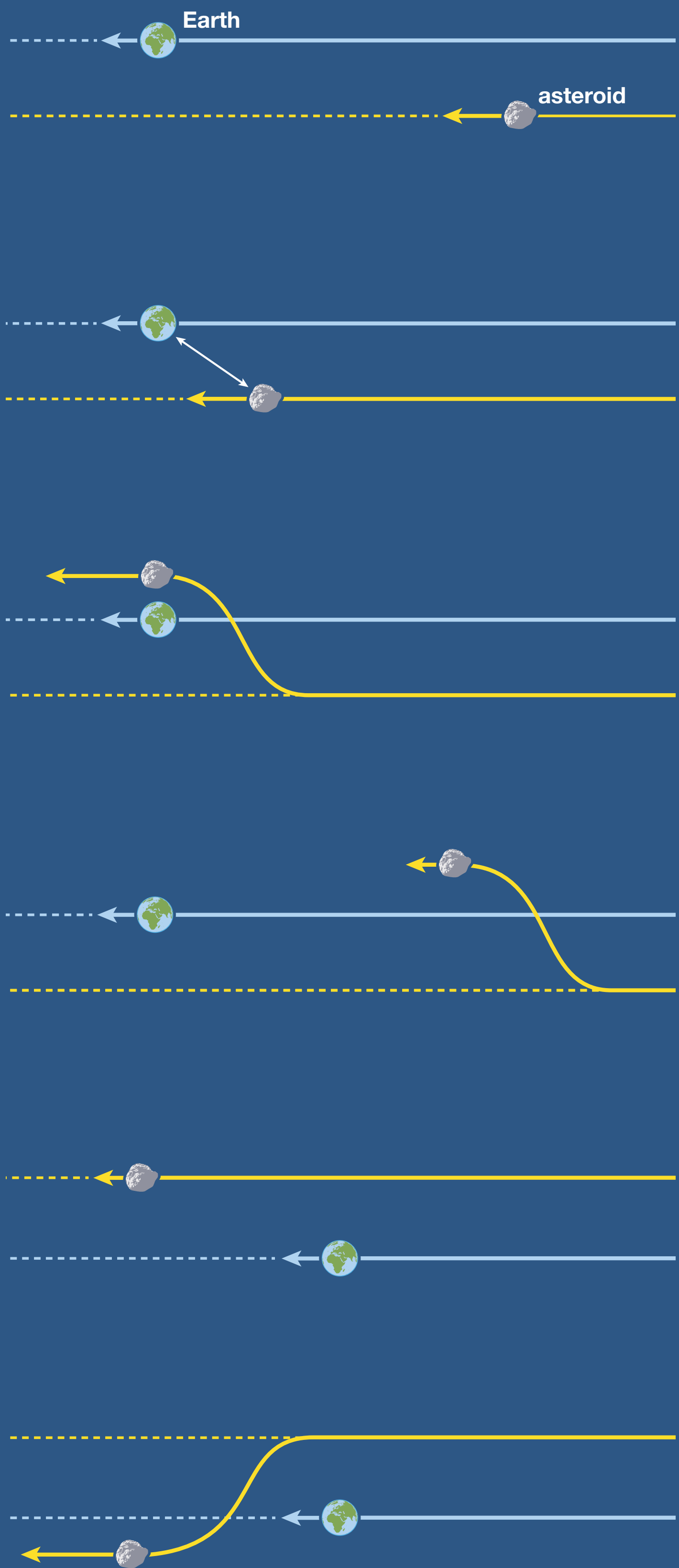
When quasi-moons are perturbed out of these inherently



▲ **THE SOURCE?** Astronomers suspect that Earth's quasi-moon Kamoʻoalewa is a roughly 50-meter-wide chunk of the Moon, ejected to space by the impact that created the 22-km-wide crater Giordano Bruno. The crater sports dramatic rays and lies just beyond the eastern lunar limb as seen from Earth. (The center of the lunar hemisphere image above is 90°E.)

LUNAR HEMISPHERE: NASA / JPL / USGS; CRATER: NASA / GSFC / ARIZONA STATE UNIVERSITY

HOW HORSESHOE ORBITS WORK



The asteroid approaches Earth from the "inside track," closer to the Sun. Because it's closer to the Sun, the asteroid is moving faster than Earth.

As the two bodies near each other, they tug on each other gravitationally.

The asteroid has no effect on the orbit of the much larger planet. But Earth's tug speeds the asteroid up, which boosts the asteroid to a slightly larger orbit.

Once the asteroid is farther from the Sun, it naturally slows down. It falls behind as Earth pulls ahead.

Eventually, the bodies' positions will line up again such that Earth approaches the asteroid from behind.

Earth will pull the asteroid inward. Now closer to the Sun, the asteroid speeds up and moves away from Earth. From Earth's perspective, it appears to change direction, receding instead of approaching.

LEAH TISCIONE / S&T

unstable orbits, usually by passing a bit too close to a planet or moon, they tend to revert to what are known as horseshoe orbits. As seen in relation to a fixed line between Earth and the Sun, these objects follow a semi-circular path, going perhaps three-quarters of the way around a solar orbit before making a sharp U-turn and heading back the other way. Essentially, it looks like the asteroid approaches Earth, stops, and then turns around, says Wiegert.

In reality, as seen from a fixed solar system perspective, the asteroid is always circling the Sun in the same direction, just sometimes faster or slower than Earth.

Objects' orbital speeds depend on their distance from the Sun: The closer an object lies to the Sun, the faster it moves. When the asteroid approaches Earth from behind, on an orbit that lies slightly closer to the Sun, Earth pulls on the asteroid as it approaches. This pull tugs the asteroid outward, enlarging its orbit to put it out past Earth's. Now farther from the Sun, the asteroid slows down in its orbit. Instead of passing Earth on the inside track, it instead falls farther and farther behind Earth.

Conversely, when Earth approaches the asteroid from behind, when it is on a slightly larger orbit than Earth's, Earth's gravity pulls it inward. Since objects on smaller orbits travel faster than those on larger orbits, the asteroid then speeds up and inches ahead of Earth, eventually leaving it in the dust. From our perspective, it looks like Earth repelled the asteroid.

"That's the curious thing about horseshoe orbits," Chodas says. They arise due to a complicated three-body dynamic among Earth, the Sun, and the asteroid. "That third-body effect has the effect of repelling the object when it comes close to Earth," he says. "Earth's gravity has the effect of pushing it away, which is counterintuitive."

In this way, these objects can share an orbit with Earth or another planet and yet never actually come too close to it. Similar orbits that follow a shorter arc are sometimes called tadpole orbits.

Horseshoe orbits are essentially a kind of elongated version of the orbits followed by Trojan asteroids — ones that lead and follow a planet in essentially the same orbit, but spaced 60° ahead of or behind the planet. Horseshoe orbits were predicted as a theoretical possibility over a century ago by astronomers including George Darwin, one of Charles Darwin's sons.

The first such object seen was the asteroid 3753 Cruithne, discovered in 1986 and seen to have a similar orbital period to Earth. But scientists did not realize it was on a horseshoe orbit until 1997, when Wiegert investigated it along with Mikkola and Kimmo Innanen (York University, Canada).

And in May 2024, astronomers discovered another asteroid, called 2024 JR_{16}, which as of this writing appears to follow a truncated horseshoe orbit. It may prove to be an Earth Trojan. If so, it would be just the third such object found near Earth.

Simulations by independent French astronomer and journalist Adrien Coffinet show that 2024 JR_{16} has been on a horseshoe orbit since about 1650. Its course over the next several centuries is difficult to pin down because several encounters with Venus will perturb its path, starting in 2049. While it is likely to stay in a horseshoe orbit until at least the year 3000, he says, close approaches over the next few years should help researchers pin down its past and future trajectory.

Meanwhile, asteroid 2024 PT_5, just discovered in August, recently transitioned from a horseshoe orbit to become Earth's temporary mini-moon. As of the time of this writing, astronomers have estimated that it would stay with us for less than two months, from September 29th to November 25th, before returning to solar orbit. It will come back to Earth's vicinity and possibly be recaptured in 2055.

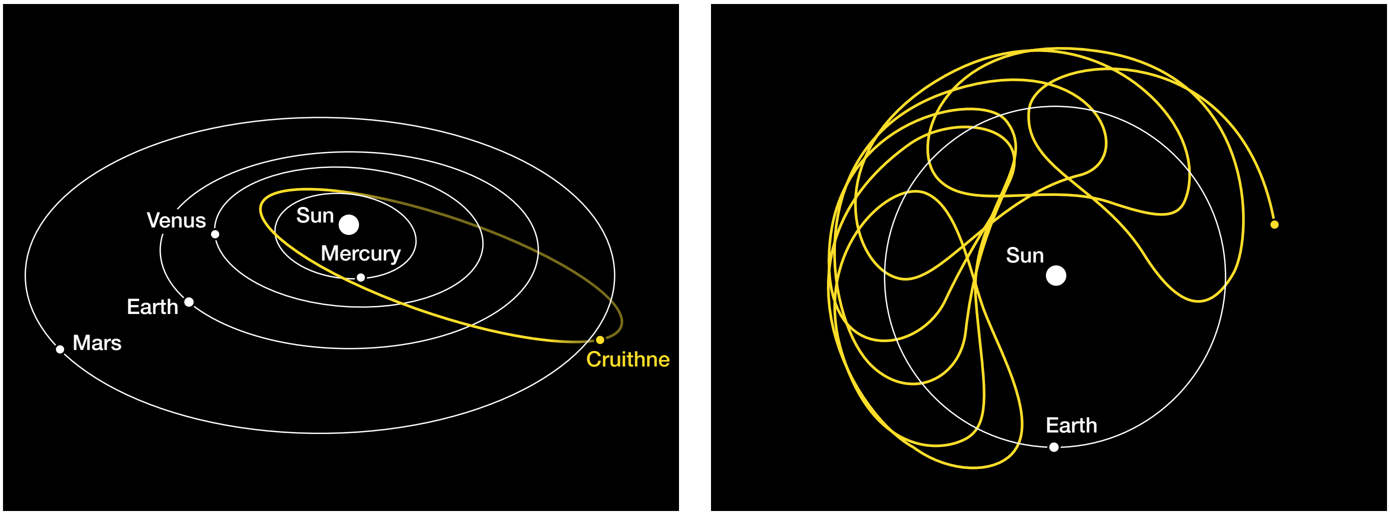
Discovery Deluge

In the last few decades, discoveries of asteroids sharing their orbits around the Sun with planets in various ways have come at a rapid clip. Earth alone seems to be accompanied by a dozen or so co-orbital asteroids on horseshoe orbits, although some are less certain than others. "We're slowly realizing that all of the planets have these co-orbitals," Chodas says. Mercury is the exception: The Iron Planet is too small and too close to the orbit of the much more massive Venus to hold onto these kinds of companions.

But tracing the past and future of all these objects is tricky, because their orbits are so easily perturbed by even fairly distant encounters with planets and their permanent moons. "They tend to be very difficult to trace over time, and that's because the solar system is a chaotic system," Wiegert says. Like with the butterfly effect, in which a tiny perturbation can lead to big effects down the line, it is hard to trace these objects back to their origins or to project them into the future — including the possibility of future collisions with Earth, for those objects that share our orbit in some way.

The objects themselves are adept at hide-and-seek. After detailed simulations, Chodas and Harris calculated that many objects that share Earth's orbit and are thus in a one-to-one resonance "can hide for years, even decades, behind the Sun and not be seen or discovered," Harris says. While these objects are very hard to find, "the good news is that impacts from such objects don't come 'from out of the blue,' but instead require many years of ever-closer encounters until finally an impact trajectory results."

In short, he says, "these near-resonant bodies don't constitute a significantly increased hazard, and in general, will give years of warning before arriving." And besides, most are quite small — ranging from a few meters across to a few hundred meters or more. In the worst case, that's big enough to wipe out a city, perhaps, but not to cause more widespread damage.



▲ **CRUITHNE'S PATH** From a perspective looking down on the solar system, we can see that the asteroid Cruithne follows an elongated, highly inclined orbit *(left)*. But as seen from Earth's perspective *(right, with Earth held stationary)*, it follows a complicated horseshoe orbit. Every year, the asteroid traces out a kidney bean. But over time, this kidney bean drifts along Earth's orbit, tracing out a spiral that, when completed some 385 years later, fills in an overlapping horseshoe shape.

Solar System Steppingstones

On the other hand, the proximity and low relative velocities of some of these Earth-accompanying objects on odd orbits do make them promising candidates for exploration by spacecraft, says astronomer Richard Binzel (MIT).

"Getting humans to Mars is even more difficult than most people recognize," he says. Paving the way by conducting missions of intermediate distance and duration, but with a real destination, would be a smart way to build the technical and human capabilities needed for a Mars mission. This concept was first advanced by planetary scientists Eugene Shoemaker and Eleanor (Glo) Helin as far back as 1978.

While Earth's quasi-moons can travel out nearly as far as the orbit of Mars or in as far as Venus or beyond, they sometimes come within a few lunar distances of Earth. These and the other Earth-accompanying asteroids "represent destinations that are closer, with shorter durations, than it would ever take for humans to make a round trip to Mars," Binzel says. "So as a steppingstone to test humans in interplanetary space, this gives astronauts somewhere to go and something to do, to see how we perform when we're so far removed from the Earth-Moon system."

There's good science to be done in studying near-Earth asteroids that make their way onto these strange orbits, he says, and although much of that could be done robotically, "humans can always do things better."

In addition to their scientific value, some quasi-moons and mini-moons might be a rich resource for future space missions. "I think the gold to be mined in near-space is water," Binzel says. "That is a resource that humans need, and it's fairly easy to extract just by heating the material. And there are water-rich asteroids among those that are near Earth."

The asteroid sample-return missions Hayabusa 2 and Osiris-Rex both found water abundances of a few percent in their respective asteroids (*S&T:* May 2020, p. 14), for example. "If you can process enough material, a few percent content of water gives you a meaningful amount," he says. That's not only sustenance for people but potentially also a source of rocket fuel, because water can be electrolyzed to make hydrogen and oxygen, which rockets can burn.

Binzel adds that the beauty of human missions to near-Earth asteroids is that "you can do them on timescales of weeks to months, whereas a human mission to Mars might take two years." So these targets provide a chance to test out many of the relevant systems, "with a faster return to Earth in the event something goes wrong."

Attempts to identify the best targets for human missions, especially a search led by Brent Barbee (NASA Goddard Space Flight Center), have combed through all known near-Earth asteroids for those with the best combination of orbital characteristics to make for both an efficient round trip and long-term radio communication with Earth. Unfortunately, the two best candidates turned out to be temporary mini-moons that were discovered just as they were leaving the parts of their orbits that would be best suited for such a mission.

"As we survey," Binzel says, "we will find objects that are quite ideal. The more we survey for asteroids that are near the Earth, the more likely we're going to find the perfect one wandering by, and we'll be able to find it decades before it makes its best wander near the Earth. That will give us enough time to plan a mission."

So in the coming years, after humans have returned to the Moon itself, the very next step in our exploration of the solar system might turn out to be a mission to a "moon" of a whole different kind.

LEAH TISCIONE / *S&T*

■ **DAVID L. CHANDLER** is a longtime science writer and author who covers space and astronomy.

1 DUSK: Face west-southwest to see the waxing crescent Moon hanging some 2° lower left of Venus. Follow the pair as it grows more conspicuous in deepening twilight. Turn to page 46 to read more on this and other events listed here.

6 EVENING: High in the south the Moon, one day past first quarter, is in Taurus about 5° above Jupiter, with Aldebaran anchoring a ragged line.

9 DUSK: Look east to see the waxing gibbous Moon, Mars, and Pollux forming a delightful, flat isosceles triangle in Gemini, with sides of about 2½°. Viewers in northeasternmost Canada, Greenland, most of the Nordic countries, and much of Russia will see the Moon eclipse the Red Planet.

12 EVENING: The full Moon and Regulus, Leo's brightest star, rise in the east with a mere 1½° between them. Follow the pair as they climb higher in the sky.

16 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:02 p.m. PST (see page 50).

17 MORNING: Face south to see the waning gibbous Moon 1° right of Spica, Virgo's lucida. The duo sinks toward the southwestern horizon as the rising Sun brightens the sky.

19 EVENING: Algol shines at minimum brightness for roughly two hours centered at 8:52 p.m. EST.

21 MORNING: The waning crescent Moon accompanies Antares, the fiery heart of the Scorpion, as they rise above the southeastern horizon separated by only 1°. The pair remains close through the dawn hours.

24 DUSK: Look low in the west-southwest to spot Mercury and Saturn less than 1½° apart shortly after sunset. Find a clear, long view to the horizon to enjoy this sight.

28 DUSK: The thinnest sliver of the Moon, just past new, is 3° below Mercury low in the west-southwest. Venus blazes above. You'll need binoculars to spot the lunar crescent.
—DIANA HANNIKAINEN

▲ The reflection nebula M78 in Orion is one of several pretty objects you can observe during winter months. Turn to page 20 for full details.
MAKIS PALAIOLOGOU / STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY

FEBRUARY 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	

FIRST QUARTER

February 5
08:02 UT

FULL MOON

February 12
13:53 UT

LAST QUARTER

February 20
17:33 UT

NEW MOON

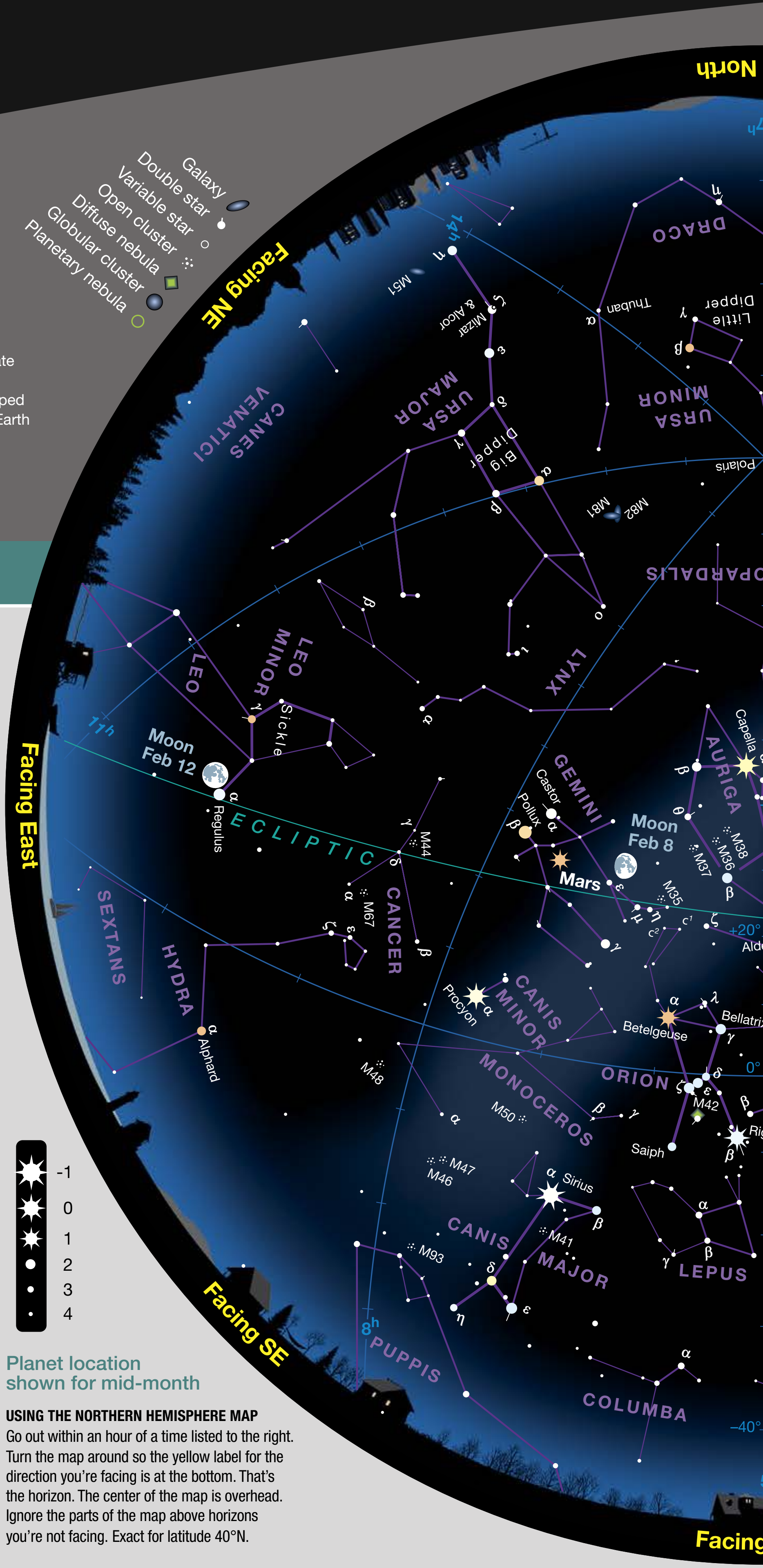
February 28
00:45 UT

DISTANCES

Perigee	February 2, 3^h UT	
367,457 km	Diameter 32′ 31″	
Apogee	February 18, 01^h UT	
404,882 km	Diameter 29′ 31″	

FAVORABLE LIBRATIONS

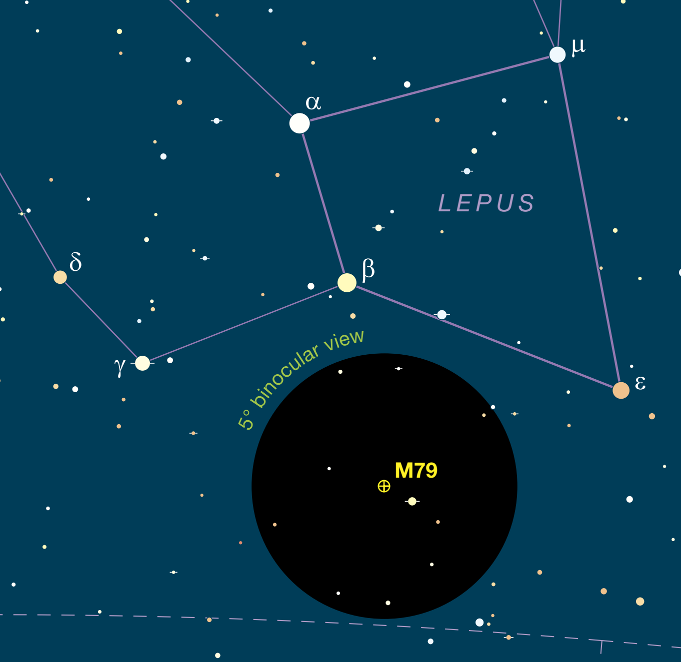
- Gill Crater — February 5
- Pontécoulant H Crater — February 8
- Hamilton Crater — February 12
- McLaughlin Crater — February 23



Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

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



Binocular Highlight by Mathew Wedel

Down the Rabbit Hole

I have a sneaking fondness for "sidekick" constellations — ones that might get overlooked in favor of their more famous and alluring neighbors. The small constellation Lepus, the Hare, might be the canonical sidekick constellation, crouching at the feet of mighty Orion, the Hunter. But this celestial rabbit deserves a closer look.

Start in the center of the constellation with the 3rd-magnitude stars Alpha (α) and Beta (β) Leporis and trace the line from Alpha through Beta an additional 4¼° south-southwest from Beta. The first thing that catches your eye will likely be 5.3-magnitude HD 35162. About ½° to the northeast you should spot the 8th-magnitude glow of the globular cluster **M79**.

Visually, M79 isn't going to knock your socks off. But it's conceptually fascinating. Some professional astronomers posit that M79 is an extragalactic globular, native not to our galaxy but rather to the controversial Canis Major Dwarf Galaxy. Other astronomers argue that there is no such dwarf galaxy, just a dense patch in the Milky Way's disk. So M79 is not just out in the galactic boondocks; it's also on the frontier of astronomical science.

While you're out there, have a look at 3.6-magnitude Gamma (γ) Leporis, about 5° northeast of M79. The brighter primary is a yellow main sequence star just a little larger than our Sun. Even 7× binoculars should easily reveal its 6.3-magnitude companion 96″ to the north. This is AK Leporis, which shares the same proper motion as Gamma and may be part of a double or multiple star system with it. True binary or not, the two make a charming binocular pair and are a useful reminder that even nearby stars — they're only 29 light-years away — can still hold plenty of secrets.

■ When he's not out stargazing, **MATT WEDEL** has a sneaking fondness for terrestrial rabbits, too.

WHEN TO USE THE MAP

Late Dec	11 p.m.
Early Jan	10 p.m.
Late Jan	9 p.m.
Early Feb	8 p.m.
Late Feb	7 p.m.

These are standard times.

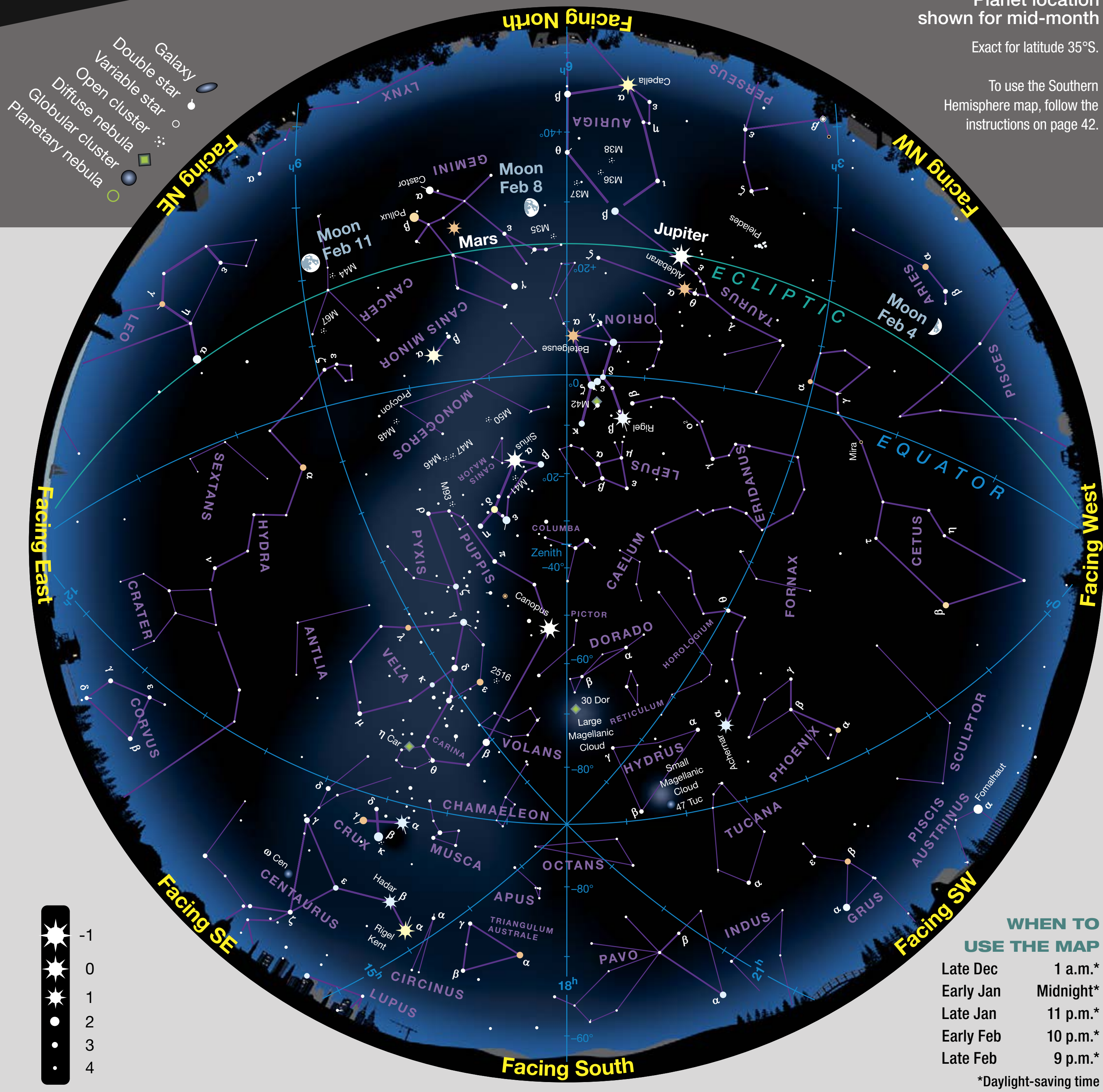
Southern Hemisphere Sky Chart

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 Dec	1 a.m.*
Early Jan	Midnight*
Late Jan	11 p.m.*
Early Feb	10 p.m.*
Late Feb	9 p.m.*

*Daylight-saving time

NESTLED BETWEEN the southern Milky Way and the Large Magellanic Cloud is the constellation **Volans**, the Flying Fish. Initially it was known as Piscis Volans, but its name was shortened in the mid-19th century at the suggestion of famed British astronomer John Herschel.

Looking at the chart above, the rightmost point is Gamma (γ) Volantis, the constellation's brightest light. To the naked eye it appears to be a single star, but it's actually a binary system made up of the yellowish Gamma[1] (magnitude 5.6) and the orange giant Gamma[2] (3.7).

In a straight line to the left of Gamma is Epsilon (ε), another seemingly single star that is in fact a quadruple system made up of two binaries! The brightest of its four stars — the one we see — is a bluish giant of magnitude 4.4. ■

The Invisible Wonder of Perseus

You don't need a telescope to see a remarkable cluster hidden in plain sight.

On February evenings, one of the most unnoticed star clusters in the night sky shines high overhead. Using this month's all-sky chart on pages 42–43, locate the constellation Perseus, the Hero, just west of the *zenith* — the point in the sky directly overhead. Look closely at Alpha (α) Persei. See how it's centered within a tiny isosceles triangle of three dim suns? Now zoom out a bit to include the three brighter stars trailing Alpha to the southeast. These two naked-eye gatherings are not a chance alignment; rather, they belong to a larger swarm of stars comprising the Alpha Persei Cluster (also known as the Alpha Persei Association) — a loose system of nearby young, hot suns, co-moving in space.

▲ Would a cluster by any other name look as sweet? The collection of stars near Alpha (α) Persei (the brightest star in this photo) is variously known as the Alpha Persei Cluster, Alpha Persei Association, Alpha Persei Moving Group, Melotte 20, and Collinder 39.

ALAN DYER

A wider view of the region reveals that the Alpha Persei Cluster lies within the hazy band of the winter Milky Way. In his classic poem *Phaenomena*, 3rd-century BC Greek poet Aratus recorded the sight metaphorically in his discussion of Perseus: ". . . he greatly strides, dust-stained, in the heaven of Zeus." The stain here is the unresolved swath of minute stars that comprise the Milky Way's Perseus Arm — one of two major arms that spiral off the ends of our galaxy's central bar.

Recent estimates place the group about 580 light-years distant. With an age of only 90 million years, the cluster's stars were born around the time when dinosaurs still roamed Earth.

The very closeness of this little gaggle of stars is, in part, why its status as a deep-sky object is so easy to overlook. While the cluster's members collectively shine near 1st magnitude, that figure is essentially meaningless because the group's light is spread out over 5° — 10 times the apparent diameter of the full Moon. That makes it one of the largest open clusters in the sky. Its core is centered on 1.8-magnitude Alpha Persei, officially known as Mirfak. This yellow-white supergiant star, 65 times larger and eight times more massive than our Sun, belongs to yet another fascinating galactic structure: Gould's Belt.

A giant ring of stars, Gould's Belt was first noted by English astronomer John Herschel in 1847. But recognition went to American astronomer Benjamin Gould, who, in 1879, traced the 2,400- by 1,500-light-year-wide structure in its entirety as a collection of bright and massive stars inclined 20° to the plane of the Milky Way. Gould's Belt includes many *OB* associations — low-density groups of young stars that are dispersing from their birthplace into their galactic surroundings like people exiting a subway station at street level. Mirfak and the Alpha Persei Cluster form the heart of the Perseus OB 3 Association.

Visually, the Alpha Persei Cluster has about 50 members. If you are under a dark country sky, far from big-city light pollution, it's possible to see about a dozen of them within 2° of Mirfak shining at magnitude 6 or brighter. Take your time, though. With a glance using direct vision, the region around Mirfak may simply appear luminous. To see its fainter attendants, you'll need to use averted vision.

By the way, in her 1942 book *Mythology*, Edith Hamilton tells us that the myth of Perseus is the only one in which magic plays a decisive part. She is referring to the three gifts given to the Hero while on his quest to slay the gorgon Medusa: winged sandals, a magic wallet, and a cap that made its wearer invisible. Perhaps it's this third gift that explains why the Alpha Perseus Cluster escapes our gaze so easily.

■ 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 Heavenly Polygon

The Moon, Jupiter, and Mars add luminosity to the Winter Hexagon.

SATURDAY, FEBRUARY 1

The month gets off to a glorious start. Face west-southwest at dusk to see a beautiful isosceles triangle that includes the **Moon**, **Venus**, and **Saturn**. The waxing lunar crescent is positioned just a bit more than 2° left of the Evening Star — a conjunction eye-catching enough that even your non-astronomical friends and neighbors are sure to notice. It's definitely a sight you don't want to miss.

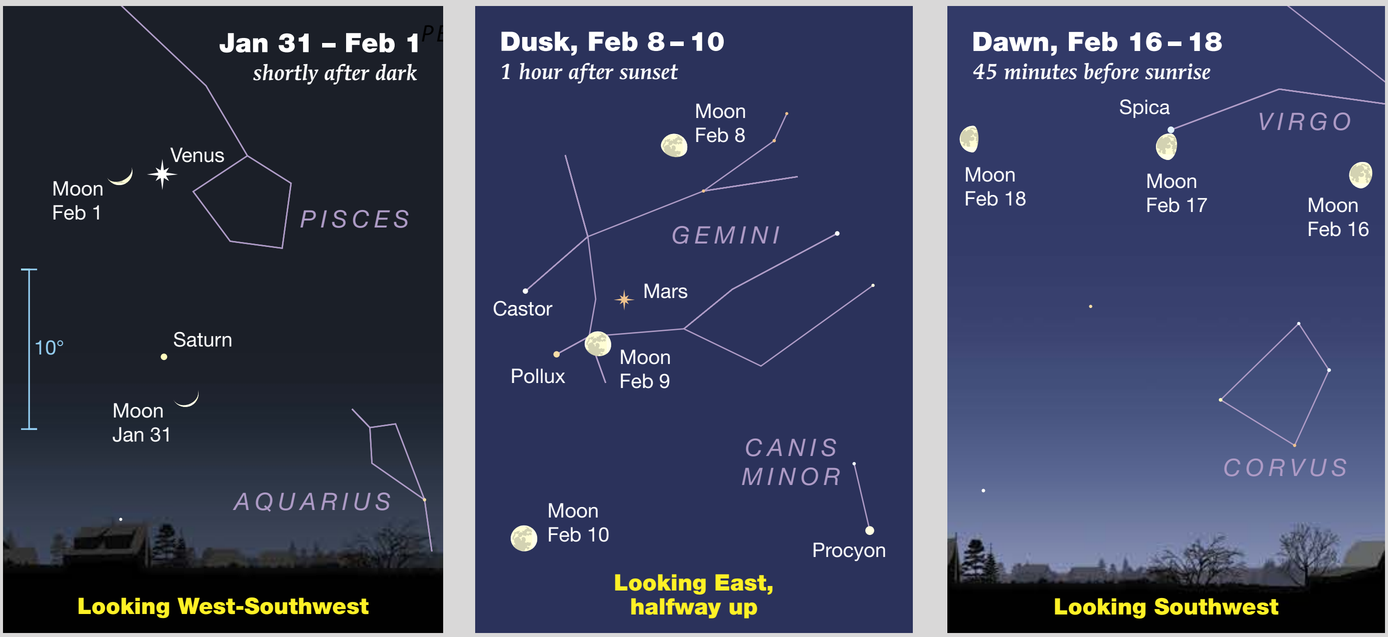
The Moon has just one more encounter with Venus before the planet's current evening apparition concludes — and that pairing (on March 1st) won't be nearly as tight or dramatic. After that, you (and your friends and neighbors) will have to wait until February 2026 for the next set of dusk Venus–Moon conjunctions to begin. And for observers in the Americas, none of 2026's meet-ups will be as close as the one this evening.

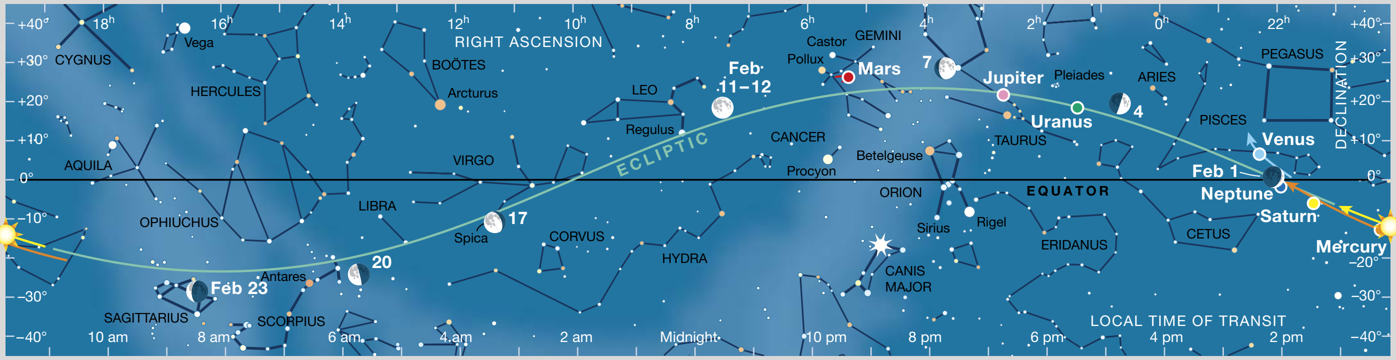
The tip of tonight's triangle is so much fainter than the other two points that it'd be easy to overlook. Poor Saturn glows at magnitude 1.1 — a far cry from Venus's magnitude –4.8 glare. The Ringed Planet is growing more and more difficult to see each night as it drifts sunward on its way to its solar conjunction next month. By the 23rd Saturn will be all but impossible to see without optical aid — another reason to soak up the sight this evening. The clock is ticking for Venus, too. It reached its greatest altitude for its current apparition on January 29th and will follow Saturn into the Sun's glare next month.

SUNDAY, FEBRUARY 9

One of the month's most arresting sights is this evening's gathering in Gemini. As darkness falls, cast your gaze towards the southeast and enjoy the sight of the waxing gibbous **Moon** keeping company with **Mars** and Gemini's brightest stars, **Castor** and **Pollux**. All this luminosity is confined to a span of sky less than 6° across. Depending on when you look, the Moon is roughly 2° from Pollux and 4° from the Red Planet. Now, expand your view a bit to take in the Winter Hexagon, along with these temporary additions. The Hexagon is traced by connecting the bright stars

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





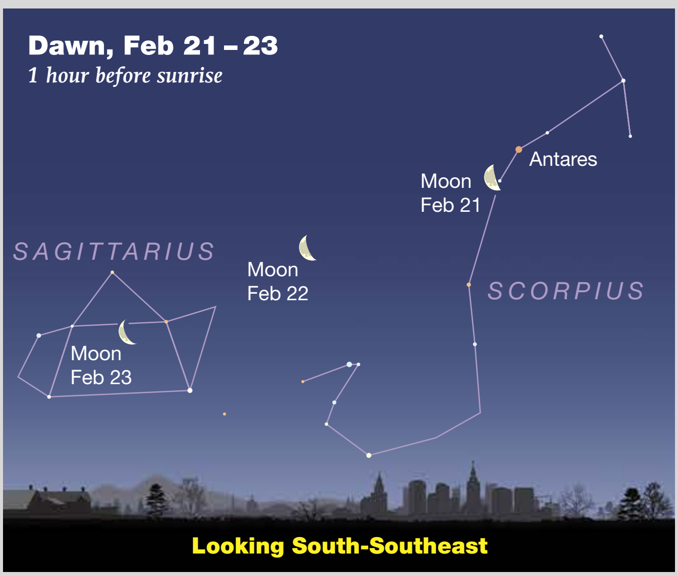
▲ The Sun and planets are positioned for mid-February; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" 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.

Capella (in Auriga), Aldebaran (Taurus), Rigel (Orion), Sirius (Canis Major), Procyon (Canis Minor), and Pollux. The six-sided shape is enhanced for the next while with the presence of Jupiter and Mars as well as the Moon this night.

If you continue watching the Moon as the night of the 9th becomes the morning of the 10th, you'll get to see it line up neatly with Castor and Pollux for a three-in-a-row configuration as they set in the west-northwest during morning twilight.

FRIDAY, FEBRUARY 21

The **Moon's** never-ending eastward march carries it past a few bright stars, including **Regulus** (in Leo) on the evening of the 12th, and **Spica** (Virgo) on the morning of the 17th. But its most interesting stellar encounter takes place on the 21st, when it rises in the predawn hours less than 1° below **Antares** — Scorpius's leading light. As the sky grows lighter, the waning lunar crescent drifts away from Antares and toward nearby Tau (τ) Scorpii, one of the two stars — along with 3rd-magnitude Sigma (σ) Scorpii — that flank Antares. Tau shines at magnitude 2.8, so it stands up to moonlight reasonably well. Indeed, if you want the best view, get out your binoculars — Tau, the Moon, Antares, and Sigma neatly fit into a single field of view. If you continue watching, the Moon passes just north of Tau. But if you're located near the Great Lakes in North America, you'll even get to see the star eclipsed by the Moon's bright limb at dawn — an event best viewed with binoculars or a telescope.



SUNDAY, FEBRUARY 23

Tonight, **Mars** reaches a significant point in its current apparition when it ceases its westward drift (*retrograde motion*) and starts heading eastward (*direct motion*) — something it will continue to do for nearly two years. At first this change in direction will be hard to detect, but thankfully it happens with the Red Planet positioned near two conspicuous, stationary markers: Castor and Pollux, which will make seeing its movements quite a bit easier. Mars quickly picks up steam, and by month's end its nightly progress is more obvious.

MONDAY, FEBRUARY 24

If you're up for a challenge (and have your binoculars at the ready), dusk presents an opportunity to see a pair of planets very close together. The planets in question are **Mercury** and **Saturn**. They're heading in opposite directions — Mercury is ascending to greatest elongation in less than two weeks, while Saturn is losing its fight against twilight as it descends toward its March solar conjunction. This evening, the two worlds meet low in the west-southwest. To see either one, you're going to need an unobstructed horizon and very clear conditions. For some idea about what you're up against, know that the planets are only a bit more than 5° up half an hour after sunset. This is not a conjunction for the faint of heart! Mercury will be the easier target, shining brightly at magnitude –1.2. Just 1½° to its left, you'll find Saturn glowing at magnitude 1.1 — some eight times fainter. Good luck!

■ Consulting Editor **GARY SERONIK** enjoys horizon-hugging observing challenges from his British Columbia home.

More 2025 Comet Prospects

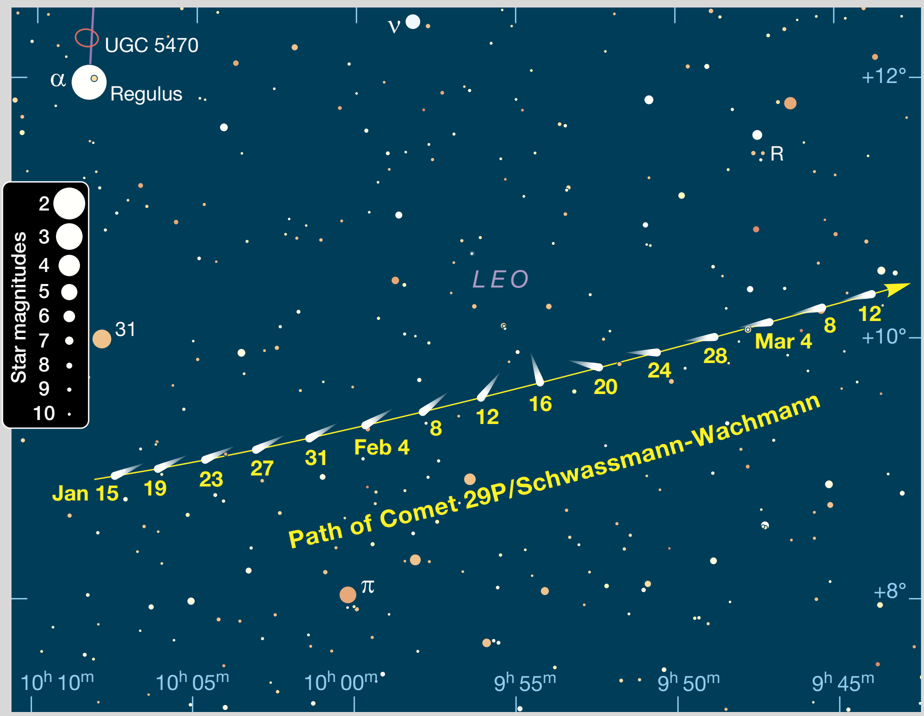
A modest collection of faint, icy visitors awaits enthusiasts.

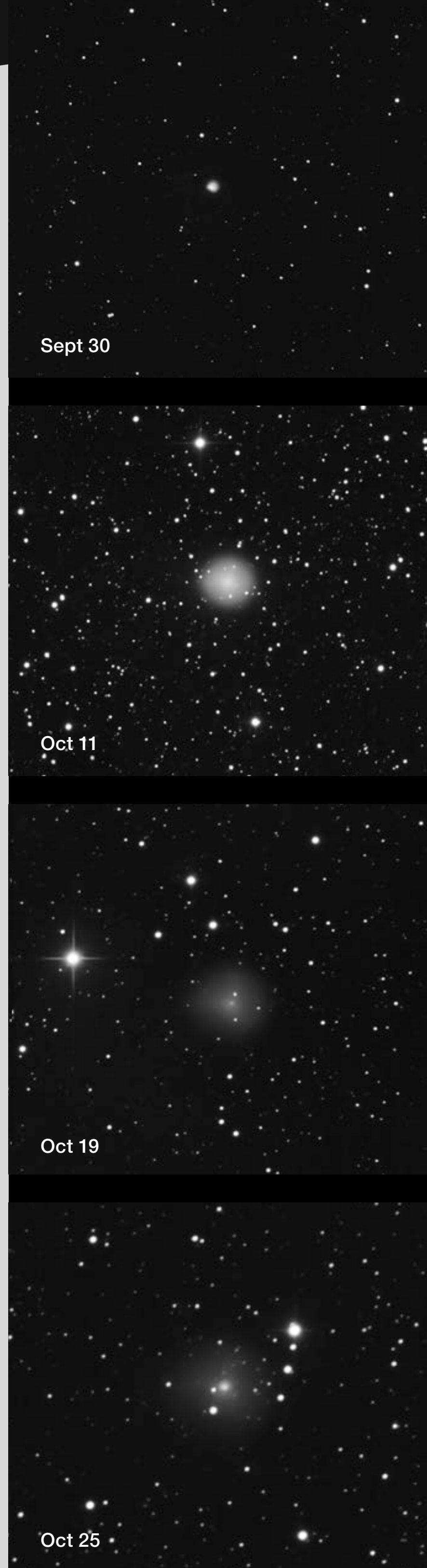
After the recent happy run of comets that included 12P/Pons-Brooks, 13P/Olbers, and Tsuchinshan-ATLAS (C/2023 A3), the remainder of 2025 offers slim pickings. So far, no comets are expected to grow brighter than 8th magnitude this year, and the brightest aren't at their best until November and December. Comet 210P/Christensen may briefly reach 9th magnitude from late November through early December low in the eastern sky at dawn. Comet Wierzchos (C/2024 E2) will achieve a similar brightness low in the west at dusk during the same timespan.

Only returning Comet 24P/Schaumasse will be well placed for easy viewing from mid-November through year's end, brightening from magnitude 10 to 8 as it treks eastward from Cancer to Coma Berenices.

But before you hang your head in sorrow, there's one comet visible almost every year in scopes as small as 6-inches aperture: Comet 29P/Schwassmann-Wachmann. German astronomers Arnold Schwassmann and Arno Wachmann discovered the object photographically in November 1927. Non-native speakers may hesitate to say the comet's name out loud for fear of mangling the pronunciation and instead opt for the simpler "29P" appellation. But why not try? SCHVASS-mahn VAKH-mahn. There, that wasn't so bad, was it?

The comet comes to opposition in February just a few degrees west of Regulus, Leo's brightest star. The icy object orbits between Jupiter and Saturn at an average distance of 6 astronomical units and glimmers around magnitude 16. Normally, amateurs wouldn't





▲ This image sequence by Eliot Herman records a bright outburst from Comet 29P/Schwassmann-Wachmann that occurred from late September through October 2021. Dusty material erupted from the nucleus appears as a tiny, bright knot in the first frame that gradually expands and fades over the course of several weeks.

bother with such a faint object. However, approximately seven times per year, 29P undergoes sudden outbursts that can catapult it to as bright as magnitude 10 when it becomes a dense, hazy ball, bright enough to be spotted in smaller telescopes.

At the start of each eruption, 29P may appear just a few arcseconds across and mimic a fuzzy star. Night by night the coma expands and fades until it dims to near invisibility within a couple weeks. Then, when you least expect it, another eruption brings it back to life. Outbursts occur throughout the comet's apparition and vary from minor to strong.

Some periodic comets return frequently, such as 2P/Encke, which has an orbital period of 3.3 years. In a lifetime of observing, you might see it a dozen times. But if you routinely observe 29P/Schwassmann-Wachmann, you'll witness at least one flare-up each year. Before long, this remote object may top your most-frequently-observed comets list.

Comet 29P is a member of a class of icy minor planets called Centaurs that orbit between Jupiter and Neptune. Only a few brighten to within reach of amateur instruments. In the forbidding cold of the outer solar system, you might expect the comet to be frozen to its core and inactive, but the approximately 60-kilometer-wide object is anything but quiet. Instead, multiple cryovolcanic eruptions routinely rock its surface.

Many of its outbursts occur once about every 58 days, which may be related to the comet's putative rotation period. Richard Miles, managing director of the British Astronomical Association's Asteroids and Remote Planets Section, postulates that the brightening is from subsurface cryomagma that erupts from cryovolcanoes. Methane and carbon monoxide, under pressure beneath the comet's crust, melt, mix, and release energy that ruptures the surface, which has been softened by the Sun's heat. Illuminated by sunlight, the fresh dust expelled by these eruptive episodes radiates brightly.

If you check in on 29P every clear night, you might be among the first to see a new outburst.

BOB KING

▲ On September 22, 2024, the waning gibbous Moon worked its way across the Pleiades, occulting several of the brightest cluster stars in the process. Skywatchers have many opportunities in the next few years to see the Moon hide each member of the cluster.

The Moon Crosses the Pleiades

THE CURRENT Pleiades occultation series began on September 5, 2023, and continues through July 7, 2029. It sees the Moon eclipsing parts of the beloved Taurus star cluster somewhere on Earth once every lunar cycle. Typically, occultations are single events involving just one star, but during a Pleiades passage we might get to see a half dozen or more stars disappear and reappear over the course of a couple hours.

On the night of February 5–6, skywatchers across the western two-thirds of the U.S. (including Alaska), most of Canada, and eastern Russia can watch the dark limb of the 60%-illuminated waxing gibbous Moon creep across the cluster. While binoculars might suffice for seeing the brightest member (2.9-magnitude Alcyone) blink out, a telescope is a better choice.

From Kansas City, Missouri, in the wee hours of the 6th, observers can see the Moon occult Electra (magnitude 3.7), Celaeno (5.5), Merope (4.2), and Alcyone at about 1:22 a.m., 1:36 a.m., 1:57 a.m., and 2:20 a.m. CST, respectively, before the Moon sets at 2:30 a.m. Farther west the cluster stands higher in the sky, so more stars will be occulted before moonset. Seattleites, for example, will see the Moon hide no fewer than seven Pleiads between 11:04 p.m. PST (February 5th) and 12:59 a.m. PST (February 6th).

You can easily simulate the occultation for your specific location using an app such as *Stellarium* or *SkySafari*. Set the date and step through the time using the clock feature. To plan your observing session, note which stars the Moon covers and when.

The brighter Pleiads are located roughly 4° to 4.5° north of the plane of the ecliptic. Since the Moon's orbit is inclined 5.1° to that plane, it can only pass in front of the cluster when the northern portion of its orbit brings it within reach of the cluster. Because the lunar orbital plane precesses westward, the occultation window is limited to six years per series. After 2029 the Moon passes south of the Pleiades until the next round begins in 2042. With so many potential opportunities at hand, it's a fun and achievable goal to see each one of the Seven Sisters occulted.

Zodiacal Light Nights

THE SOLAR SYSTEM'S salt and pepper — spent comet dust, crumbs from asteroids, and even dust from Mars — all contribute to the gritty granularity of the zodiacal light. From Earth, the trillions of tiny grains (sized from 0.001 mm to 0.300 mm) look like the myriad distant stars of the Milky Way scrunched together into a luminous haze. In truth, however, each zodiacal-light particle is spaced several kilometers from the next.

From about February 13 to 22, when the Moon is absent from the evening sky, Northern Hemisphere observers get to see the zodiacal light at its best. The wedge-shaped glow is broadest and brightest at its base near the western horizon. From there it gradually tapers and becomes more and more attenuated with altitude. Under exceptionally dark skies, the wedge narrows to a cone that extends high into the southern sky and continues eastward as the extremely faint *zodiacal band*.

The zodiacal light is named for the *zodiac*, the belt of sky centered on the ecliptic. The dust that produces the glow is concentrated in a pancake-like disk that extends out to beyond the orbit of Mars. From February through April, the ecliptic meets the western horizon at dusk at a steep angle, tipping the zodiacal light into good view for observers at mid-northern latitudes.

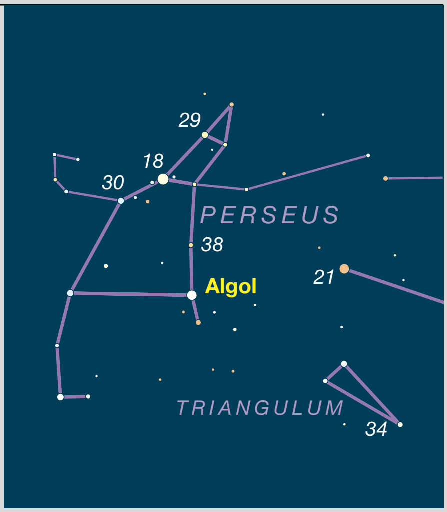
The bottom of the cone measures about 20° across near its base, while its apex reaches altitudes of 45° to more than 80°, depending on sky conditions. Since the zodiacal light follows the ecliptic, it slants southward like a wispy Leaning Tower of Pisa.

Look for the ghostly glow towering in the west starting about 90 minutes after sunset. It slowly sinks in the west over the next 90 minutes.

Minima of Algol

Jan.	UT	Feb.	UT
2	7:53	2	20:55
5	4:42	5	17:45
8	1:31	8	14:34
10	22:21	11	11:24
13	19:10	14	8:13
16	15:59	17	5:02
19	12:49	20	1:52
22	9:38	22	22:41
25	6:27	25	19:30
28	3:17	28	16:20
31	0:06		

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 is conveniently positioned at the zenith during evening hours in February. 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).

Action at Jupiter

JUPITER IS NOW solidly an evening-sky target, transiting the meridian on the 1st of the month about 2½ hours after sunset. That means it's at its best at a convenient hour for most observers. By the time midnight rolls around, Jupiter's altitude has dropped from its maximum of 72° to about 35°, for those at mid-northern latitudes. By the end of February, the planet transits just a few minutes after sunset. During the month, the Jovian disk shrinks slightly from 43.4″ to 39.7″ while it dims imperceptibly from magnitude –2.5 to –2.3. The bottom line is this shortest month of the year is a fine one for training your telescope on the solar system's most dynamic planet.

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

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Standard Time is UT minus 5 hours.)

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

27: 3:22, 13:18, 23:13; **28**: 9:09, 19:05; **29**: 5:00, 14:56; **30**: 0:52, 10:48, 20:43; **31**: 6:39, 16:35

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

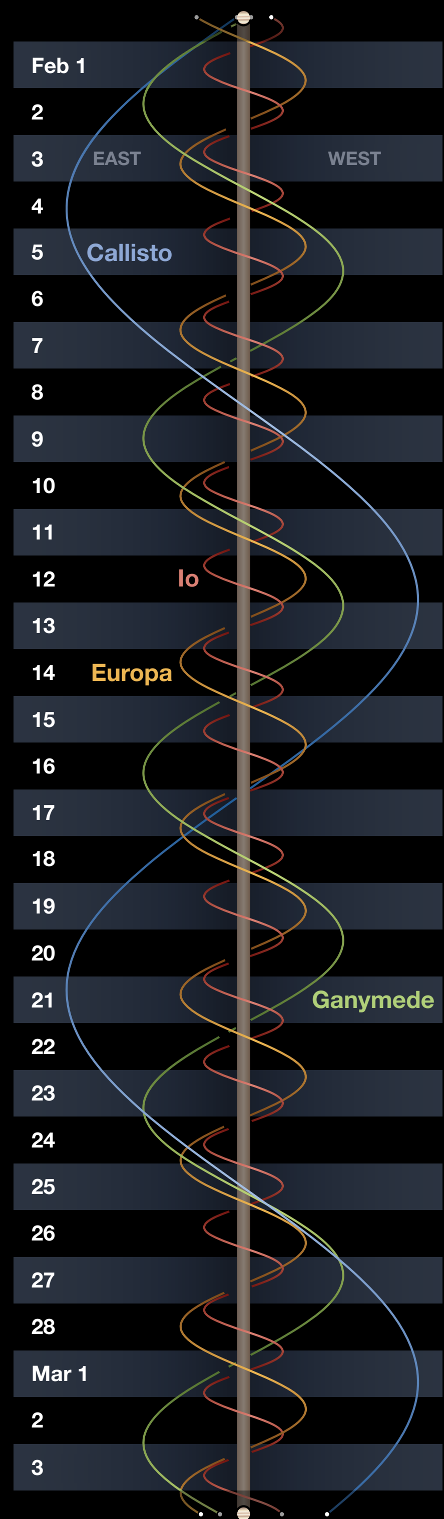
These times assume that the spot will be centered at System II longitude 69° on February 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 69° and $1\frac{2}{3}$ minutes later for each degree more than 69°.

Phenomena of Jupiter's Moons, February 2025

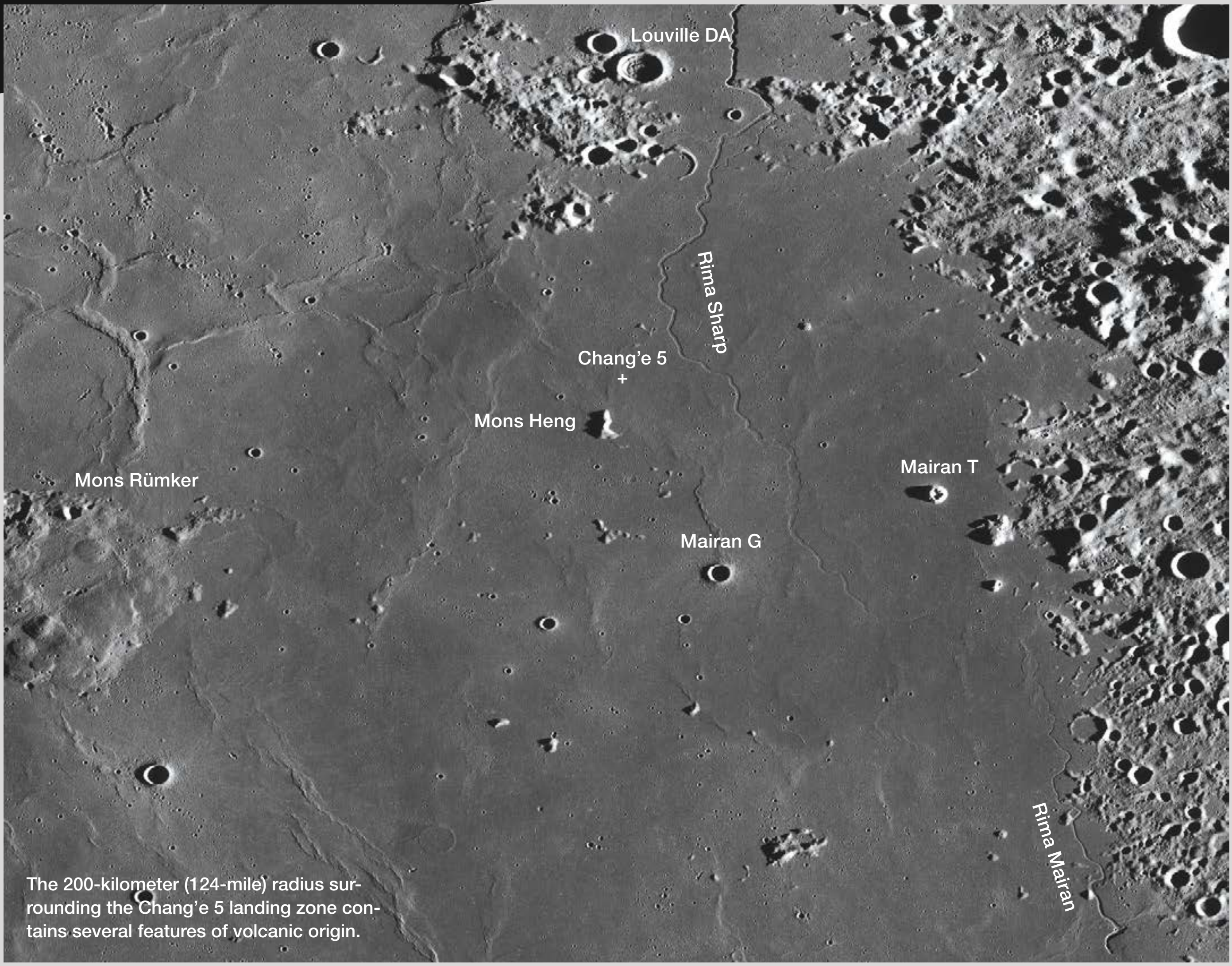
Feb. 1	0:15	II.Tr.E
	2:31	I.Oc.D
	2:32	II.Sh.E
	5:52	I.Ec.R
	23:41	I.Tr.I
Feb. 2	0:50	I.Sh.I
	1:53	I.Tr.E
	3:02	I.Sh.E
	15:58	II.Oc.D
	20:58	II.Ec.R
	20:59	I.Oc.D
Feb. 3	0:21	I.Ec.R
	18:09	I.Tr.I
	19:19	I.Sh.I
	20:21	I.Tr.E
	21:31	I.Sh.E
Feb. 4	1:56	III.Tr.I
	4:10	III.Tr.E
	6:40	III.Sh.I
	9:01	III.Sh.E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

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

Jupiter's Moons



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



The 200-kilometer (124-mile) radius surrounding the Chang'e 5 landing zone contains several features of volcanic origin.

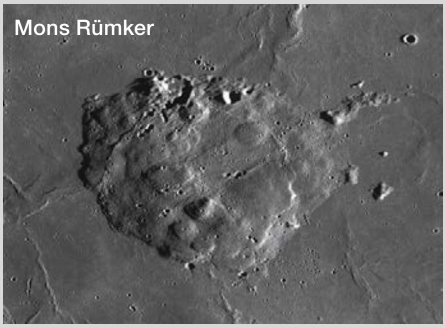
Possible Origins for Young Volcanics

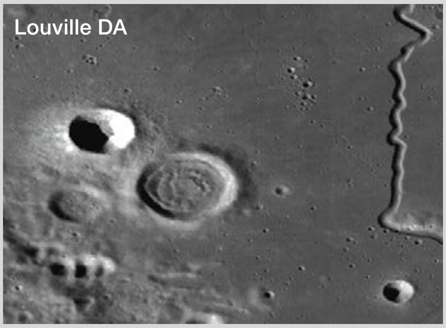
China announces evidence of recent lunar eruptions. So where did they originate?

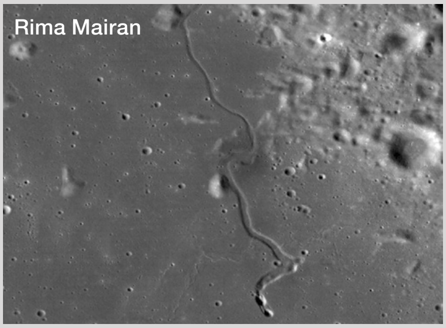
Analysis of samples returned by the Apollo missions established that the Moon experienced a period of widespread volcanism from about 4 to 3 billion years ago. Crater-count estimates of unsampled regions suggested that some mare volcanism continued until around 2 billion years ago and perhaps as recently as 1 billion years ago. These same estimates show that most volcanism younger than 3 billion years took place in northern **Oceanus Procellarum**. In 2020, China's Chang'e 5 mission returned rock samples to Earth from lava flows 175 kilometers (110 miles) northeast of the volcanic dome complex **Mons Rümker**. The samples confirmed the crater-count age for the lava flows.

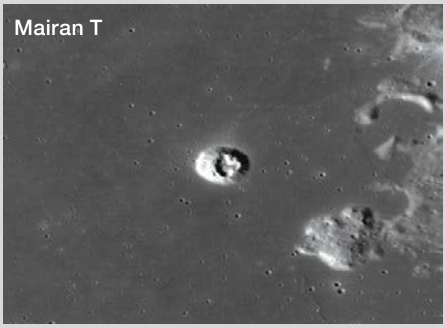
Comprehensive analyses of hair-thick glass beads in the samples reveal that explosive volcanism occurred somewhere near the Chang'e 5 site as late as 120 million years ago. This finding was totally unexpected because the heat sources that drive eruptions were assumed to have largely cooled long before that time.

Glass beads are common on the Moon, being formed by high-energy events that melt tiny blobs of regolith, which quickly cool. The energy can come from an impact event that pulverizes and melts target rocks, or from explosive volcanic eruptions of molten lava. Impact-formed beads occur everywhere on the Moon because impacts do, but volcanic glass beads typically occur within dark-mantle, pyroclastic deposits like those seen just south of **Sinus Aestuum**. Frustratingly, impact and volcanic glass beads are nearly identical, and Wen









Wang of the Chinese Academy of Sciences, Beijing, and colleagues painstakingly examined some 3,000 glass beads, identifying only three of volcanic origin by their unique sulfur isotopes.

As with all planetary exploration missions, Chang'e 5 discovered several important new facts about the Moon, with the evidence for volcanism 120 million years ago being the most astounding. Clever petrologists and thermal modelers may discover ways to explain very young lunar volcanism (or to offer non-igneous origins for the "volcanic" beads). But if not, this finding will provoke significant revisions to standard lunar thermal modeling, which is what good science does.

So where are the source vents of these beads? Explosive pyroclastic eruptions produce ash and glass beads that are often dark and distinct even 3 billion years later. Eruptions from merely 120 million years in the past should have conspicuous sources and deposits, but since only 3 out of 3,000 beads are volcanic, the source may have been small or far away from where Chang'e 5 set down.

The area is rich with volcanic formations. The spacecraft landed on mare basalt lavas, sample-dated at 2 billion years, which the Chinese scientists interpret as coming from **Rima Sharp**, located about 15 km away. About 165 km to the west-southwest of the landing site is the aforementioned Rümker volcanic dome complex; 100 km to the landing site's north is the 11-km diameter **Louville DA** concentric crater, and the steep-sided, caldera-topped volcanic cone of **Mairan T** (6.5 km diameter) is only 90 km to the east. Each of these volcanic features conceivably could have been a source of Chang'e 5's glass beads, but crater counting indicates all have ages measured in billions rather than hundreds of millions of years. Additionally, none has conspicuous dark-mantle deposits, which could mark source areas for the beads. Darn!

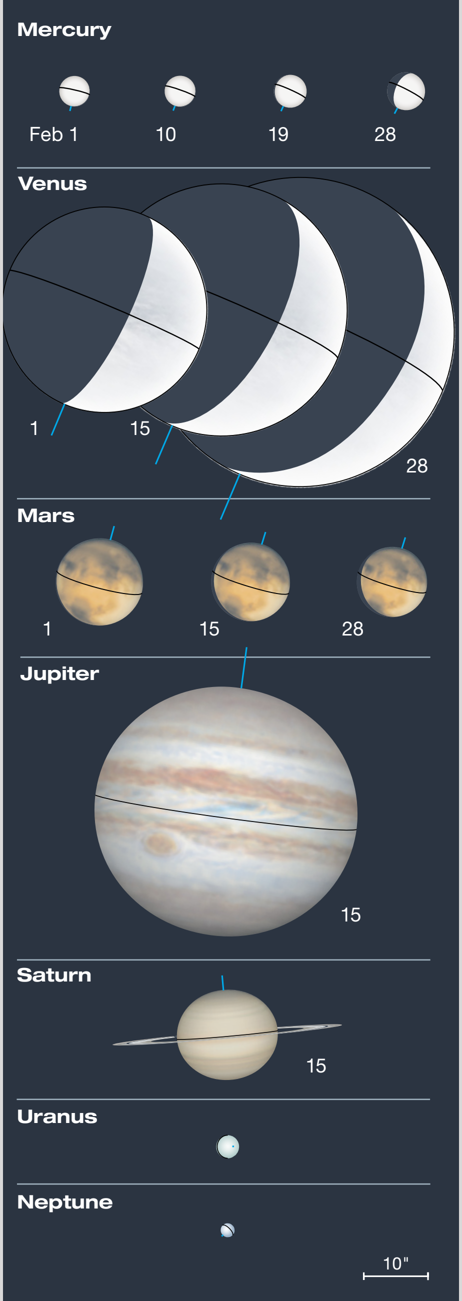
In 2021, three years before the volcanic beads were identified, Yuan Chen and colleagues from the Chinese Academy of Sciences expected that some of the glass beads could be the result of gas-rich explosive volcanism. They found one potential source, **Rima Mairan**, 220-km southeast of the Chang'e 5 landing site. The evidence for explosive volcanism consists of three dark-mantle deposits (DMDs); a dozen or so irregular mare patches (IMPs) 10 to 100 meters wide; very young-looking irregular depressions; and one shallow, rimless depression. Yuan Chen's team cited stratigraphic evidence that the very small DMDs were likely to be 1 to 2 billion years old. They argued that the rimless depression could be a volcanic pit but provided no evidence that it was younger than the estimate. The IMPs are the most intriguing potential link to 120-million-year-old volcanic beads because there's no agreement of the origin or age of IMPs. Some scholars consider IMPs to be tens to hundreds of millions of years old, while other experts believe they are billions of years old.

The tiny features near the vent of Rima Mairan may have formed explosively and contain volcanic beads, but there's no compelling evidence that it's very young, nor is there a means of transporting the beads 200 km away. Based on the older ages of the larger volcanic landforms within 100 kilometers of the landing site, as well as the uncertain ages of the small volcanic features near Rima Mairan, there's no obvious nearby source for the volcanic glass beads.

You may want to observe the areas described here because Chang'e 5 was a recent mission to an unvisited sector of the Moon, and its discovery of very young volcanics evokes fundamental questions about the Moon's thermal history. The landing site itself isn't easily identifiable but is found just north of the L-shaped, 10-km-long hill recently named **Mons Heng**. Mons Rümker is the most identifiable volcanic feature, and the narrow Rima Sharp is distinctive when a rising Sun creates a line of black shadow. Concentric crater Louville DA is large enough to see in amateur telescopes, but its inner-ring of ball-like hills is unlikely to be clearly resolved, as is the same for the summit collapses of the Mairan T volcanic cone. The volcanic features near the start of Rima Mairan are too small to be identified, but you may wish to hunt for other possible volcanic bead sources along the entire 350-km length of the combined Mairan-Sharp rilles.

■ Contributing Editor **CHUCK WOOD** enjoys deciphering the visual clues that hint at the history of the Moon's formation.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk starting on the 21st • **Venus** visible at dusk all month • **Mars** visible at dusk and sets before morning twilight • **Jupiter** transits at dusk and sets in predawn • **Saturn** visible at dusk to the 22nd.



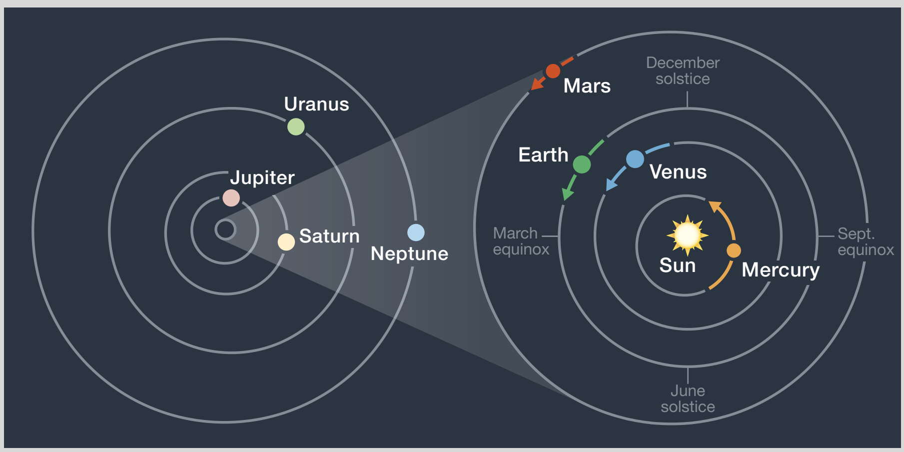
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

February Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$20^h 57.9^m$	–17° 11′	—	–26.8	32′ 28″	—	0.985
	28	$22^h 43.5^m$	–8° 05′	—	–26.8	32′ 18″	—	0.991
Mercury	1	$20^h 35.7^m$	–20° 41′	6° Mo	–1.0	4.8″	99%	1.412
	10	$21^h 38.3^m$	–16° 15′	2° Ev	–1.6	4.8″	100%	1.391
	19	$22^h 40.6^m$	–9° 54′	8° Ev	–1.4	5.1″	96%	1.308
	28	$23^h 38.9^m$	–2° 15′	15° Ev	–1.1	5.9″	79%	1.139
Venus	1	$23^h 46.3^m$	+0° 38′	45° Ev	–4.8	31.9″	38%	0.523
	10	$0^h 07.7^m$	+4° 29′	42° Ev	–4.8	36.3″	31%	0.459
	19	$0^h 22.3^m$	+7° 46′	38° Ev	–4.8	41.7″	24%	0.400
	28	$0^h 27.9^m$	+10° 07′	32° Ev	–4.8	48.0″	16%	0.348
Mars	1	$7^h 29.8^m$	+26° 08′	158° Ev	–1.1	13.7″	99%	0.684
	15	$7^h 16.8^m$	+26° 15′	141° Ev	–0.7	12.3″	96%	0.759
	28	$7^h 14.6^m$	+25° 56′	127° Ev	–0.3	11.0″	94%	0.854
Jupiter	1	$4^h 37.8^m$	+21° 36′	119° Ev	–2.5	43.4″	99%	4.543
	28	$4^h 41.6^m$	+21° 49′	93° Ev	–2.3	39.7″	99%	4.961
Saturn	1	$23^h 15.5^m$	–6° 53′	35° Ev	+1.1	16.0″	100%	10.411
	28	$23^h 27.1^m$	–5° 38′	11° Ev	+1.1	15.7″	100%	10.583
Uranus	15	$3^h 22.7^m$	+18° 18′	87° Ev	+5.7	3.6″	100%	19.576
Neptune	15	$23^h 54.9^m$	–1° 56′	32° Ev	+7.9	2.2″	100%	30.727

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**.

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



An Easy Moon Shot

This basic approach to lunar photography uses equipment you probably already have.

Capturing images of the Moon is a natural gateway into the world of astrophotography. It's a familiar sight — often gracing our sky, sometimes even during the day. We see it tracing our paths on highways or slipping between treetops. Twelve humans have walked on its surface, with more set to follow. Yet its proximity is only part of the allure. The Moon is a dynamic and ever-changing subject, constantly transforming as it orbits Earth. From a delicate crescent to a brilliant full disk, it reveals surface details with the shifting interplay of shadow and light.

Photographing the entire Moon in a single shot is a rewarding challenge that's distinct from trying to create wide-angle landscapes that include the Moon, or zeroing in on individual lunar features. And the best part? If you're into photography even a little, you likely already have everything you need to get started.

The Essential Gear

The most important piece of equipment is a DSLR or mirrorless interchangeable lens camera — any recent model will do for photographing the Moon.

Stability is crucial for sharp Moon photos. That means using a decent tripod with a good quality pan-and-tilt head or ball head. It also matters where you set up. You want a solid ground. Grass, concrete, or packed dirt are good, but skip wooden decks where even slight vibrations from footsteps can produce image-blurring camera shake. A little shake is an annoyance in visual astronomy, but it's a deal-breaker for astrophotography. In addition, a shutter-release cable or wireless remote is very handy, because any time you touch your camera you run the risk of introducing image shake.

▲ **CRESCENT DELIGHT** Illustrating that you don't need a lot of gear to capture an appealing Moon photo, the author captured this $1/125$-second exposure of the lunar crescent with a tripod-mounted Canon EOS Rebel T7 DSLR camera working at ISO 100 and a Canon 75-to-300-mm zoom lens set to 300 mm and f/7.1.

When it comes to the lens, it's the focal length that matters most since it impacts how big the Moon appears in your photo. Aim for a focal length of at least 200 to 250 mm. Longer is better, but the difficulty of getting

▲ **BASIC GEAR** *Left:* The author's basic Moon photography setup includes a Canon EOS Rebel T7 DSLR, Canon 75-to-300-mm zoom lens, ball head, and tripod. If you're into photography, chances are you already have similar equipment and are ready to take your own Moon shot. *Right:* Key to capturing sharp lunar photos is minimizing vibration by ensuring the camera's shutter is triggered remotely. You can use a wireless remote or a full-featured intervalometer like the one pictured here. Most cameras also have some kind of self-timer function that delays the shutter from firing for several seconds — long enough for vibrations to die down.

BLUE-SKY MOON This daylight shot of the waning lunar crescent was captured with a 1/250-second exposure made with a Canon Rebel T7 DSLR set to ISO 200, and a 75-to-300-mm lens zoomed to 300 mm and f/8. The Moon is one of the few targets available for a daylight astro-imaging session.

sharp images with a basic setup goes up with the focal length (more on this in a moment). Your camera's sensor size is also important. Many beginner and mid-range cameras use APS-C-size sensors, which are smaller than so-called full-frame models. This difference creates a *crop factor* that narrows your field of view, making the Moon appear bigger. For example, a Canon APS-C sensor has a 1.6× crop factor, so a 200-mm lens has the same field of view as a 320-mm lens on a full-frame camera. Nikon and Sony have a 1.5× crop factor, giving a 200-mm lens the effective field of a 300-mm lens.

If you have a small telescope, this can provide the desired focal length — the main hurdle to clear is how to attach your camera to the scope's focuser. You'll need a T-adapter made for your camera's specific make and model.

Dialing In Your Settings

To begin, let's look at some basic camera and lens settings. Switch your camera to Manual (M) mode so you can (you guessed it!) manually control exposure settings. Next, set your camera to capture and store photos in RAW format to best capture the Moon's impressive dynamic range, and to allow you to adjust the white balance and other settings during post-processing. You can initially set the white balance to Daylight or Auto (AWB).

To reduce shake and capture sharper images, tweak a couple more settings. If your camera or lens has image stabilization (IS), turn it off. While it's useful for handheld shots, with a tripod-mounted camera IS can actually create unwanted shake by trying to correct motion that isn't there. For mirrorless cameras, enable the electronic front-curtain shutter (EFCS) to cut down on vibrations. On a DSLR, switch to Live View mode to eliminate mirror slap and so that you can preview the scene on the LCD display. Finally, if your camera and lens have autofocus (AF), it's better to switch to manual focus (MF). The bright lunar disk against the dark sky can throw off AF, but with manual

STARTING POINT This is the unprocessed version of the image on page 55. The author used image-processing software to boost contrast, adjust the color balance, and sharpen the RAW frame for the final version.

focus, you can fine-tune the sharpness for a clearer shot.

Now it's time to aim your camera at the Moon by adjusting the tripod head. If you're using a zoom lens, start with the widest setting, which makes your target easiest to center. Once you've done so, zoom in for a closer view. Adjust the shutter speed or increase the ISO until the image on your viewscreen is acceptably bright for focusing. Use your camera's digital zoom to magnify the live view and fine-tune focus with the lens's focus ring. After each adjustment, let the setup settle before assessing the results. The goal is to bring the Moon's edges and surface details into sharp focus.

Exposing for Sharpness

With your camera in Manual mode, it's time to adjust the exposure settings: shutter speed, ISO, and lens aperture (f/stop). Manual control is key for lunar photography since the contrast between bright highlands and craters with the darker plains and background sky can confuse auto settings. Keep in mind that the optimal exposure depends on the Moon's phase, your gear, and sky conditions.

Start by adjusting the shutter speed to find the longest exposure that avoids the blurring effects of Earth's rotation. The longer your lens's effective focal length, the faster the Moon appears to move across the frame. Try starting at a shutter speed of 1/100th of a second, an ISO around 100, and your lens aperture wide open. Fire your shutter by using your remote release or by setting your camera's self-timer to a short delay. Remember: The name of the game is to avoid shaking the camera when making your exposure. After each test shot, zoom in on the Moon's edges to check for smearing. If there's blurring, shorten the exposure until you get a sharp result. If the image is too dim, increase the ISO. The goal is to find the slowest shutter speed that prevents blur, while adjusting the ISO as needed to brighten or dim the image.

You can also control the Moon's brightness with the aperture of your lens. The wider the aperture setting (the lower the f/number), the more light reaches your camera's sensor and the shorter the exposure you can get away with. However, even expensive lenses typically have a sharpness "sweet spot." Apertures in the middle of the range (f/5.6 or f/8, for example) generally provide the best results, but try different settings to find the ideal aperture for your specific lens.

The ISO setting, which controls your camera's sensitivity to light, is another critical factor. The higher the ISO, the more noise you'll introduce into your image, so aim to keep it as low as possible. Some cameras handle noise better than others and can function quite well at values exceeding ISO 800 or 1600. In general, though, for a crescent, quarter, or gibbous Moon, start with an ISO between 200 and 400; for a full Moon, ISO 100 to 200 is usually sufficient.

As you adjust the exposure settings, keep an eye on your camera's histogram display. You want to avoid clipped highlights, which present bright regions as featureless expanses of pure white with data spilling off the right side of the histogram graph (see page 73).

▲ **COLOR THE MOON** This striking photo of the full Moon was taken with a Canon EOS Ra and processed in Adobe *Photoshop*. The author emphasized the colors of the lunar surface by combining several saturation and vibrance adjustment layers. The original 1⁄10-second exposure was made with a 110-mm refractor telescope with a 770-mm focal length. A tracking platform was also utilized to counteract smearing introduced by Earth's rotation.

Shooting and Processing

Taking multiple shots of the Moon can be really helpful. It gives you more chances to get a sharp image, especially if you accidentally bump the tripod, catch a gust of wind, or deal with changing atmospheric conditions. Try taking 25 or more images, repositioning the Moon as it drifts from the center of the frame.

In addition to taking multiple shots with the same settings, you can also try exposure bracketing — capturing multiple frames, each with different exposure settings. Typically, you'll want to capture a few shots above and below your normal setting. These offsets are often described in exposure value (EV) increments. Bracketing above and below by ½- or ⅓-stop steps is a good strategy to ensure you get the ideal exposure. Many cameras have an "exposure bracketing" setting that lets you cycle through different exposures in a sequence.

After your imaging session, it's time to transfer your photos to your computer for review. Toss out any that aren't sharp and edit the best ones with software such as the free, open-source program GIMP, or Adobe *Lightroom*, or *Photoshop*. Both Canon and Nikon provide RAW processing software with their cameras. The ins and outs of lunar image processing could be an entire, separate article (and might be in future), but your main task is to ensure details are sharply rendered and the Moon's full dynamic range is preserved.

During processing, you can use Levels and Curves controls to bring out more contrast and detail. You can also sharpen the image and use noise reduction for a more polished look. Finally, if you wish, crop the image so that the lunar disk appears a reasonable size within the frame. The longer the focal length of your lens, the less blank sky you'll likely end up trimming.

Beyond these basics, there's room for personal taste, too. For example, you might want to emphasize the contrast between the bright highlands and the grey maria. Or perhaps it's the subtle colors of the lunar surface that appeal to you most. The Moon is rich with minerals like iron and titanium, which create subtle hues. By using image-processing software, you can gradually build up saturation and vibrance to bring out these colors and create a stunning "mineral Moon" that showcases both the composition of the lunar surface and your own artistic style. (I have a video describing this approach at **https://is.gd/minmoon**.)

How much you enhance your Moon shots is totally up to you. By slowly adding adjustments, you'll create images that are both scientifically fascinating and visually striking, capturing the Moon in all its beauty.

■ **SARAH MATHEWS** is a passionate astrophotographer who loves helping others explore the night sky and capture its beauty through her YouTube channel (**youtube.com/@SarahMathsAstro**), workshops, website (**sarahmaths.com**), and various outreach programs.

Galactic Tides

Give these challenging tidal tails a go.

◀ **THE WHIRLPOOL** The pair sports many signs of interaction, including a three-pronged feature often called the E, a faint tidal tail emanating from NGC 5195 (the smaller companion), and the tidally distorted arms of the larger galaxy. The author was able to observe all of them in his 18-inch under excellent skies.

RON BRECHER

As a civilization, our lives are significantly influenced by the tides in Earth's oceans. The same forces that cause tides play a significant role in shaping our universe. For example, gravitational forces have tidally locked the Moon's rotation, so essentially only one side faces us. On a much larger scale, tides generate stunning displays of tails and bridges in some galaxies and bejewel other galaxies with starbursts. These intriguing tails have fascinated me for quite some time, but the vast majority can only be seen in long-exposure photographs. Is there any hope for visual observers? Absolutely! With a bit of patience and determination, many spectacular examples are visible through our amateur telescopes.

In 1972, Alar Toomre (Massachusetts Institute of Technology) and Juri Toomre (at the time, New York University) presented the first convincing demonstration that the tails of interacting galaxies astronomers saw in photographs have their origins in tides. Using computer simulations, they successfully explained the observed structures and reproduced the morphologies of numerous galactic interactions in great detail. Through these simulations, astronomers understood that for beautiful tidal tails to form, two galaxies must be in close proximity for a significant amount of time. The most obvious tails form when the perturbing galaxy's orbit and the perturbed galaxy's rotation are in the same direction. The tidal force provides an impetus, pulling tails out of the galactic disk, which continue to flow out long after the perturbing galaxy has marched along in its orbit. Ready to observe some examples? Let's go.

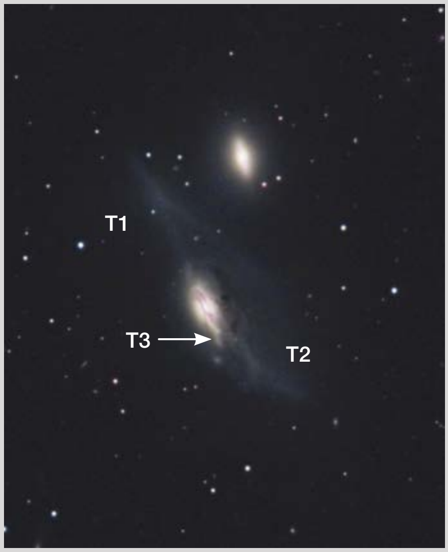
Diffuse Tails and Streams

The **Whirlpool Galaxy** (M51) is one of the best-known galaxies in the Northern Hemisphere and a perennial star-party hit. Look for it 3.6° southwest of 1.9-magnitude Eta (η) Ursae Majoris (Alkaid). You've probably seen the larger galaxy's spiral arms, but have you noticed the four faint tidal streams emanating from its companion **NGC 5195**? To view them clearly, you'll need dark, transparent skies and a keen eye for subtle changes in contrast. I'll never forget the night I pointed my 18-inch f/4.5 Dobsonian at M51 under the pristine skies of Massacre Rim in Nevada. The conditions were excellent — not a single light dome was visible on the horizon and a highly structured Milky Way was overhead. I was surprised that, at 103×, I caught the dim, E-shaped tidal structure with averted vision, even though I wasn't specifically looking for it. This inspired me to sketch the galaxy carefully, and in the process, I was able to spot the fourth faint tidal stream.

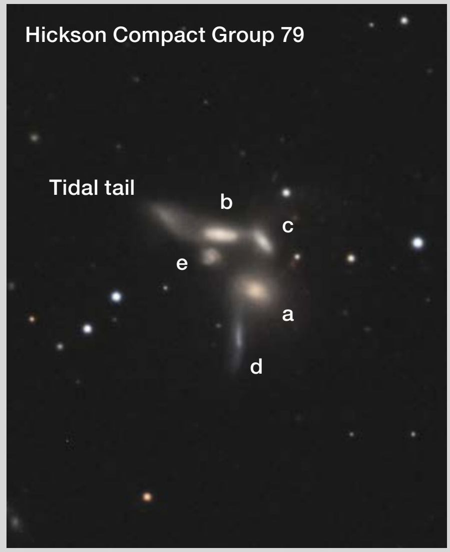
Likewise, dark skies and transparency are crucial for detecting **NGC 3628**'s tail. NGC 3628 is the northernmost galaxy of the Leo Triplet and lies about 2.3° southeast of 3.4-magnitude Theta (θ) Leonis. I assumed its diaphanous tail wasn't a visual target until I saw Contributing Editor Howard Banich's sketch in the April 2021 issue of *Sky & Telescope* (page 23). It took me multiple attempts before I finally managed to detect the dim structure in my 18-inch telescope. I spent three hours carefully studying the region under transparent skies to confirm the visual sensation was reproducible.

Howard's article "Markarian's Marvelous Chain" (*S&T:* Apr. 2022, p. 22) inspired me to tackle the tidal tails of **NGC 4438** that, along with its companion, NGC 4435, is known as The Eyes. I start at M84 and M86 and trace eastward along Markarian's Chain until I land on this object. At 207× I was able to pick up the northern tidal tail (labeled T1 in the image at right) under the dark skies of the White Mountains of California. Had conditions been even more favorable, I might have picked up the southern tail (T2) as well.

The Antennae Galaxies, **NGC 4038** and **NGC 4039**, are among the most famous interacting pairs in the spring sky. To locate them, extend an imaginary line joining 2.9-magnitude Delta (δ) and 2.6-magnitude Gamma (γ) Corvi an equal distance west-southwest and scan the area with a wide-field eyepiece. With my 18-inch at 413×, I was able to detect the bright star-forming knots adorning the rim of NGC 4038 that were triggered by the merger. By studying the pair at low power (103×) for more than 20 minutes, I also picked up a faint, puffy extension stretching south from the eastern end of NGC 4039. I remember seeing this short tidal feature in a friend's 25-inch scope more than a decade ago, and it was a lot easier than in my 18-inch! In addition, Jimi Lowrey's 48-inch revealed both faint tidal tails that give this object its moniker. I found the northern tail more accessible than the southern one. Scanning the far end of the southern tail in Jimi's scope at 287×, I was able to detect a weak brightening at the end. That dim smudge corresponds to a tidal dwarf galaxy, consisting of recycled gas and stars pulled out into the tidal tails.



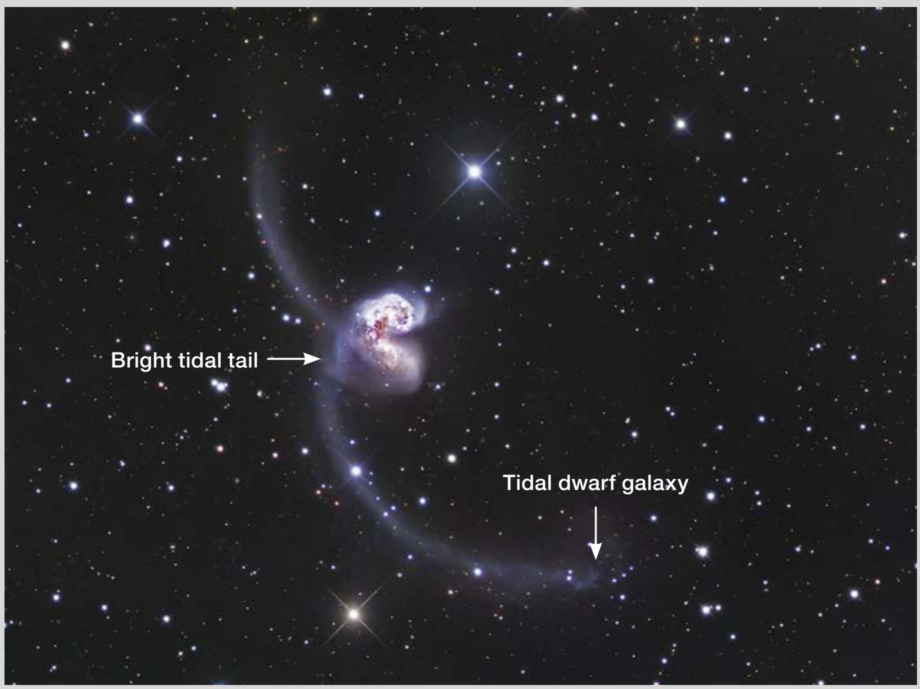
▲ **THE EYES** NGC 4438 in Markarian's Chain forms a pair with NGC 4435 and sports several tidal tails. The author picked out only T1 in his 18-inch but plans to attempt all three tails in his 28-inch soon.



▲ **SEYFERT'S SEXTET** Hickson 79 is a tight grouping of four interacting galaxies, a background interloper (HCG 79e), and a tidal tail flung out from HCG 79b. The tidal tail has a brightening at its far end.

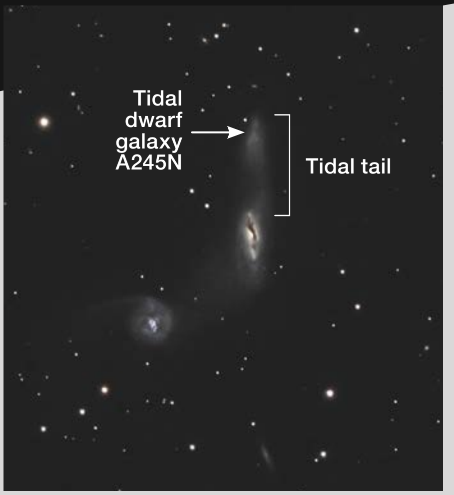
Thinner Tails

The two galaxies that are cataloged as **NGC 4676**, also known as The Mice, possess the best tidal tail I've seen in my 18-inch. The pair is an "early merger" having passed its first closest approach about 170 million years ago. Since it's in a region devoid of bright stars, I first locate the galaxy duo NGC 4656 and NGC 4631 (magnitudes 10.5 and 9.2, respectively) and then star-hop in a wide-field eyepiece to The Mice, 1.5° south-southeast of NGC 4656. Averted vision at 207× reveals a long straight



▲ **THE ANTENNAE** NGC 4038 and NGC 4039 are beautiful to look at in any large telescope, but an observer with dark skies and patience can also pick up the bright tidal tail segment marked on the image. The fainter antennae and the tidal dwarf galaxy are best reserved for monster Dobs.

THE EYES: RON BRECHER; SEYFERT'S SEXTET: GARY IMM; THE ANTENNAE: ROBERT GENDLER



◀ **IN HYDRA** Arp 245 features a tidal tail and a tidal dwarf galaxy that the author managed to pick out in his 18-inch telescope. A larger-aperture scope could reveal the tidal tail curving southeast from NGC 2993.

pencil of light shooting outwards from the northern member, which I could detect even in a suburban sky. The straightness of the tidal tail indicates that we are viewing it edge-on.

You'll have to wait until the predawn hours to observe Draco's **NGC 6621** and **NGC 6622** in February. Also known as Arp 81, you'll find the pair at the center of a triangle formed by 4.2-magnitude Phi (φ) and 4.8-magnitudes Omega (ω) and 42 Draconis. In my 18-inch at 345×, I've picked up hints of its hairclip-shaped tidal tail, with intermittent glimpses of the thick northwestern section where it curves off from NGC 6621. I reexamined Arp 81 during first light of my 28-inch f/4.1 Dob at the 2024 Golden State Star Party. At 291×, I was able to detect this feature and got a few fleeting glimpses of the rest of the thin tail.

Returning to Leo, **NGC 3509** (Arp 335), located 1.5° northeast of 4.8-magnitude 58 Leonis, presents another possible tidal arm that's fantastic in my 18-inch. At 207×, I readily detected the brighter portion of the hooklike structure from a dark, rural site in central Texas. Its tidal nature is in question, but I think it's a cool feature with a similar visual appearance!

You'll find Arp 245, comprising **NGC 2992** and **NGC 2993**, about 12′ north of the midpoint between 4.1-magnitude 39 Hydrae and 5.1-magnitude Kappa (κ) Hydrae. In my 18-inch at 200×, I repeatedly glimpsed the tidal tail of NGC 2992 as a long, thin extension shooting north-northeast from the galaxy. At low power (148×), I managed to detect the tidal dwarf A245N, which lies about 2′ from the core of NGC 2992.

Digging Deeper

Let's explore some more challenging targets. The Tadpole Galaxy, **UGC 10214**, is famous for its long tidal tail, which spans more than 280,000 light-years. Look for the field about 3.2° south-southeast of 4.0-magnitude Theta Draconis. My 18-inch didn't reveal the feature even under excellent conditions, but my 28-inch did. At 208×, the galaxy itself appeared elongated east-west and was fairly bright. I caught occasional glimpses of the tail, curving slightly northward from the body of the galaxy and extending about 2′ in length.

Hickson 79, also referred to as Seyfert's Sextet, is a very compact group of four interacting galaxies and a background interloper located 1.8° east-southeast of 4.8-magnitude Rho (ρ) Serpentis. The challenge is to bust apart the members. The three brightest members (HCG 79a–c) are not too difficult in my 18-inch and, at 460× with averted vision, are steadily visible. I could not see HCG 79e, while I only picked up HCG 79d on exceptional nights. What's the remaining member of the sextet, you ask? That's the tidal tail of **HCG 79b**. I find this feature about as challenging as HCG 79d, and it flashes into view only under great conditions. Using my 28-inch at 416×, the tidal tail emerges, and I can resolve a brightening in it.

If you're as fascinated by tidal features as I am, you'll be delighted to know that this article only scratches the surface. Since tidal features are a common byproduct of galactic interactions, there are plenty of examples to keep a passionate observer with a large telescope hooked for a long time!

■ **AKARSH SIMHA** has seen farther by standing on the ladders of giants — he's grateful to Jimi Lowrey, Steve Gottlieb, and Howard Banich for their enduring mentorship. He thanks William Keel for educating him on the physics of tidal tails. Read more about Simha's astronomical pursuits at **https://asimha.net**.

Tidal Tails and More

Object	Constellation	Mag(v)	RA	Dec.
M51	Canes Venatici	8.4	13^h 29.9^m	+47° 12′
NGC 5195	Canes Venatici	9.6	13^h 30.0^m	+47° 16′
NGC 3628	Leo	9.5	11^h 20.3^m	+13° 35′
NGC 4438	Virgo	10.2	12^h 27.8^m	+13° 01′
NGC 4038	Corvus	10.3	12^h 01.9^m	–18° 52′
NGC 4039	Corvus	10.6	12^h 01.9^m	–18° 53′
NGC 4676	Coma Berenices	13.0	12^h 46.2^m	+30° 44′
NGC 6621	Draco	13.1	18^h 12.9^m	+68° 22′
NGC 6622	Draco	15.3	18^h 13.0^m	+68° 21′
NGC 3509	Leo	12.7	11^h 04.4^m	+04° 50′
NGC 2992	Hydra	12.2	09^h 45.7^m	–14° 20′
NGC 2993	Hydra	12.6	09^h 45.8^m	–14° 22′
UGC 10214	Draco	13.9	16^h 06.1^m	+55° 26′
HCG 79b	Serpens	13.8	15^h 59.2^m	+20° 46′

Right ascension and declination are for equinox 2000.0.

GARY IMM

A Lyrical Look at Luna

STILL AS BRIGHT: *An Illuminating History of the Moon from Antiquity to Tomorrow*

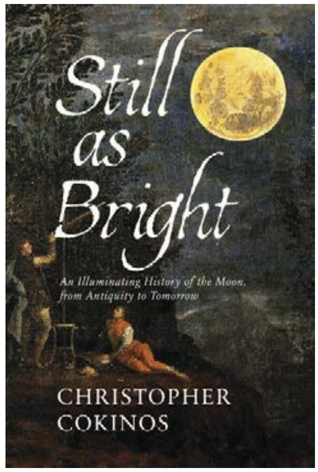
Christopher Cokinos
Pegasus Books, 2024
320 pages, ISBN 9781639365692
US$35, hardcover

IN BASEBALL, it's known as a *pitcher's pitch*: a ball tossed with such perfect placement, such precise spin, such stunning velocity that the batter can do nothing but watch it whizz by. The stadium roars in appreciation (if the pitcher's on the home team), and other pitchers nod and whisper silently to their colleague in battle, "Well played."

With apologies to the non-baseball-minded, that's the metaphor that comes to mind to describe the tour de force that is Christopher Cokinos's most recent book, *Still as Bright*. A writer's book, it's a journey of language, depth, and straight-shooting investigative journalism that's so expertly presented that I found myself at times just sitting back and acknowledging Cokinos's mastery of his craft: "Well played."

So where to begin with this exquisite tome? The book is half lunar history and half memoir of a middle-aged man who never quite outgrew his childlike wonder for gazing up at the night sky and wondering what we truly see when we look at the Moon.

On its face, *Still as Bright* is an inquiry: What is humanity's relationship with our nearest celestial neighbor? Is the Moon more timekeeper or keeper of tides? Is it a portent of evil, or a bringer of peace? A source of inspiration for poets, or a utilitarian tool to win the international space race? These are potent, expansive questions, and Cokinos dives deeply into his topic and resurfaces time and again with fresh and captivating insights about the Moon's place in our planet's history and in our own as a species.



As he proceeds from a description of the 1966 "picture of the century" (NASA's Lunar Orbiter 2 image of Copernicus Crater) to his commitment to earn lunar observing certificates from the now-defunct American Lunar Society and the more demanding Royal Astronomical Society of Canada, we accompany the author through the identification of every lunar feature and shadow. Mare Crisium. Lacus Temporis. The twin craters Hercules and Atlas. Every feature has a name, and Cokinos seems determined to document every last one of them. He touches on the names that faded into history as well as those that stuck.

This is an expert long-form writer in full control of his talent. Part of that talent involves tapping an array of dictionaries, globes, and lunar atlases as well as masterful research skills and an impressive travel itinerary to bring every facet of the Moon to life. We meet our satellite as the lush garden envisioned by our ancestors, giving way to the modern understanding of the Moon as a world of gray lifelessness — and then, the unlikely discovery of water molecules in its soil. The Moon, it turns out, never fails to surprise us.

We also see the Moon as the source of our planet's slowing rotation through the eons, which gave ancient cyanobacteria more time to photosynthesize and release oxygen molecules into the atmosphere — a literal giver of life. And in a stunning chapter in which Cokinos flexes some serious investigative muscle, he presents the Moon as a reflection of humanity's dark history — reminding us, for instance, that the Saturn V rocket that helped take the Apollo astronauts to the lunar surface had its beginnings inside the Nazi war machine.

Cokinos ushers us, too, into his childhood backyard, the better to watch the stars but also to escape an unhappy household under the roof that adjoins it. He describes the telescopes he's owned and the dark-sky areas he's lived in. A failed first marriage gives way in time to a content second relationship with a woman who clearly understands Cokinos's "lunar obsession."

Ultimately, the author's Moon becomes a metaphor: A chapter on Luna as dead orb morphs into a meditation on life itself, as Cokinos reflects on his father's declining health and his emerging understanding that both his dad and he himself will someday take on the same gray, lifeless hue as the Moon.

As a long-time observer of the stars, I like to say that books are for cloudy nights. But *Still as Bright* is one for your permanent collection, too. You can open it to any chapter and dive instantly into a new way of looking at this most familiar of celestial companions. Cokinos is a splendid observer of detail and a weaver of words both lyrical and profound. Simply put: Well played.

■ **NICOLE NAZZARO** is a biochemist and science writer based in Edmonds, Washington. A Focal Point essay by Cokinos entitled "Still as Bright" ran in the July 2019 issue of *S&T*.

 by John Bozeman

Processing James Webb Imagery

Here's how to make amazing pictures using data recorded with the largest space telescope.

LIKE A PRO Making your own pictures using data recorded by the James Webb Space Telescope (JWST) lets you work on images even during periods of poor weather. Author John Bozeman shows you how to access the archive and process the calibrated exposures to produce colorful composites like this result of NGC 3132, the Southern Ring Nebula.

Who hasn't marveled at the incredible results produced with the Hubble Space Telescope since the telescope was launched 35 years ago? Today, the James Webb Space Telescope (JWST) is stealing Hubble's thunder. But are you aware that you can process Webb pictures yourself? There's a cornucopia of excellent scientific data available online, and it's becoming easier to access, too. With just a little understanding of the basics, you can produce jaw-dropping JWST images yourself. Here's how to do it.

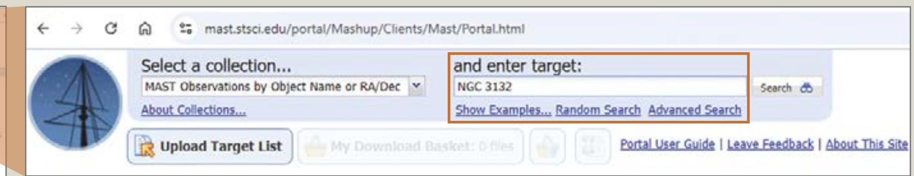
Retrieving Data

The first step on your image-processing journey is accessing the data. As a U.S. taxpayer-funded NASA mission, all the raw data produced by the JWST as well as all other NASA missions eventually become publicly available. Some are embargoed for a year to give the scientists that proposed the observations time to examine the data for their research and publish their work. Other observations are released immediately to encourage citizen scientists like you and me to create our own interpretations of the image data.

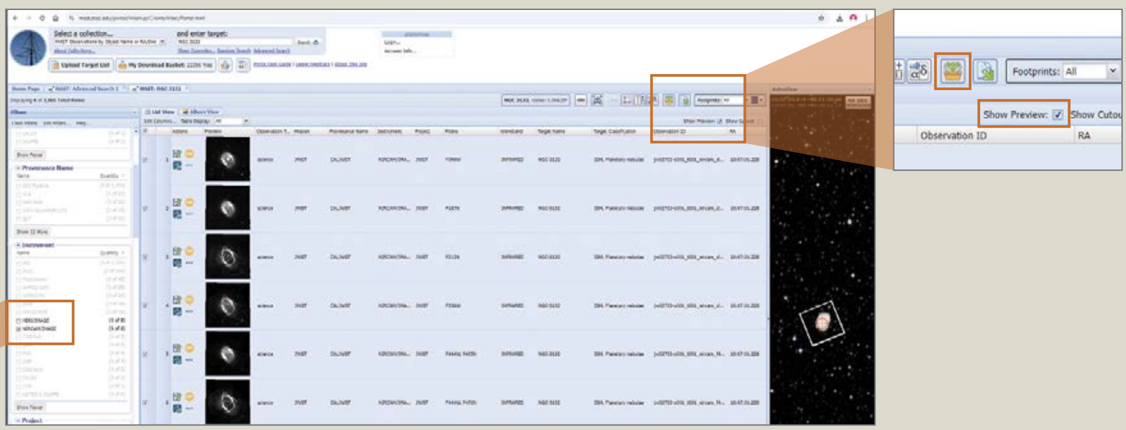
Most of this information is found in the Barbara A. Mikulski Archive for Space Telescopes (MAST) at **https://mast.stsci.edu**. This is the central data portal for 23 satellite and terrestrial missions, including HST and JWST.

Navigating the archive is a bit daunting until you're familiar with its structure. There are several ways to find what you're looking for, though the easiest is to enter an object's name in the bar along the top of the screen and click the ***Search*** button to the right. This often produces a list of many images recorded by a variety of different missions. Along the left side of the screen, you can narrow your search by limiting the mission, instrument, and many other variables. There's also the ***Advanced Search*** function to browse by mission, though this method returns tens of thousands of images, and it can take a while to find a specific one.

Let's use the example of finding the raw data for NGC 3132 recorded by JWST. After inputting the object's designation and selecting JWST in the Mission section of the Filters column, MAST returns a list of 10 files taken through the Near-Infrared Camera (NIRCAM/IMAGE) and the Mid-



▲ **FREE DATA** Raw, unprocessed (but calibrated) images from JWST are available on the Barbara A. Mikulski Archive for Space Telescopes (MAST) website. To start hunting for specific image data, simply type in the name of your target in the second box at the top of the page (within orange box), though this only works if you know both the target's proper designation and if the mission has imaged it. If that doesn't work, click the ***Advanced Search*** feature just below the box.



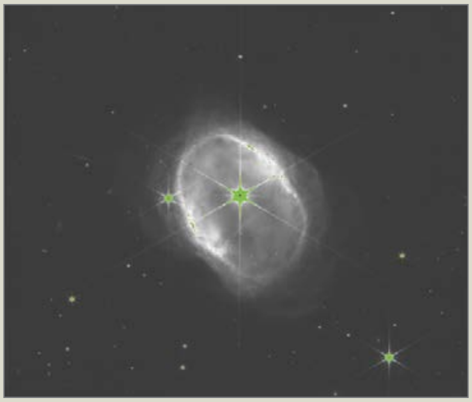
▲ **RETRIEVING FILES** Once you've narrowed your search, click the ***Show Preview*** checkbox at the upper right to see if you're selecting single images or a mosaic. Then click the ***Add data products to Download Basket*** icon and the site will gather your files.

UNLESS OTHERWISE NOTED, ALL IMAGES ARE COURTESY OF THE AUTHOR; NGC 3132: NASA / ESA / CSA / STSCI / JOHN BOZEMAN

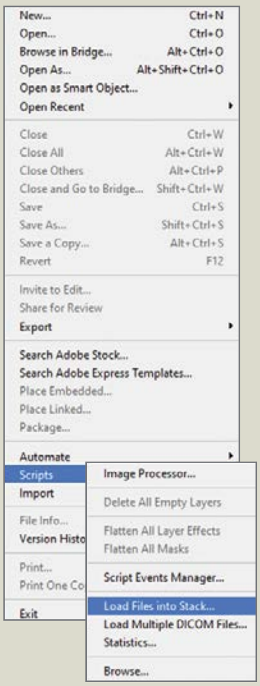
Infrared Instrument (MIRI/IMAGE). Since JWST records exclusively in infrared wavelengths, there are no traditional red, green, or blue exposures. Instead, the filters the telescope shoots through are titled by wavelengths: Shorter wavelengths have lower numbers, and longer ones have higher values. Much like in narrowband imaging, you can combine these any way you'd like, though it's often effective to assign the shortest wavelength to the blue channel and the progressively higher wavelengths to the green and red channels.

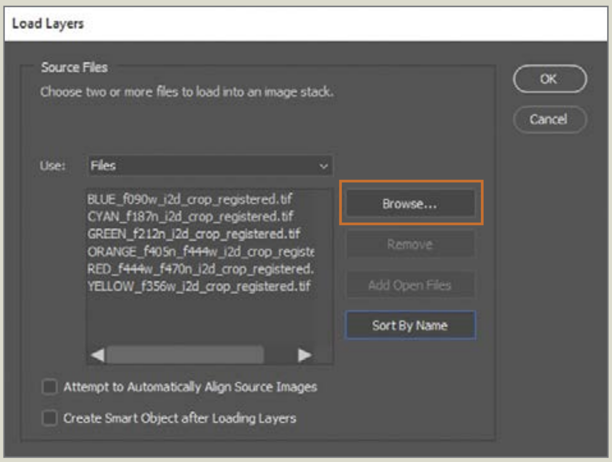
In the Filters column, scroll down to the Instrument section and deselect MIRI/IMAGE to reduce the results to only the NIRCam datasets since, in this case, the MIRI images are combined into an odd-shaped mosaic. This process shrinks the list of files to six taken through several filters, the last two a combination of data made with two filters. Clicking on the ***Show Preview*** box at the upper right in the List View section can help identify a set of pictures that will produce a nice color result. Click the ***Selected*** check box for each, and then click the ***Add data products to Download Basket*** icon that resembles a potted plant near the top right of the screen. At this point, a "Retrieving Files" box appears in the middle of the screen. It can take anywhere from a few seconds to several minutes to load, depending on how busy the site is at the time.

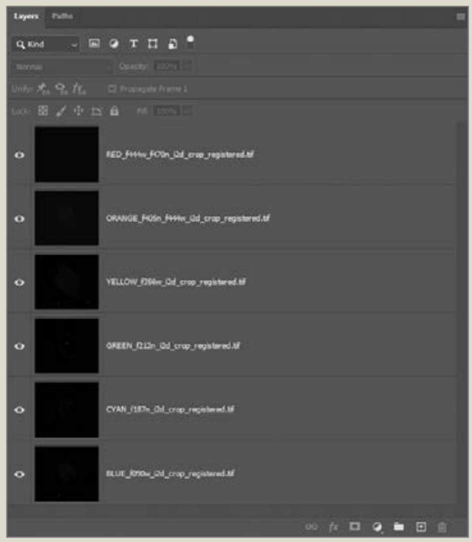
Once the site is done retrieving your files, you'll see a folder titled JWST. Double clicking on it reveals subfolders for each of the selected datasets. Double clicking on each of these shows a group of five files, most of which are unnecessary — we're only interested in the large FITS file. Deselect everything but the exposure in each, and then you're ready to retrieve the pictures. Click the ***Download*** button at top-right



▲ **CONVERTING FORMAT** The FITS files retrieved from the MAST site contain multiple nested files and can only be opened by certain programs. NOIRLab's free program *FITS Liberator* is easy to use for opening the JWST FITS images and converting them to TIFF format, which is compatible with any image-processing software. You can perform some basic stretching if desired using the histogram along the bottom of the screen. For more on histograms, see page 73.







▲ **AUTOMATIC LAYERING** Stacking all the frames in *Photoshop* into a single layered file only requires a few commands. *Left:* Select the ***Load Files into Stack*** script, then click the Browse button to navigate to your prepared files (above). In a few moments, *Photoshop* has an image with each file as an individual layer (right). You can retitle the layers and rearrange their order.

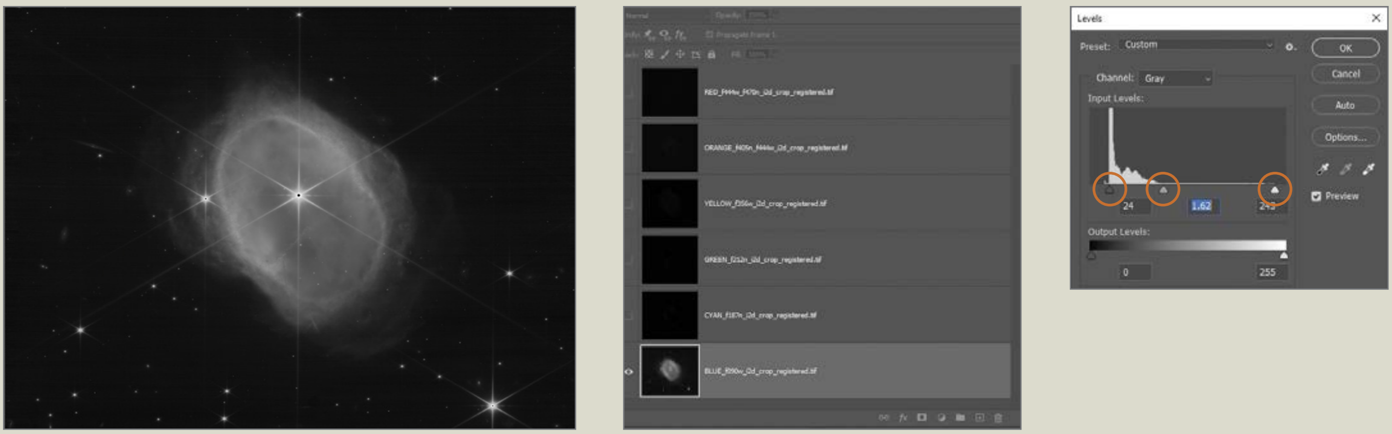
of the screen, and you're presented with a choice of compression formats that the data will be transferred as, with ZIP as the default. Hit the ***Download*** button in this box, and in a few minutes your file transfer is complete. It should be noted that the files are extremely large, typically 600+ megabytes apiece, though they aren't nearly that size after you convert them to another format, as you'll see momentarily.

Once the download is complete, unzip the files to a folder of your choice. I typically rename the subfolders with the filter name (f444w, for example).

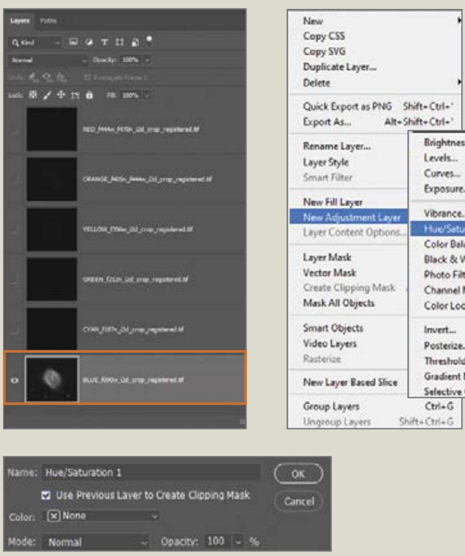
Converting and Pre-Processing

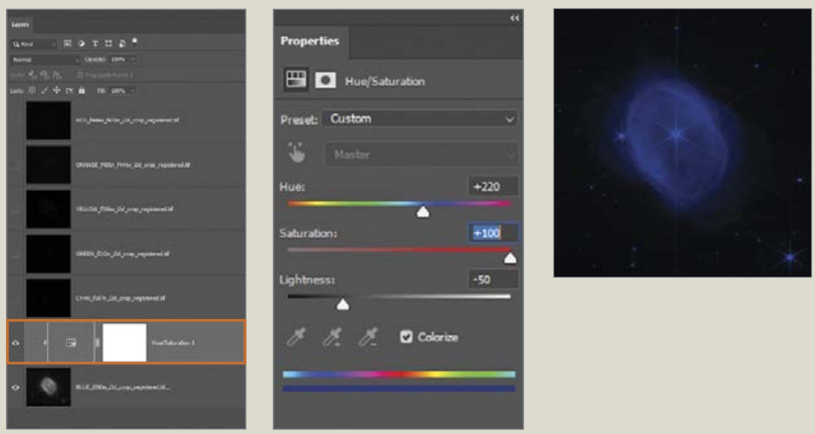
Now that you have the raw data, you have two options to open a downloaded FITS file. The JWST files have additional, nested data contained within, so most amateur image-processing programs can't open them. The only ones I've found that work are *PixInsight* (**pixinsight.com**) and the free program *FITS Liberator* (**https://is.gd/fitsliberator**). When opening the data in *PixInsight*, each contains eight nested files, only one of which we're interested in. Typically, the "cleanest"-appearing image is the one to work with. On the other hand, *FITS Liberator* opens the file without all the extra baggage and lets you convert it to TIFF format and keep the data in a linear state, making it compatible with most any image-processing software. I do the bulk of my processing in a suite of programs and find it's easiest to create the TIFF file in *FITS Liberator*, then perform some pre-processing in *PixInsight* before assembling the color composite in *Adobe Photoshop*.

Converting the files to TIFF in *FITS Liberator* is quick and easy. Simply open the program, then drag and drop each FITS

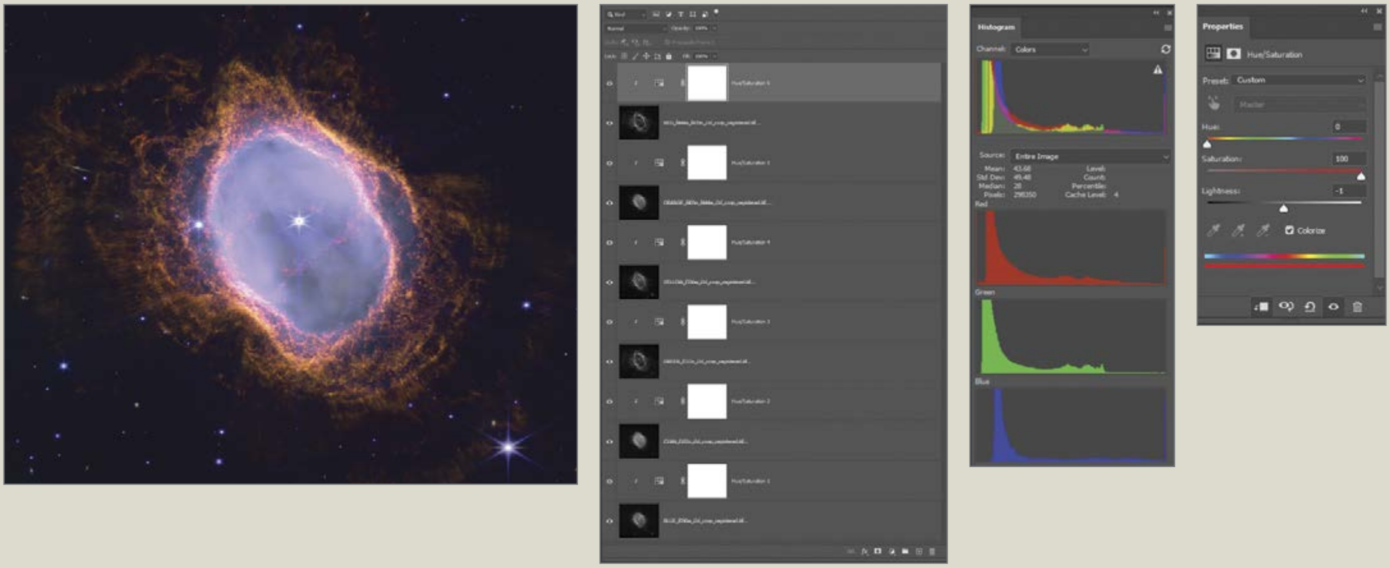


▲ **LEVELS ADJUSTMENT** Stretching each layer to show its entire dynamic range requires selecting each one and opening the ***Levels*** tool. Move the black-point slider (left) until it's below the start of the histogram signal. Then set the mid-point slider so that it's just after the point where the signal goes flat and move the white-point slider to just below the last bit of signal in the histogram at right.

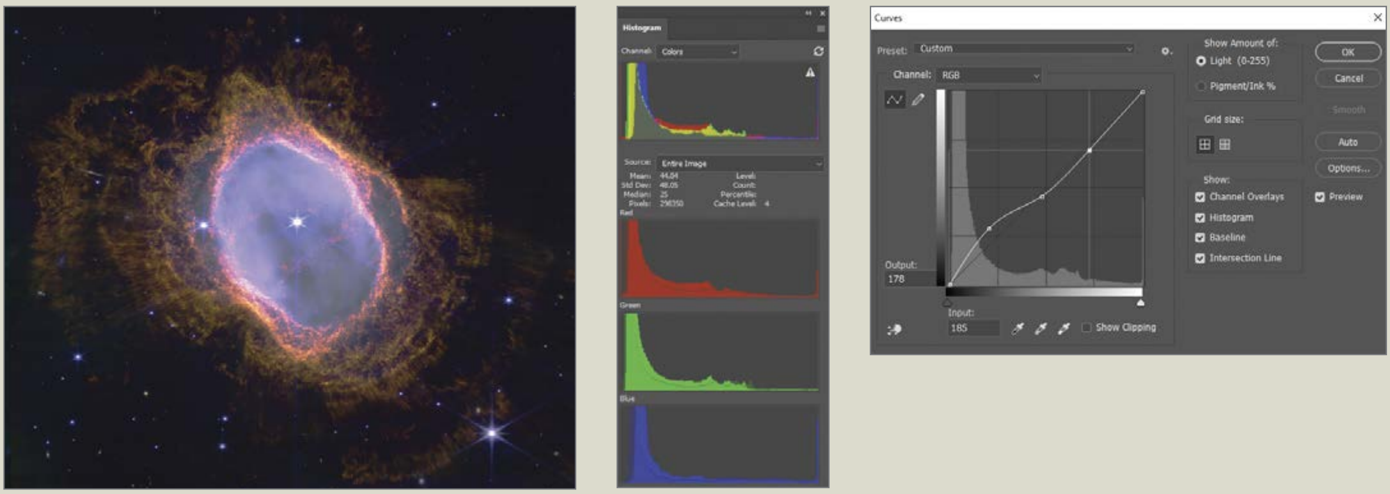




◀▲ **COLORING LAYERS** *Left:* Once you have converted the image to RGB, adding color to each layer is a multi-step process. First, select the bottom layer and choose ***Layer > New Adjustment Layer > Hue/Saturation*** from the pulldown menu, and be sure to click the ***Use Previous Layer to Create Clipping Mask*** checkbox. *Above:* Click on the Hue/Saturation adjustment layer and set the levels for each layer as described in the text.



▲ **COLOR BALANCE** With each layer colorized and its blending mode set to ***Lighten***, you can then adjust the Lightness slider in each layer's Hue/Saturation setting to establish a good color balance that takes advantage of the data from each of the six image layers. When you're satisfied with your results, combine the layers using ***Layer > Flatten Image***.



▲ **CONTRASTING CURVES** The Curves tool found at ***Image > Adjust > Curves*** lets you fine-tune particular areas of the histogram while leaving other regions as they are. This is useful for boosting the outer regions of your subject without blowing out the highlights.

file into its window. When the file opens, be sure to undo the automatic stretching the software performs by dragging both ends of the histogram found along the bottom left of the window all the way to the left and right. Now click the ***Save*** button and repeat the same steps for each image.

Open up *PixInsight* and drop all six images into the program. I typically start by applying a screen stretch to the files (***Image*** > ***STFAutoStretch***) to make it easier to see what I'm working with.

Most JWST files have jagged edges that need to be cropped out, so I then open the ***DynamicCrop*** process from the pull-down menu (***Process*** > ***Geometry*** > ***DynamicCrop***) and frame the picture to my liking. Before applying the crop, make your selection and then drag the triangle at the bottom-left corner of the ***DynamicCrop*** window onto the empty background of the program. This records the precise cropping as a temporary file called Process1 that you can then drag and drop onto each open file to quickly repeat the same cropping proportions reliably.

Often, I perform gradient correction using the ***DynamicBackgroundExtraction*** process or the ***graXpert*** plug-in, because even spacecraft images have gradients that require addressing. I then typically deconvolve the images with Russ Croman's ***BlurXTerminator*** plug-in, available at **www.rc-astro.com/software**.

The final steps I perform in *PixInsight* are to align all the files using ***Process*** > ***ImageRegistration*** > ***StarAlignment*** to one of the images and save the results.

Layering Color in *Photoshop*

With the files ready, it's time to assemble and process them into a beautiful color composite. The easiest way in *Photoshop* is to simply load three of the TIFFs and combine them as an RGB by opening the Channels window (***Windows*** > ***Channels***) from the pulldown menu. Clicking on the top-right of this window brings up several options; choose ***Merge Channels***, and in the action window that opens, change the Mode from ***Multichannel*** to ***RGB Color***. You then assign the longest filter wavelength to red, the middle value to green, and the shortest wavelength to blue. This leaves you with a color result ready to stretch.

A more complex approach is required to combine all six of the filtered exposures of NGC 3132 into a color composite. The advantage to using more files is you get to utilize additional data that often contain very different and interesting features.

Start by selecting ***File*** > ***Scripts*** > ***Load Files into Stack*** from the pulldown menu. When the control window opens, click the ***Browse*** button and navigate to your registered TIFFs. Select all six files, then hit OK. In a few moments, the program is done. Open the Layers window (***Window*** > ***Layers***) and you'll see each of the files in its own layer.

You can change the order of the layers by clicking on each and dragging it into the position in the stack you desire — I prefer to arrange them in descending wavelength order to make it easiest to keep track of which layer is which. With these six exposures, I'll assign this color scheme: f470n is red, f444w orange, f356w yellow, f212n green, f187n cyan, and f090w blue. Double-click on the names of each layer to retitle them with the color scheme.

Next, work on each layer individually. Click on the "eye" icon to the left of each layer except the blue (bottom) layer to hide the others, and then click on the blue layer's preview. Open the ***Levels*** tool (***Image*** > ***Adjustment*** > ***Levels***) and move the mid-point slider near to the edge of the histogram where all the signal resides at the left and click ***OK***. The screen will show lots of details in the nebulosity, though the background will appear gray. To set the black point, open the ***Levels*** tool again, to see the histogram values distributed in a wider range, reflecting the stretch you did a moment ago. This time move the black-point slider (left) to the start of the signal in the histogram, and the white point slider until it's below the point where the histogram drops to almost a flat line. Repeat this stretching process until you're satisfied with the results.

With the blue layer stretched, click the eye icon on the next layer and repeat the same ***Levels*** stretching steps on each layer until all display a good range of values throughout the nebula.

With each layer stretched to your satisfaction, it's time to convert the picture from grayscale to an RGB color space by selecting ***Image*** > ***Mode*** > ***RGB Color*** from the pulldown menu. A small window opens asking if you'd like to merge the layers before mode change — click ***Don't Merge***.

Hide all the layers except the bottom one, then click on it and select ***Layer*** > ***New Adjustment Layer*** > ***Hue/Saturation*** from the pulldown menu. In the Layer options window, click the check box to the left of ***Use Previous Layer to Create Clipping Mask***. Selecting this new adjustment layer opens its properties window. Near the bottom, check the ***Colorize*** box and then change the values for Hue to 220, Saturation to +100, and Lightness to -50. The blue layer should now look blue. Repeat this process for the other layers but change the Hue values to match these: cyan 180, green 150, yellow 50, orange 30, and red is left at 0.

Once colors have been assigned to all the filters, select each image layer and change the blending mode from ***Normal*** to ***Lighten***. The full picture then appears in color. You can fine-tune the color balance by selecting the clipping mask on each of the six adjustment layers and changing the Lightness value until you're pleased with the results. When you're content with the color balance, you can get rid of the layers by selecting ***Layer*** > ***Flatten Image***.

At this point, you can perform some additional enhancements to suit your taste. I often create duplicate layers and apply additional adjustments to further neutralize the background, or selectively sharpen inside the core region to make the wispy filaments a bit more pronounced. The last thing I do is apply some final noise reduction using another Russ Croman plug-in, ***NoiseXTerminator***.

Happy Hunting

This tutorial should get you started on some exciting adventures exploring and processing the ever-growing archive of JWST data. Searching through the archive is often half the fun. While you can search by object name, you can find lots of exposures for objects that haven't appeared in splashy news releases. To do this, use the ***Advanced Search*** function and limit the results to short time periods. Try searching the MAST archive in one-month increments since the telescope has only been online for two years. Also, some object designations don't produce results, while alternative catalog names do. For example, M81 might prove to be a fruitless search, while its NGC designation (NGC 3031) bears results.

I find that working with Webb imagery improves my processing skills and helps me produce better results with shots captured with my own gear. Regardless of your goals, there's a massive treasure-trove of high-quality data that is available for anyone with a fast internet connection and an interest in working with the premier space telescope.

■ JOHN BOZEMAN is an astrophotographer who enjoys processing astrophotos, recorded from both Earth and space.

Wood Wonders Eyepiece Case and Stand

This elaborate case shows that some companies do still make them like they used to.

Mythological Two Drawer Eyepiece Case

U.S. Base Price: $359. Stand: $189
wood-wonders.com

What We Like
Beautiful and attractive
Heavy-duty brass components

What We Don't Like
No padding in drawers

◀ The Wood Wonders Mythological Two Drawer Eyepiece Case with optional stand is an ornate, heirloom-quality case for your eyepieces and visual-observing accessories. The eyepiece case is made of red oak with brass hardware. The Celestial and Mythological case models feature machine-engraved bas-relief carvings of the planets or mythological figures on the top, front, and sides.

OVER THE COURSE of my decades as an amateur astronomer, I've bought and sold many eyepieces. Lately, I feel I've reached nirvana with a collection of premium Pentax, Takahashi, and Tele Vue eyepieces and accessories. For a while I stored them in a cheap, foam-lined case. At the same time, I've accumulated some fine instruments, which I treat with reverence, so why shouldn't my ocular collection deserve the same?

While attending the Northeast Astronomy Forum a few years ago, I came across the Wood Wonders booth operated by craftsman Ron Burrows. There he displayed his intricate eyepiece cases, stands, and observing chairs. His booth and products made me remember a time when craftsmanship was a thing to be cherished. So I looked up their website and then decided to have a closer look at the company's work.

Custom Cases

Located in Pinckney, Michigan, Wood Wonders offers two primary products: eyepiece cases and observing chairs. Each is made from red oak, and there are multiple sizes and additional options for customization of the eyepiece cases. The company offers a single-drawer model, and a larger version with two drawers. Both are available with three design options: plain, celestial, or mythological. The Celestial models include 3D bass-relief carvings of the planets on the top, front, and sides of the case. The Mythological versions include relief depictions of Perseus, Pegasus, and Centaurus as well as the phases of the Moon and stylized "shooting stars." I chose the Mythological Two Drawer Eyepiece Case with the optional stand and tablet holder.

You can select from five different hole layouts for the central eyepiece holder or upload your own custom hole pattern that accommodates your particular collection. I chose one with enough 2-inch holes for my best 2-inch eyepieces, with additional 1¼-inch spaces for my standard-size ones. The underside of the lid has a hinged Plexiglass compartment for additional storage of star charts and maps, and it includes a dimmable red LED powered by a standard 9V battery. The light automatically turns on when the lid is opened and off when closed.

The delivered case weighs 5.4 kilograms (12 pounds) when empty and measures 50.8 × 25.5 × 22.9 centimeters (20 × 10 × 9 inches), with solid brass hardware for the hinges, latch, and carrying handle. By default, the wood is covered with Minwax Helmsman Spar urethane for long-term protection of the wood, but for an additional $45 you can select from 22 different stains. I chose the Colonial Maple stain. The urethane was somewhat pungent when the case first arrived, so you may want to let it cure a bit more in the garage or basement on arrival.

I took advantage of a few premium customizations. First is the NiteGlo-Constellation w/Personalized Monogram option ($45) that allows up to 30 characters. I chose the Sagittarius Teapot and my name, which turned out even better than I expected when I saw it in person. The design is etched into the wood and filled with phosphorescent resin rather than painted on, so it won't get scratched or chipped off during normal use.

I also selected the Tablet Option ($60), which adds a holder for an iPad or Android tablet in the lid compartment, so I could reference the more extensive deep-sky catalogs in my preferred planetarium apps when necessary. You'll be asked to specify your tablet size when ordering. The tablet option can also be retrofitted for an additional cost ($75) if you decide upon it after the fact. The total lid storage space without the tablet option is 48 x 22 x 3.1 cm deep. The two side drawers have a storage space of 12 × 21 cm with 5 cm of depth, and the storage areas beneath the two side drawers are each 13 × 22.9 × 9.5 cm.

The only thing I felt was missing was some padding or velour lining in the drawers. Fortunately, there was plenty of room to fit the foam from the shipping boxes of another large eyepiece. For the top drawers, I got some thin, green foam from a hobby store, which I cut to size to pad the bottoms and protect the additional odds and ends that are part of my visual observing kit. You can also purchase a case heating option, powered by Kendrick Astro Instruments, to keep eyepieces from dewing up in particularly humid climates (though I didn't explore this option).

For another $189 I added the accompanying eyepiece stand. This heavy-duty wooden stand folds flat during storage and is designed to hold the eyepiece case about 76 cm off the ground. This sounded much better than leaving the eyepiece case on the damp ground or having to bend over to root around while observing. The stand can be stained to match the case for another $45. Some assembly is required of the stand — there were no instructions, but putting it together was obvious given the photos of the fully assembled kit.

In Action

Under the stars, the case and stand together did exactly what they're meant to do in the field — keep my eyepieces, star charts, and tablet dry and easily accessible while I enjoy my time at the telescope. I no longer fumble around in the trunk or in cases on the ground looking for the right eyepiece or Barlow. With the optional stand, everything is right next to my telescope at a comfortable height when I reach for things. The dimmable red LED made it easy to find everything quickly without fumbling in the dark. It's so beautifully made that I felt the need to place a small tarp under the stand in the field. The wood is varnished, but part of me just doesn't want to see it getting wet and dirty.

▲ The case includes built-in, dimmable red LEDs that turn on when the lid is open.

The Wood Wonders Mythological Two Drawer Eyepiece Case paired with the stand is the upgrade I didn't realize until recently that I needed. For those who appreciate fine craftmanship, it's a great home for your ocular collection.

■ Contributing Editor **RICHARD S. WRIGHT, JR.** is a 3D graphics software engineer and developer by trade. Look up "Utah teapot" to understand his preoccupation with the Sagittarius asterism.

▲ *Left:* Inside the case are two drawers with additional storage beneath. The company offers a selection of five hole patterns for the central section. The lid as shown includes the optional tablet holder and still has room for planispheres, star charts, or other printed material. The built-in LED switch is seen at the top right. *Right:* The fully stocked case is shown with the author's eyepiece collection. Although the drawers come unlined, foam sheeting from a hobby store was cut to provide additional padding for the two side drawers.

Starfield Optics 1.25″ Herschel Wedge

Here's an excellent filter designed for observing and photographing the Sun with small refractors.

Starfield 1.25″ Solar Wedge

U.S. Price: $250
starfieldoptics.com

What We Like

Heat diffuser doubles as solar finder

Integrated, variable polarizing filter

What We Don't Like

Camera rotates when adjusting filter

Loose M42 camera threads

SOLAR MAXIMUM IS FINALLY upon us, and the Sun's photosphere is constantly adorned with sunspots both big and small. According to spaceweather.com, there hasn't been a day without sunspots since 2022, and that was just for a single day. So now is the perfect time to pick up a solar filter and enjoy viewing the nearest star.

One accessory that has grown in popularity among solar observers in recent years is the Herschel wedge. This device, first proposed by John Herschel in the 1830s, operates like a specialized right-angle diagonal to provide safe views of the Sun's photosphere. I've used several models in the past and find they work better than most front-mounted solar filters. Herschel wedges typically come in 2-inch format, but while visiting the Starfield Optics booth at the Northeast Astronomy Forum last year, I noticed they offered a 1¼-inch model, and I immediately arranged to borrow one to try out.

Filtering with a Prism

A Herschel wedge (or solar wedge) is a 90° prism diagonal designed specifically for use with refracting telescopes. But unlike a conventional star diagonal, this solar variant uses a trapezoidal prism that diverts a tiny percentage of the Sun's light to the eyepiece while passing the rest through to a heat-absorbing ceramic disk, where it won't pose a threat to your vision. These wedges are not recommended for use with reflecting or catadioptric telescopes like Schmidt-Cassegrains or Maksutovs because they don't prevent sunlight from entering the tube, potentially damaging internal components in your instrument.

▲▶ The Starfield 1.25″ Solar Wedge is a white-light solar filter that works as a drop-in replacement for your refractor's star diagonal.

There are two aspects to the devices that make them more complex than a full-aperture filter. The first is that the light directed towards the eyepiece is still too powerful to be safe for viewing, so additional attenuation is required. The other issue has to do with dispersing the excess light and heat that are diverted through the rear of the prism — this needs to be accomplished in a manner so that they don't burn anything (or anyone). The Starfield Optics 1¼-inch Solar Wedge does both quite well.

The wedge deals with the unwanted solar energy with a frosted, white ceramic diffuser on the rear side of the diagonal body. In addition, an integrated circular-polarizing filter in the eyepiece holder lets you quickly adjust the brightness of the view to comfortable levels for either visual or imaging applications. Once you dial in your preferred brightness, you can lock the setting in place with a thumbscrew located just above the ceramic heat diffuser.

The Starfield wedge is interesting in that it's the first one I've encountered made for refractors with 1¼-inch focusers. This smaller size is more versatile than the 2-inch model in some ways, as many inexpensive achromats come with 1¼-inch-only focusers. The caveat, though, is that you must ensure that your telescope's focuser is all metal rather than plastic, which can quickly

ALL PHOTOS COURTESY OF THE AUTHOR

melt when exposed to unfiltered sunlight. Still, this small-format wedge can be used on most any small refractor. Starfield recommends apertures of 100 mm (4 inches) or smaller; users with larger refractors should consider the 2-inch version, which includes additional filtration.

Catching Some Rays

The little wedge is hardly any bigger than a standard star diagonal. Its sleek design includes a metal compression ring to secure your eyepiece or camera without marring the barrels. Additionally, there are M42 threads (also known as T-threads) on the top of the eyepiece holder to attach cameras. I connected my Canon DSLR using a T-adapter, and the connection did an adequate job, though the threads were a bit loose, allowing the camera to wiggle slightly. I got a better connection with a high-speed video camera that screwed down until the inner stop within the camera contacted the wedge's threads.

The unit has a clear aperture of 26.5 mm and requires 115 mm of focus travel, which easily came to focus with several refractors I own, ranging from a Tele Vue 70-mm Pronto to a Celestron 102-mm achromat. The clear aperture may seem small but was fine for providing full-disk views of the Sun with all of my eyepieces. Higher-magnification views of sunspots simply required adding a Barlow or one of my Tele Vue Powermates between the wedge and eyepiece.

I compared the view using the same instruments and both full-aperture Baader Planetarium AstroSolar Safety Film and a glass filter. The comparison with the glass filter wasn't even close — I've always found glass solar filters to impart a little mushiness to the image. The sharp, contrasty view through the wedge was on par with those with the same scopes equipped with the Baader film, though the wedge had the advantage of letting me dial in the perfect brightness with the circular polarizing filter. I also find it's much easier to store a diagonal than a full-aperture solar filter, especially when travelling.

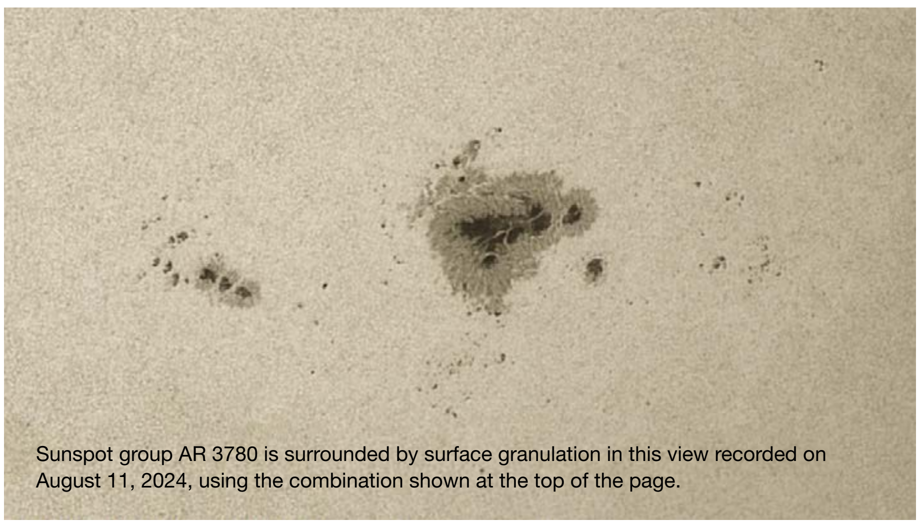
▲ *Left:* The Starfield wedge disperses the unwanted light and heat with a ceramic disk on its back side. The disk does double duty as an excellent solar finder — centering the Sun on it ensures the Sun is centered in the eyepiece. *Right:* Imaging with the Starfield wedge is simply a matter of swapping out an eyepiece for a camera. M42 (T) threads are also included as an alternate method for connecting a camera.

Adding the wedge to a refractor effectively eliminates the need for a separate finder. When the Sun is in the telescope's field of view, its bright (though out-of-focus) image is projected onto the device's ceramic heat-diffusing disk, so when the Sun is centered there, it's also in the middle of the eyepiece. That ceramic part did its job dispersing unneeded solar energy, too — after hours of use, the disperser was warm to the touch, but not uncomfortably so.

Imaging with the Starfield wedge is also easy. While the threaded eyepiece turret permits attaching a DSLR, you're better off with a high-speed video camera like those sold by QHY, Player One Astronomy, or ZWO paired with a tele extender. I preferred setting the polarizer near its brightest setting to achieve extremely short exposures at low gain. Imagers should note that rotating the eyepiece turret to adjust the polarizing filter also rotates the camera.

The Starfield 1.25″ Solar Wedge quickly became my favorite white-light filter for views of the solar photosphere. Its simplicity and the excellent views it provides make it easy to recommend for refractor owners.

■ Associate Editor **SEAN WALKER** likes that he never has to lose sleep over solar observing.



Sunspot group AR 3780 is surrounded by surface granulation in this view recorded on August 11, 2024, using the combination shown at the top of the page.

▲ DEEP-SKY CAMERA

Camera manufacturer QHYCCD announces a new model for deep-sky imaging. The QHY487 Pro I camera is designed around the ultraviolet-sensitive 2/3-inch Sony IMX487 BSI CMOS detector, which has a 2,856 × 2,848 effective array of 2.74-micron-square pixels measuring 7.8 × 7.8 mm. This 8.13-megapixel, back-illuminated sensor provides native 12-bit A-to-D conversion and has an impressive quantum efficiency of 50% at 300 nanometers. Its dual-stage, thermoelectric cooling produces stable operating temperatures of as much as 35°C below ambient temperature. The camera includes an electronic global shutter to ensure undistorted images when using short exposures. Each camera comes with a 2-meter (6½-foot) USB 3.0 cable and CD containing the camera drivers and control software. Price to be determined.

QHYCCD
503, Block A, Singularity Center, Shahe Town, Changping District, Beijing, China 102206
Phone: +86(10)-80709022-602; qhyccd.com

▲ PLANETARY IMAGER

Astronomical camera manufacturer ZWO now offers the ASI662MC ($149), a high-speed video camera designed for planetary imaging. The ASI662MC features the highly sensitive Sony IMX662 backside-illuminated CMOS detector with a 1,920 × 2,080 array of 2.9-micron pixels. This USB-3.0 camera is capable of recording 108 uncompressed frames per second at full resolution and many more with on-chip ROI. Its on-board 256 megabytes of DDR3 RAM acts as a buffer to ensure no frames are lost due to a slow transfer speed on older computers. Additionally, the camera can operate in 12-bit format and can function as an autoguider for your deep-sky imaging needs with its built-in ST-4 autoguider port. The camera comes complete with a 2-meter USB-3.0 cable, a 1¼-inch nosepiece adapter, and a removable fisheye lens.

ZWO
6 Moon Bay Rd., Suzhou Industrial Park, Jiangsu Province, China 215000
Phone: 0-51265923102; zwoastro.com

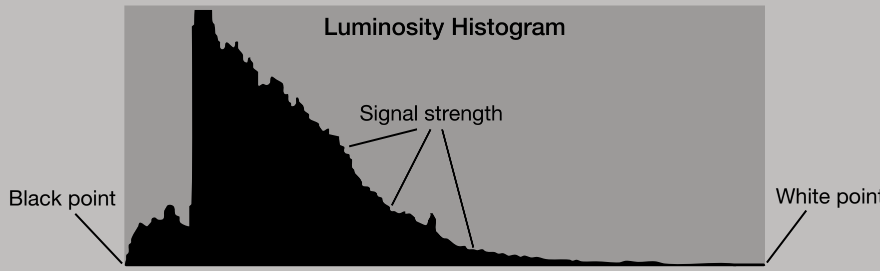
◀ APOCHROMATIC TRIPLET

Taiwanese manufacturer Founder Optics announces the FOT106 ED ($2,399). This 4.17-inch f/6 triplet apochromat utilizes two objective elements made of super ED glass (S-FPL 53 and S-FPL 51) as well as a lanthanum element to produce sharp images free of chromatic aberrations. The telescope weighs 6.7 kilograms (14.8 lbs) with its included tube rings. Its 2.7-inch-format, dual-speed, rack-and-pinion focuser is fully rotatable to quickly frame your targets. The scope includes a dedicated field flattener that produces a 44-mm corrected field. Each purchase comes with a Vixen-style dovetail mounting bar, 2-inch and 1¼-inch eyepiece adapters fitted with twist-lock collets, a universal finder mounting bracket, and an aluminum carry case.

Founder Optics
Phone: +886-3-218-0938; founderoptics.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.*

What Is a Histogram?



READING A HISTOGRAM The histogram is an extremely useful tool that displays the number of pixels across a range of brightnesses. Typically, the darkest pixels are displayed along the left edge of the graph while the lightest are near the right.

FIRST-TIME ASTROPHOTOGRAPHERS often ask me how they can improve their results, and immediately I ask if they've examined the image's histogram. "The what?" is usually their response, but once I show them what that graph is revealing, they often quickly improve their pictures.

While we can enjoy the night sky without considering much of the math involved, eventually you may need to interact with the data side of the hobby, particularly if you're interested in more than casual glances through a telescope and use a digital camera as part of your observations. A *histogram* is one of the most common and useful tools for examining data or evaluating a photo beyond its aesthetic beauty.

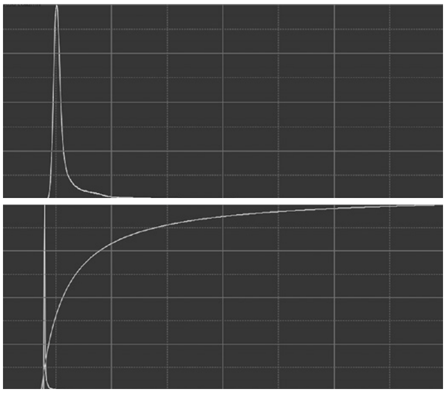
A histogram is simply a frequency diagram; it's the visual representation of the signal distribution in a file displayed as an easy-to-understand graph. It splits a single, continuous measure into "bins" that represent a specific range of values. In photography, these graphs display the amount of signal recorded in a picture — the horizontal axis represents how the pixels in the image are distributed based on their color intensity and luminosity values, while the vertical axis displays how many pixels contribute to each intensity level.

A histogram is very useful for revealing if your photo has clipped highlights or shadows. For example, in a picture with plenty of exposure such as a daylight scene or a close-up of lunar craters, the histogram displays a wide range of tone spanning the entire graph. An underexposed image will have the majority of its signal appearing in the left side of the histogram, while overexposed images will peak at the far right, where objects look completely white in the photo. Most consumer cameras offer a histogram display that allows you to quickly assess the quality of your exposures.

Typically, the histogram is arranged so that the darkest part of the image appears at the leftmost point of the graph, and the white point is at the far right. Some tools in *Adobe Photoshop* display a histogram with the white point at left, though the program allows you to reverse this if desired.

Naturally, you may think that you'll want the histogram levels in your astrophotos to start at the very left and fully extend to the right. But that isn't usually the case. In a properly exposed deep-sky image, the signal often appears as a narrow spike close to, but not abutting, the leftmost edge of the graph. This is because, unlike in a daylight scene, the dark background sky and stars dominate deep-sky astrophotos. The actual signal we are interested in resides within that narrow spike, and we have to "stretch" that data in order to display the full range of values of the galaxy or nebulae we've photographed. But there's much more to it than that, as is often discussed in the astrophotography articles we regularly feature in *S&T* (see page 62).

The histogram is a simple yet valuable tool that helps you to better comprehend how the signal you record is distributed. Understanding exactly how it works can greatly improve the quality of your images, whether they're for research or simply to show the beauty of the night sky. ■



SEAN WALKER (4)

▲ **ENHANCEMENT** *Middle top:* This illustration shows the histogram for the image of M33 in Triangulum at left before any enhancements. Note that the signal in the top graph is confined to a narrow region in the histogram. *Middle bottom:* The lower graph shows that stretching the data brings out the full range of tones present in the same picture as seen at right.

Focus on Keeping Warm

Insulate the heat sinks on your telescope.

◀ Colored duct tape over neoprene foam insulates fingers from the cold metal of your focuser knobs and preserves the familiar color coding between coarse focus (silver) and fine focus (black).

I LOVE THE bumper sticker that reads, "Astronomers do it in the dark." This is such a truism, it's funny. But I want one that acknowledges the reality behind that truth. I want one that says, "Astronomers do it in the cold." Because where I live anyway, the nights get downright frigid.

I put on wool socks and felt-lined boots and ski pants, and I wear multiple jackets and a wool stocking cap, so my body stays fairly warm, but my fingers wind up freezing on all except the warmest nights. I wear fingerless gloves (hand-knit by my wife, and that knowledge keeps me at least 10° warmer), but my fingertips are still exposed. There's nothing I can do about that, really. I need them free to handle eyepieces and the focuser.

And therein lies the problem: The eyepieces and focuser are heat sinks, drawing the warmth right out of my fingers every time I touch them. And because I like to view objects at multiple magnifications, and I like to travel back and forth through the focal point until I get it spot-on, I have a hand on an eyepiece or the focuser almost continuously.

Finally, this last winter as I was packing up one night with fingers numb from the experience, I had an epiphany: If I can't insulate my fingers, why don't I insulate the eyepieces and the focuser knobs?

It was a "Eureka" moment worthy of Archimedes. The next day I gave it a try, cutting strips of ⅛-inch-thick neoprene foam, the kind people use to make cosplay costumes, and wrapping them around the focuser knobs. I attached them with double-stick tape, but their natural springiness overpowered the tape and the ends stuck out like starched collars, so I overwrapped them with duct tape. That held them down, and it gave me an opportunity to use silver tape for the coarse-focus knob and black tape for the fine focus, duplicating the manufacturer's color scheme so my instinctive reach still finds the right target.

For my eyepieces I cut wider strips of the same foam and wrapped them around the bodies of my favorites, marking their focal lengths on the outer tape wrap with a silver Sharpie.

It seems like too simple a fix to make a significant difference, but let me tell you what: Next time I went out, my fingers stayed warm. That insulating foam felt positively picante to the touch compared to the former bare metal. And there was a bonus: None of my eyepieces dewed up, and that was on a night of a Messier marathon.

I totally recommend this simple modification. It'll keep your fingers much warmer. I used neoprene foam, but EVA or any dense foam rubber would work just as well. A strip of old inner tube would probably do. Even a wrap or two of cereal box cardboard — anything that keeps your hands from touching metal or hard plastic.

How long should you make the strips? Pi times the diameter will get you close, but that doesn't account for the thickness of the foam. Better to make it a bit long and cut off the overlap after you've wrapped it around.

If your scope has metal trusses, those can also be terrible heat sinks if you hold onto them when slewing the scope. Pipe insulation works wonders

▶ To insulate your focuser or eyepiece, you need some thin foam rubber, double-sided tape, duct tape, and a few basic tools.

ALL IMAGES COURTESY OF THE AUTHOR

▲ Double-sided tape keeps the foam from creeping but won't hold the ends down tight. Duct tape over the top solves that problem.

▲ Even a plastic eyepiece barrel can suck heat from your fingers. A layer of foam rubber wrapped around it can help keep you warm. A silver Sharpie makes a good label.

▲ Pipe insulation works well to keep hands from touching cold aluminum trusses.

to keep your hands away from that heat-sucking metal, but even a single wrap of ⅛-inch-thick foam rubber will help immensely.

Sometimes it's the simplest additions to your gear that provide the most payoff. If your fingers get cold while observing, give this a try. It's one of the best modifications I've made to my scope in ages.

■ Contributing Editor **JERRY OLTION** still can't play the flute, but his fingertips are at least staying warm now.

TAIL OF THE SWAN

Vince Farnsworth

This dusty area of Cygnus hosts an immense cloud of ionized hydrogen gas spanning some 50 light-years across. Opaque dust splits the nebula into several regions known today as the North America Nebula (NGC 7000, top left), the Pelican Nebula (IC 5067 and IC 5070, right), and IC 5068 (lower right).

DETAILS: *Canon EOS Rα camera and 300-mm lens. Total exposure: 4 hours at f/4, ISO 3200.*

◁ SOUTHERLY BARRED SPIRAL

Massimo Di Fusco, Adriano Anfuso, and Telescope Live Team

Pinkish star-forming regions and dark dust lanes lace the spiral arms of M83 in Hydra. With an apparent magnitude of 7.5, it's one of the brightest spiral galaxies in the night sky.

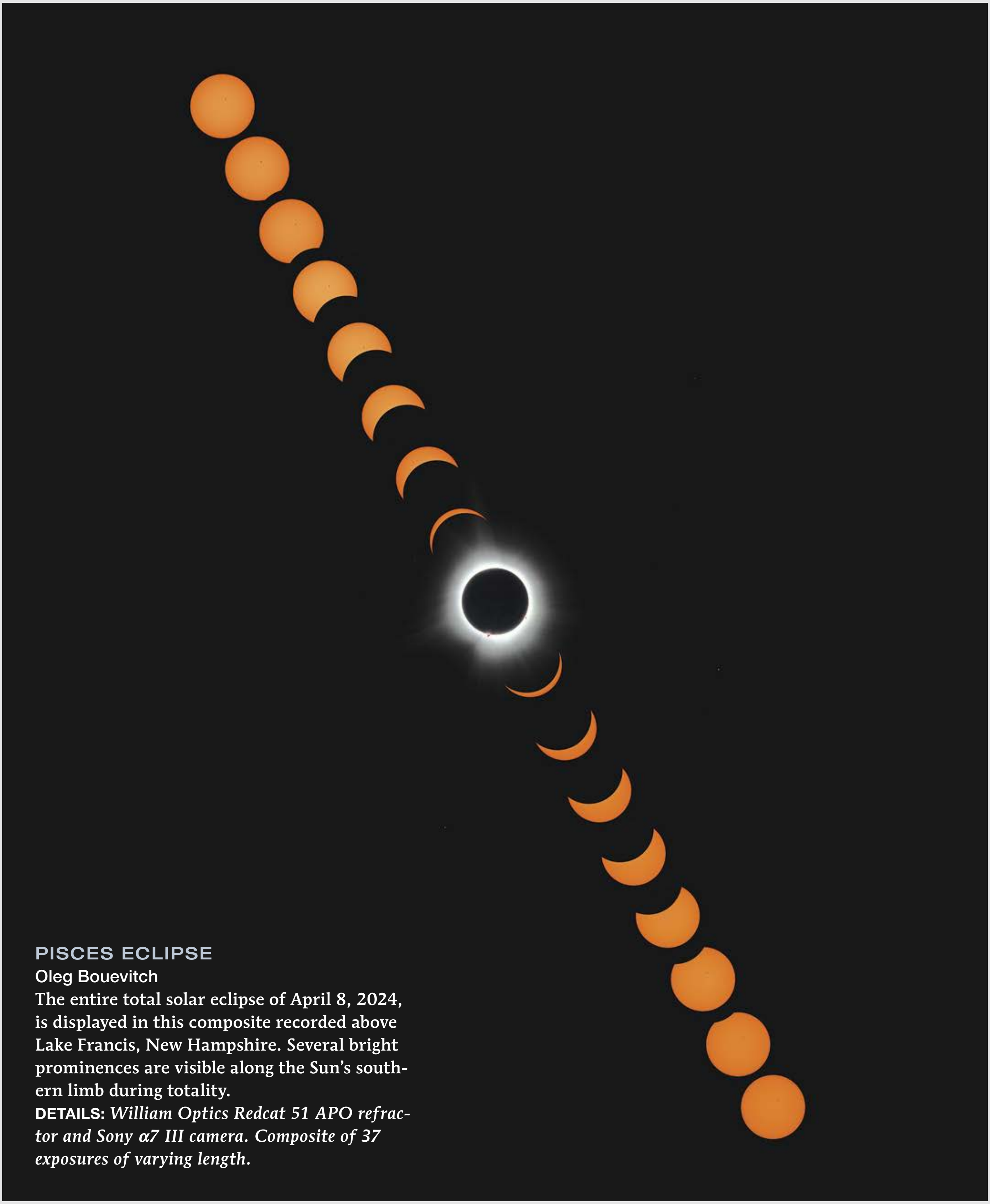
DETAILS: *PlaneWave CDK24 Corrected Dall-Kirkham telescope and FLI ProLine 9000 camera. Total exposure: 6.75 hours through LRGB filters.*

▽ COMETARY COVER-UP

Chris Schur

The long tail of Comet Tsuchinshan-ATLAS (C/2023 A3) passes in front of the distant globular cluster M5 on the early evening of October 14, 2024. As Earth moved through Tsuchinshan-ATLAS's orbital plane, the comet exhibited a prominent, needle-thin antitail made up of dust left behind in its orbital path.

DETAILS: *ZWO ASI2600MC camera and Samyang 135-mm lens. Total exposure: 9 minutes at f/2.4.*



PISCES ECLIPSE

Oleg Bouevitch

The entire total solar eclipse of April 8, 2024, is displayed in this composite recorded above Lake Francis, New Hampshire. Several bright prominences are visible along the Sun's southern limb during totality.

DETAILS: *William Optics Redcat 51 APO refractor and Sony α7 III camera. Composite of 37 exposures of varying length.*

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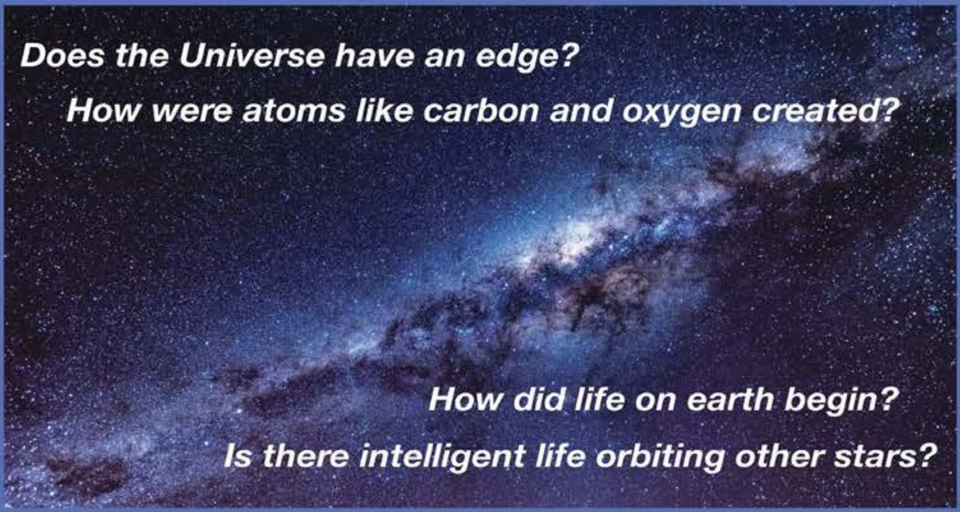

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A Grand Milestone

With its 1,000th issue, Sky & Telescope *joins an elite club of long-lived monthly magazines.*

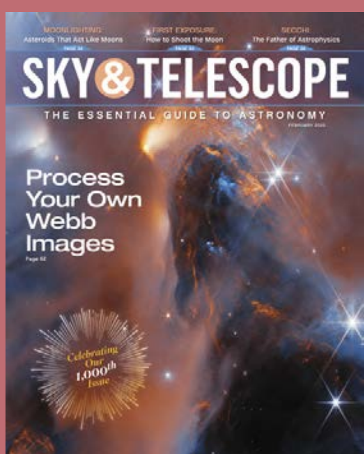
YOU'RE READING this magazine's 1,000th issue. This puts *S&T* in very rare company. To find out how rare, I did some online research to generate a comprehensive list of monthly magazines that are at least 80 years old and have been published every month since their founding without interruption.

I came up with this list: *Scientific American* (founded in 1845), *Harper's Magazine* (1850), *Good Housekeeping* (1885), *National Geographic* (1888), *Vogue* (1892), and *Sky & Telescope* (1941). I expected the list to be short, but not *that* short. I was also surprised to find that half the magazines on the list regularly cover science and that all but *S&T* are household names.

Of course, print magazines are a vanishing breed. Hardly a month goes by when you don't hear of another well-known title going digital-only or out of business. *S&T* faced its own most dire threat in 2019, when its then-owner went under. But on my suggestion and after months of due diligence, the AAS (for which I worked at the time) acquired the magazine. So, thankfully, *S&T* has lived to join the shortlist of monthlies that have published at least 1,000 consecutive issues.

It's tempting to compare the state of astronomy in November 1941, when *S&T*'s first issue appeared, with that of the field today. But I and others have done that on the magazine's 70th, 75th, and 80th birthdays in the November 2011, 2016, and 2021 issues, respectively. But I urge you to examine our timeline (pages 12–13) and marvel at some of the key discoveries and events that *S&T* has covered since its inception. Here I want to focus on the future.

While I see both professional and amateur astronomy facing serious threats, I remain hopeful that together we'll find ways to mitigate them. For example, worsening light pollution — from excessive or poorly designed lighting down here and the rapidly growing population of artificial satellites up there — could render stargazing from the ground frustrating or even virtually impossible, which might in turn make much of *S&T*'s content irrelevant.



▶ From its 1st to its 1,000th issue, *S&T* has come a long way.

But astronomers aren't alone in recognizing that we have to restore dark night skies. It's now clear that artificial light at night harms a wide variety of living things, including humans. Accordingly, night-sky-friendly lighting is becoming more common, new light-pollution filters are cutting through the skyglow, and satellite operators (some of them anyway) are cooperating with astronomers to minimize interference with telescopic observations. So there are reasons to be hopeful that future generations will be as inspired by the starry night sky as readers of this magazine have always been.

I'm hopeful, too, about *S&T* not being abandoned by astronomy enthusiasts, who now have so many other ways to learn about important cosmic discoveries and upcoming celestial happenings. Someday the print magazine may go the way of the dodo, but I expect *S&T* to live on in some form and to remain indispensable to those who appreciate having authoritative, understandable astronomical information delivered in a convenient, affordable package.

With that in mind, I look forward to reading *S&T*'s 1,437th issue to prepare for Comet Halley's July 2061 swing around the Sun. Of course, I'll have to live to 105, but hope springs eternal.

■ **RICK FIENBERG** was *S&T*'s Editor in Chief from 2001 to 2008. Last year he received the Astronomical Society of the Pacific's Klumpke-Roberts Award (**https://is.gd/ASPaward**).

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