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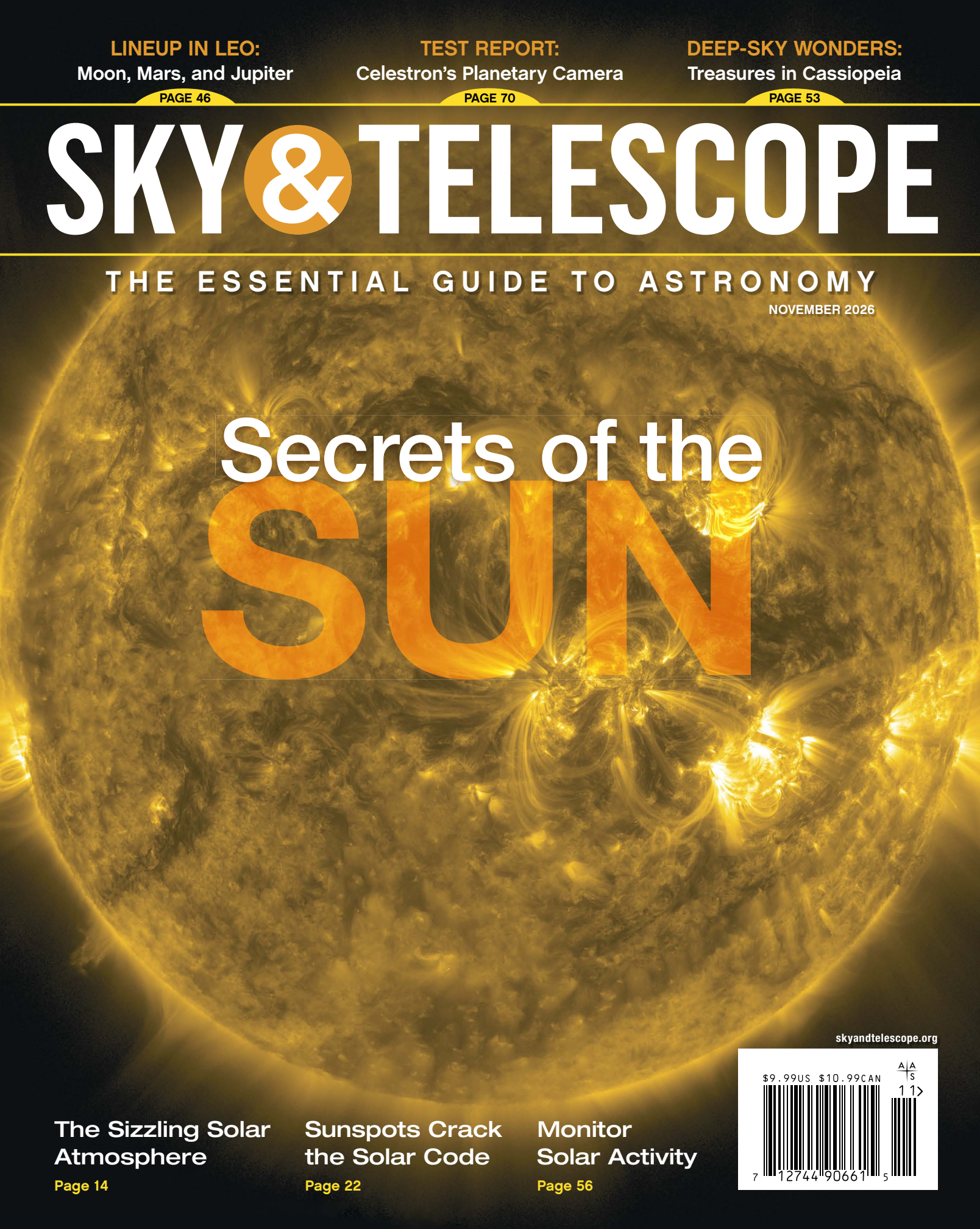
THE ESSENTIAL GUIDE TO ASTRONOMY

NOVEMBER 2026



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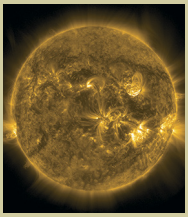

The Sun at an ultraviolet wavelength of 17.1 nm on July 1st

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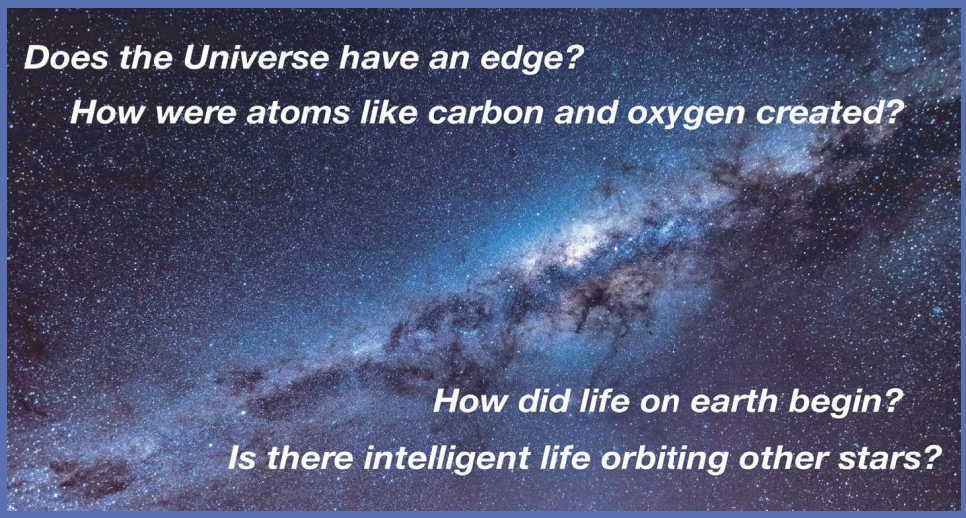

The universe in 16 weeks

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Wonders Among Us

HAPPY BIRTHDAY TO US! We turn a venerable 85 years old this November. We have published monthly ever since November 1941, without missing a single issue. And we couldn't have done it without you, faithful readers. Thank you for cheering us on through the decades.

Amidst our celebrations, we are also saying fond farewells to a couple of longtime columnists. Lunar scientist Charles "Chuck" Wood is retiring after writing about the Moon for us since July 1999, when his first Lunar Notebook column appeared. This redebuted as Exploring the Moon, which has run since July 2004. His final essay will appear in next month's issue.

We also bid farewell to observer extraordinaire Ken Hewitt-White and his Suburban Stargazer column, which had its swan song in the September issue. While we're sad to see them both go, I'm sure you'll join us in wishing them well.

The good news is that those pages won't remain empty. After the inimitable Sue French hung up her pen a few years ago, we decided to give the Deep-Sky Wonders column time to rest on its laurels. But now we're bringing it back with a bang. And who better to take that on than David Eicher, who as a young teenager started his own magazine, *Deep Sky Monthly*, so inspired was he by reading Walter Scott Houston's column in these pages. Between Scotty and Sue, Dave has big shoes to fill, but if anyone can do it, he can.

Closer to home, Michael Bakich is taking charge of Exploring the Solar System. (You might have noticed he penned last month's column.) We're sure you'll enjoy voyaging with him through our little corner of the Milky Way.

Now let's turn to the issue you currently have in your hands.

It continues to flabbergast me that we still have so many mysteries to unravel about our nearest star. The corona's scorching temperatures — as compared to the solar surface — have baffled scientists for nearly a century. But they're finally starting to understand how this ethereal entity can pack so much punch, temperature-wise. Turn to page 14 to read Science Editor Camille Carlisle's comprehensive deep dive into the marvelously mysterious world of the Sun's corona.

It was only with the advent of the telescope that early solar astronomers learned that the Sun isn't a smooth ball of fire. Instead, it's often speckled with a motley bunch of freckle-like dots. The discovery of sunspots and their subsequent study likely tipped astronomy from a practice of passive observation to one of active astrophysical research. Nicola Cusanelli's debut article starting on page 22 brings you the story of how this transpired.

As we turn 85, we can look backwards and bask in the glow of some marvelous decades behind us. But we must also look forward, and we sincerely hope you will continue with us on this journey through the cosmos.



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The Essential Guide to Astronomy

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Seeing Deeper

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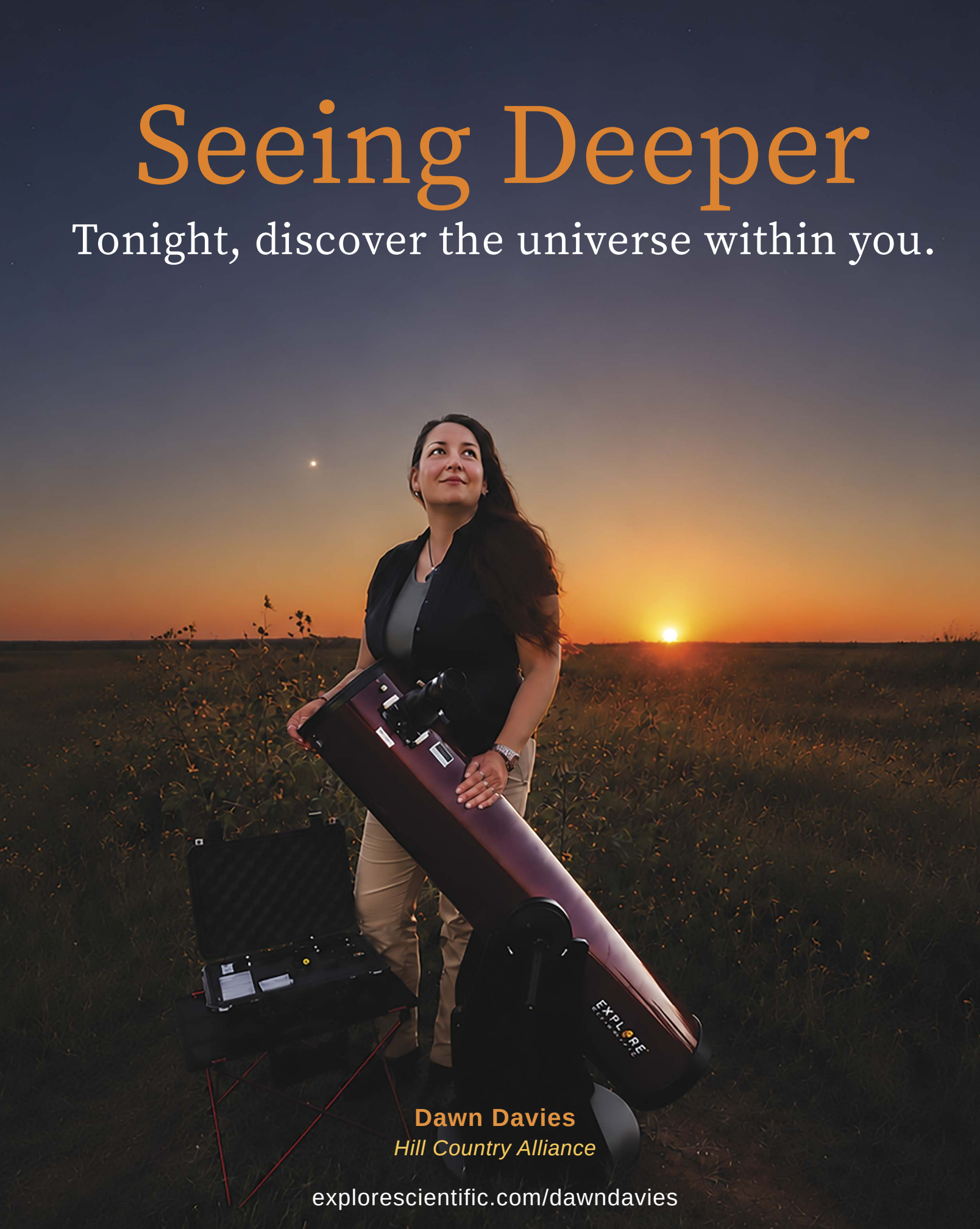

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New Martian Horizons

Seeing the Viking Lander image again in "First Feet on Mars" by Ben Evans (*S&T:* July 2026, p. 20) was like getting a visit from an old friend. In 1976, I was leading a talented image processing team at the Jet Propulsion Laboratory (*S&T:* Jan. 2024, p. 6).

On July 20, 1976, the first two images from Mars's surface began appearing in the JPL flight operations area on low-resolution television screens, and we knew we had a successful landing. We grabbed the tapes, raced down the hill to the JPL Image Processing Laboratory, and ran our software to calibrate the images. We had rigged up a Polaroid camera to the computer. The Polaroids of the first two images passed muster, and we sent the digital files over to the JPL photo lab for distribution to the world.

I saved those Polaroids: the photo of the lander footpad and an image looking forward showing the first part of a 360° panorama (on pages 26–27 of Evans's article). In all the excitement, we smudged the print of the first panorama. Recently, as my family prepared to move from our home, I found the sheet of paper with the original photos glued on. I donated the original sheet with the Polaroids attached to the JPL archives. But before I did, I took one last nostalgic photo of the first images ever sent from the surface of Mars.

William Green
Reseda, California

One of my strongest childhood memories is of a walk I took on the streets of Los Angeles, California, with my dad, an English literature major who had grown up reading Flash Gordon. As I remember it, Dad abruptly stopped in front of a newspaper vending machine for some unspoken reason. In went a hard-earned dime (I think it was a dime!) and out came a newspaper with pictures from the surface of Mars. Memories can deceive, but I'm pretty sure my usually loquacious father was speechless.

Thanks to Ben Evans for dusting off this memory and putting the awe-inspiring Viking mission into its scientific, political, and technological context.

Joshua Roth
Arlington, Massachusetts

Ben Evans's wonderful article on the 50th anniversary of the Viking missions evoked memories of the event and how it fed my appetite for all things Martian. Reading the sidebar and learning that the landing sites are now memorials was delightful.

Finding out that the Lander 2 site is now the Gerald Soffen Memorial Station evoked another Martian memory: In 1967, as a teenager living in Quito, Ecuador, with unlimited access to a 10-inch refractor, I anticipated the opposition of Mars that year. I had the opportunity to meet with Gerald Soffen as he traveled through South America, and he was charmed to find an eager young astronomer deep in the Andes. Soffen (1926–2000) led the Viking team's experiments and shaped NASA's astrobiology program.

Following our meeting, he wrote to me from JPL, "We are all primed for the Mars opposition here. It should be an important year for Mars . . . I asked about your filter and [the best suggestion for observing details on Mars] is get 'any yellow haze filter.'" Later, he sent me one, and I have used the Gerald Soffen Memorial Filter whenever Mars calls for it.

Robert D. Hicks
Cheltenham, Pennsylvania

Binofinder

"Build a Custom Bino-Chair" by Jonathan Kissner (*S&T:* July 2026, p. 74) was a great article, but at 16×, it could use a finder. Mine is three sticks, some paint, and two small bits of glow-in-the-dark plastic from the Halloween store, held on with Alien Tape and magnets.

It's a binocular sight, two glowing dots on sticks. You look past each side. Nothing in the direct field of view, no field-limiting frame, just four glowing dots bracketing the target.

Mark Goll
San Antonio, Texas

Wild Numbers

I was fascinated by Emily Lakdawalla's "Rubin Observatory Finds Fast-Spinning Asteroids" (*S&T:* July 2026, p. 8). The article states that of 2,103 asteroids detected, 1,900 were previously unknown. That is amazing. There are tens of thousands of named asteroids

WILLIAM GREEN

and hundreds of thousands of numbered asteroids in the solar system. With more than 300,000 unique observations of solar system objects, Rubin detected only 203 known asteroids — why weren't more known asteroids captured?

James Richards
Gulfport, Mississippi

Monica Young replies: *Great question! The 2,100 asteroids that were detected were found in only a short sequence of Rubin images that viewed a small region of sky. The detections came from 1,185 images that covered much of the Virgo galaxy cluster — essentially, Rubin was viewing through a keyhole into space. Within that keyhole view, Rubin's sensitive imagery picked up far more asteroids than we'd seen before.*

As Rubin begins its Legacy Survey of Space and Time, it's going to be viewing far more than that keyhole — it'll be seeing all of the southern sky. It'll then pick up those hundreds of thousands of known asteroids as well as millions more. (You can read the full news story, with more detail on the detections, here: **skyandtelescope.org/Rubin-asteroids***).*

Dedication

The July 2026 issue of *S&T* marks the 60th continuous year of my subscription. I sent for a sample issue in June 1966 for $0.25 and received my first issue in July 1966.

Now at age 74, I don't get out under the stars as much due to the sky pollution in northeastern New Jersey. However, my passion for all things astronomical and *Sky & Telescope* are as strong as ever. I'm going to keep on for as long as possible. Thank you for producing such an excellent magazine all these years.

Michael Blake
Emerson, New Jersey

Celestial Travels

Thank you for publishing Joe Barry's "Freedom's Beacon" (*S&T:* June 2026, p. 14). I was aware of Harriet Tubman's extraordinary skills in rescuing her comrades but not of her knowledge of Polaris and celestial navigation. The historical articles you've published on the use of stars for navigation and Don W. Olson's articles examining paintings and photographs for linkage to the night sky are particularly interesting to me.

Helen Gjerde
Saratoga, California

FOR THE RECORD

- After accounting for obscuration and other design features, the Giant Magellan Telescope's effective light-collecting area is 368 square meters, or equivalent to that of a 21.6-meter mirror, not a 25.4-meter instrument (*S&T:* May 2026, p. 28).

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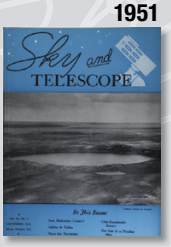
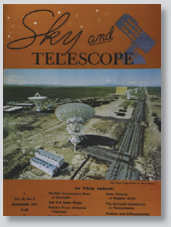
75, 50 & 25 YEARS AGO by Sabrina Garvin

1951



1976



2001



November 1951

Ananke "A telegram received at the Harvard Observatory clearinghouse on Saturday, October 6th, read: 'Object magnitude 19 probably a new satellite of Jupiter photographed by Seth B. Nicholson with [the] 100-inch . . .'

"Jupiter already has 11 known satellites, three of them discovered by Dr. Nicholson. He is on the staff of the Mount Wilson Observatory . . . If this discovery is conclusive, Dr. Nicholson will rank with Galileo as having found four of Jupiter's moons."

Ananke was confirmed as Jupiter's 12th moon shortly thereafter. As of this past March, Jupiter has 101 officially recognized moons.

November 1976

The Enterprise "In the years since the final Apollo mission, NASA has been preparing the next step in manned space exploration — the Space Shuttle. . . . September 17th was the dedication date for the first of five proposed shuttle orbiters . . .

"Routine access to outer space became visibly one step closer as OV 101, the first Space Shuttle orbiter, was formally rolled out of its nine-story hanger at the Rockwell International Space Division plant in Palmdale, California. Thousands of spectators came to view the nearly flight-ready vehicle, bearing . . . the name *Enterprise.*

"Many NASA officials credit the popular television series 'Star Trek' with much of the public interest in the space program, and a vigorous letter-writing campaign by the show's fans (called Trekkies) had a decided effect on President Ford's selection of the name. As the real-life *Enterprise* was pulled into view, an Air Force band played the theme music from 'Star Trek.' Many members from the series' cast were also present. . . .

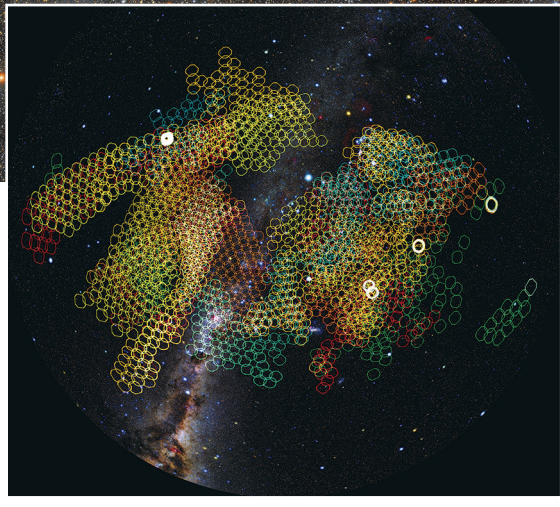
"For the present, OV 101 will be used as a test vehicle only. A second orbiter . . . is scheduled to make an in-orbit test flight during March, 1979, with payload deliveries to begin in 1980. If completed on time, the European Space Agency's Spacelab (a manned, self-contained laboratory) will probably be the shuttle's first operational payload."

November 2001

Rush-Hour Fireball "Just at the peak of the evening rush-hour commute on July 23rd, a dazzling meteor lit the blue skies over much of the northeastern United States. Visible from Virginia to the Canadian border, the intruder tore into the atmosphere above Pennsylvania at 6:19 p.m. Eastern Daylight Time (EDT), penetrating deep enough to create sonic booms audible from Williamsport and surrounding areas. Residents there reported hearing 'a deafening thunderclap,' and some thought the fireball was a falling airplane. Within minutes emergency-services switchboards filled with hundreds of calls. Early estimates of the meteor's magnitude ranged from –20 all the way up to –26 (as bright as the Sun)."

TELESCOPES

Rubin Observatory Begins Long-Awaited Survey of Space and Time



▲ This map shows a representative week of Rubin observations for the Legacy Survey of Space and Time. The color of each tile represents the filter used for the exposure, spanning a series of ultraviolet to near-infrared wavelengths.

NSF–DOE VERA C. RUBIN OBSERVATORY / NOIRLAB / SLAC / AURA (2)

ONE YEAR AGO, the Vera C. Rubin Observatory released its first photos (*S&T:* Oct. 2025, p. 8) — tiny windows on a multitude of asteroids and galaxies, captured in only 10 hours of test observations. Those were tantalizing morsels compared with what's to come.

On June 30th this year, the observatory officially began its Legacy Survey of Space and Time (LSST). Designed to survey the sky every three days in ultraviolet through near-infrared light from Rubin's site on Chile's Cerro Pachón, LSST will capture an unprecedented time-lapse movie of the universe.

"It's what I could only dream about 25 years ago," says planetary scientist Mike Brown (Caltech).

Since first light, the Rubin team has tested for functionality, data quality, and consistency. Now, the $800 million observatory swivels the 8.4-meter Simonyi Survey Telescope to a new section of sky every 40 seconds. Over the next 10 years, the world's largest digital camera will capture each point on the sky around 800 times.

Whenever the telescope detects an object that has moved, brightened, or dimmed, the processing center at California's SLAC National Accelerator Laboratory sends out an alert. Astronomers expect up to 7 million alerts every night (*S&T:* July 2026, p. 11).

▲ The Vera C. Rubin Observatory photographed this 1.7-gigapixel image of a field of stars in Lupus, revealing interstellar gas and dust that dim the stars ever so slightly.

Thousands of supernovae detected every night will keep astrophysicists occupied, while planetary scientists look forward to the 6 million new solar system objects they expect LSST to find over the 10-year program. Still others will look for dozens of predicted interstellar objects; before Rubin, only three were detected.

Beyond that, "the most important questions LSST will help us answer are possibly the ones we haven't even thought of yet," adds Kat Volk (Planetary Science Institute).

Those questions may touch on the ever-elusive dark matter and dark energy. The giant telescope will employ *weak gravitational lensing*, for example, to search for dark matter's subtle effects on the appearance of distant galaxies.

But perhaps the biggest impact on astronomy will be its sheer deluge of information (*S&T:* Sept. 2016, p. 14). Every night, the observatory will log 10 terabytes of data — the equivalent of 1,000 high-quality feature films. Within one year, the Simonyi telescope is expected to image more objects than all other visible-light observatories in human history combined.

Unfortunately, not all of this information will be pristine, points out Samantha Lawler (University of Regina, Canada). The 15,000-plus satellites now zooming overhead may add streaks to images or obscure fainter astronomical sources, and the number of satellites is only expected to grow. The response to both the data flood and the satellite defects leans on artificial intelligence (*S&T:* Apr. 2026, p. 62).

"This moment is marking a new era in astronomy," says cosmologist Arun Kannawadi Jayaraman (Duke University), who helps manage Rubin data, "not just in terms of the data volume and quality that the LSST will usher in, but also in how research in astronomy gets done."

■ HANNAH RICHTER

BLACK HOLES

Euclid Telescope Finds Earliest Quasars

THE EUROPEAN SPACE AGENCY'S Euclid space telescope has picked up 31 early quasars that have evaded detection until now. One of these is the new record-holder for earliest known quasar: This voracious supermassive black hole formed within 670 million years of the Big Bang.

Euclid has the resolution and sensitivity of the Hubble Space Telescope, but with a field of view 270 times larger (*S&T:* Sept. 2025, p. 14). As a result, Euclid can sweep vast swaths of sky for rare objects like early quasars.

But Euclid can't confirm that a point of light really is a quasar; that requires spectroscopy. So Daming Yang (Leiden University, The Netherlands) and colleagues employed *machine learning* as well as statistical methods to select thousands of promising candidates out of millions of individual sources for follow-up spectroscopy, ultimately obtaining a trial run of 123 spectra.

Most of these spectra turned up nothing — either the object wasn't a quasar after all, or there wasn't enough light to obtain a good spectrum. Yet Yang and colleagues still found 12 quasars born within 770 million years of the Big Bang and another 19 within the first 830 million years. Their report appears in the July issue of *Astronomy & Astrophysics*.

Unlike previous record-breaking discoveries, which were found precisely because they were exceptionally luminous, these new quasars aren't so bright. "For the first time, we can study the typical early-universe quasar, not just exceptional outliers," says team member Eduardo Bañados (Max Planck Institute for Astronomy, Germany).

So far, only one quasar has a mass estimate based on its spectrum: about 100 million solar masses. That's a lot, both relative to its host galaxy and to the young universe it resides in — but it's also highly uncertain and requires more data to confirm. "Webb observations of the sample are underway," Yang says.



◀ The black hole at the center of this quasar, shown in an artist's impression, isn't visible, but the gas swirling around and into its maw is.

"If they prove to be 'overmassive' relative to their host galaxies," posits Ryan Hickox (Dartmouth University), who was not involved in the study, "that would imply that the black hole grows more rapidly than the galaxy it forms within."

This sample, and others like it gleaned from Euclid's ongoing survey, will show how quasars formed and grew in the early universe.

■ MONICA YOUNG

More at: skyandtelescope.org/EuclidQSOs.

SOLAR SYSTEM

Lucy's View of Peanut-Shape Asteroid

ON ITS WAY TO future encounters with Trojan asteroids, NASA's Lucy spacecraft made a practice run past the tiny asteroid 52246 Donaldjohanson on April 20, 2025. Now, the Lucy team, led by Simone Marchi (Southwest Research Institute), has published the findings in the June 18th *Science*, detailing the eventful history of the little binary world while proving the capability of Lucy's instruments.

Lucy's images of Donaldjohanson show two large lobes stuck together at a narrow neck. The lobes have heavily cratered surfaces at least 40 million years old, consistent with the asteroid being part of the Erigone family, created 155 million years ago in a catastrophic collision in the asteroid belt. Lucy's spectroscopic measurements, which suggest the presence of iron-rich clay minerals, support the Erigone connection. But the neck that joins the lobes has a much younger surface, less than 20 million years old.

How can the neck be younger than the lobes it joins? A clue comes from Donaldjohanson's rotation. Lucy's measurements show the asteroid is slowly tumbling, with two rotation rates, one every 10.5 days and a secondary one every 19 days.

Contact binaries typically have much higher rotation rates, measured in hours, not days or weeks. At those faster rates, centrifugal acceleration counters self-gravity, pushing material toward the ends of an elongated asteroid.

But the Sun's heat and radiation pressure gradually caused Donaldjohanson's rotation to slow to its current rate. As a result, the centrifugal effect of the asteroid's rotation became negligible. At a rotation period longer than 10 hours, self-gravity took over, pulling material toward the center of mass. Since the center of mass is inside the larger lobe, loose material on the smaller lobe will, if given the chance, slide down the neck's slope toward the larger lobe, erasing the neck's craters and making it look younger.

Next year, Lucy will be approaching 3548 Eurybates and its moon, Queta, for an even more informative encounter. Eurybates is more than 10 times the size of Donaldjohanson and rotates once every 9 hours, so Lucy will be able to detect it sooner and see all faces of it multiple times before its August 2027 close approach.

■ EMILY LAKDAWALLA



▲ The neck of asteroid Donaldjohanson is much smoother than its heavily cratered lobes, indicating a younger surface.

QUASAR: ESA / CC BY-SA 3.0; DONALDJOHANSON: NASA GODDARD / SWRI / JOHNS HOPKINS APL

SOLAR SYSTEM

Supernovae Sprinkled Earth with Radioactive Elements



▲ Within this piece of deep-sea crust, researchers found nuclei of iron-60 and plutonium-244 with interstellar origins. The 3.2-cm coin is shown for scale.

EXPLODING STARS of different sorts rained radioactive elements down on Earth multiple times in the past.

Previously, astronomers have examined radioactive iron-60, found all over our planet and beyond: It's in Antarctic snow, sediments, lunar regolith, and *ferromanganese crust* (slow-growing mineral deposits on the sea floor). Massive stars make iron-60, spreading it into space when they die in supernovae. Given its short half-life of 2.6 million years, studies have been able to connect its abundance to at least two relatively recent supernovae: around 2.5 million and 7 million years ago, respectively.

Now, a longer view into Earth's past comes from radioactive plutonium-244, which has a half-life of 81 million years. It's too heavy to be produced even in the most massive stars; instead, it likely comes from the *rapid neutron-capture process*, or r-process, that occurs when two neutron stars collide in a *kilonova*.

A team led by Dominik Koll (Helmholtz-Zentrum Dresden-Rossendorf, Germany) reanalyzed 720 grams (1.6 pounds) of ferromanganese crust recovered from the bottom of the Pacific in 1976. The researchers found 77 plutonium-244 nuclei from outer space (out of a total of 286, the rest being contaminants from nuclear weapons tests). With these atoms the team traced the element's history, publishing on June 15th in *Nature Astronomy*.

While iron-60 arrived in two distinct and relatively recent events, the scientists found that plutonium-244 has been consistently present over millions of years. Yet the team also found no trace of interstellar curium-247, another r-process element with a half-life of 15.6 million years that kilonovae should create alongside plutonium. Comparing their findings, the researchers conclude that the r-process stellar explosion that made the plutonium must have occurred more than 100 million years ago, leaving plenty of time for the curium to decay away.

"Koll and colleagues have made the best determination of the history of interstellar plutonium-244 deposition on Earth," says Brian Fields (University of Illinois, Urbana-Champaign).

But Fields, who wasn't part of the team, cautions that we don't fully understand kilonovae's production of r-process elements. "Another possibility is that curium was made much less abundantly than expected," he says. If that were true, then the originating event might have occurred sooner than 100 million years. Additional data from other radioactive elements might offer means of confirmation.

■ JAN HATTENBACH

ASTEROIDS

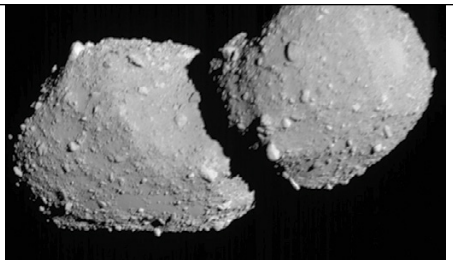
Spacecraft Visit Two Near-Earth Asteroids

THE JAPAN AEROSPACE Exploration Agency (JAXA) revealed a look at asteroid 98943 Torifune, captured on July 5th by the Hayabusa 2 mission.

The spacecraft previously made a name for itself by returning samples of asteroid 162173 Ryugu to Earth before flying off into deep space. Now it has obtained images and scientific data just 800 meters (0.5 miles) away from Torifune's surface.

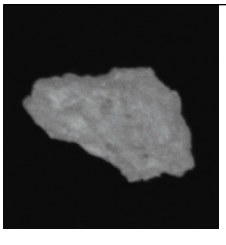
Like Donaldjohanson (see p. 9), Torifune is a contact binary, sporting twin lobes that likely came together in a gentle impact. Such collisions may have been common in the early solar system.

Torifune's surface is speckled with boulders, which may help shed light on its history. "The boulders come in a variety of shades that may show they have different compositions," says Sara Russell (Natural History Museum, London), a member of Hayabusa 2's analysis team.



▲ Japan's Hayabusa 2 took this image of bilobed asteroid Torifune from 800 meters away, revealing a familiar-looking world.

Discovered in an asteroid-hunting survey in 2001, Torifune is an Apollo-type object, which means its orbit crosses Earth's. Measuring 450 meters (1,500 feet) along its longest axis, it's about half the size of Ryugu.



◀ The quasi-moon Kamoʻoalewa appears in a fuzzy image taken from 20 km away. The Tianwen 2 mission will eventually approach this object and take a sample.

After two Earth flybys, Hayabusa 2 will arrive at its next target in 2031: the asteroid 1998 KY_{26}, which spins around every 5 minutes. Team members have studied the possibility of touching down on this fast-spinning world.

Meanwhile, China's Tianwen 2 mission announced on July 6th that it had rendezvoused with a "quasi-moon" companion to Earth called 469219 Kamoʻoalewa (*S&T:* Feb. 2025, p. 34). A fuzzy image, taken only 20 km from its surface, reveals what might be a jagged, solid fragment or a loosely gathered rubble pile. Any real analysis awaits sharper images as well as the sample-return itself. If all goes well, expect to see pieces of Kamoʻoalewa arrive on Earth by late November 2027.

The Tianwen 2 spacecraft, meanwhile, will head to its next target: Comet 311P/PanSTARRS.

■ DAVID DICKINSON

OCEAN CRUST: DOMINIK KOLL / HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF; TORIFUNE: JAXA; TIANWEN 2: CNSA

EXOPLANETS

Two Cotton-Candy Exoplanets



This illustration shows two "super-puff" planets; their *F*-class star is off to the left.

NASA / DANIEL RUTTER

ASTRONOMERS HAVE discovered two giant exoplanets in the same system 1,100 light-years from Earth — and each one is as light as cotton candy. Only one other such system is known. First identified by citizen scientists perusing data from Transiting Exoplanet Survey Satellite (TESS), the "super-puff" planets provide the strongest test yet of how such strange worlds form.

TOI-791b is the same size as Jupiter but has only 3% of its mass. That gives the world a density of just 0.038 gram per cubic centimeter — 26 times less dense than water. Its sibling, TOI-791c, is larger than Jupiter and has twice the mass of TOI-791b, giving it a marginally higher density. The discovery is published in the July *Monthly Notices of the Royal Astronomical Society*.

Georgina Dransfield (University of Oxford, UK), who led the study, calculated the planets' masses based on their near-perfect 5:3 orbital resonance: For every five orbits the inner planet completes, the outer planet completes almost exactly three. The planets pull on each other when one laps the other, nudging their locations slightly. These nudges mean the times when they transit their host star from our perspective can shift by up to 50 minutes.

However, according to Caroline Piaulet-Ghorayeb (University of Chicago), who wasn't involved, such measurements are hard to make. "It is really difficult to know the true planet masses, because different combinations of the masses of the two planets can cause the same signal," she says. "A definitive answer on how puffy these planets are will likely require future follow-up."

Astronomers think gas giants need to form far from their stars, where the planet's gravitational pull has less to compete with: The gas is cooler, with less thermal pressure causing it to escape, and the star's own gravity is weaker, too. But while the planets are relatively far from their star, on orbits 139 and 232 days long, respectively, they're closer to their star than the sweet spot for gas-grabbing. It's possible they formed farther out before migrating inward. Their inward migration then stopped when they were still far enough from the star to prevent the stripping of their puffy atmospheres.

The team plans to target the system with the James Webb Space Telescope, using the atmospheric chemistry to tell whether the planets brought their hydrogen-and-helium-rich envelopes from a colder birthplace.

■ COLIN STUART

IN BRIEF

FCC Approves Space Mirror

On July 9th, the U.S. Federal Communications Commission (FCC) approved the Reflect Orbital's Earendil 1 satellite for future launch, over strong objections from the astronomical community. This spacecraft is essentially a large mirror that will reflect sunlight to Earth's nightside. The American Astronomical Society (AAS) warned the FCC that Earendil 1 poses a "potential for eye damage to amateur astronomers looking through reasonably sized telescopes." But the FCC stated in their ruling that such concerns are outside of their role in allocating the use of the radio-frequency spectrum, adding that harm from the reflector is not likely to occur. The spacecraft will orbit at an altitude of about 625 km (390 mi) and reflect sunlight to a spot on the ground at least 5 kilometers (3 miles) wide. The company intends to launch 50,000 of these Sun-reflecting satellites in the coming years. Besides the potential for retinal injuries, the AAS also advised the FCC about the detrimental impact on astronomical research. While reflected sunlight would not be aimed at observatories, scattering of the intense beams as they pass through Earth's atmosphere would double or triple the sky brightness even at remote locations, according to recent research by Olivier Hainaut (European Southern Observatory). And of course, within illuminated areas, the light from Reflect Orbital's satellites would render stars invisible.

■ ANTHONY MALLAMA

Read more details at **skyandtelescope.org/SpaceMirrors**.

Mission Launches To Rescue Swift Observatory

On July 3rd, NASA launched a robotic craft built by Katalyst Space Technologies that will attempt to save a key astrophysics facility: the Neil Gehrels Swift Observatory. Originally designed for detecting and following up on gamma-ray bursts (GRBs), Swift combines three telescopes into one observatory, together making it capable of detecting gamma rays, X-rays, ultraviolet, and visible light. In addition to GRBs, astronomers have also used Swift to study supermassive black holes, stellar flares, and neutrino sources. But over the two decades since its launch, Swift's orbit has decayed from its original 600-kilometer (370-mile) altitude down to just 360 km. To prevent reentry into Earth's atmosphere, the Link spacecraft is meant to dock with the observatory, using lidar along with a trio of manipulators to connect to the spacecraft bus. Over several months, Link would then push Swift into a higher orbit. However, on July 28th, Katalyst reported technical issues that resulted in a multi-axis spin, disrupting communications. The team is working to recover the spacecraft. In the best-case scenario, Swift might resume science operations in the autumn of 2026, though it's unclear how the recent issues will affect that timeline.

■ DAVID DICKINSON

Find updates at **skyandtelescope.org/Link**.

Unusual Meteors

Let's take a look at misbehaving shooting stars.



▶ **A NOVEMBER TO REMEMBER** This Plate XII from *The Trouvelot Astronomical Drawings Manual* published in 1882 illustrates the various types of meteors that French artist Étienne Léopold Trouvelot witnessed during the exceptional 1868 Leonid shower.

NOVEMBER IS AN EXCITING TIME for meteor watchers as it brings two fireball-producing showers that overlap each other: the Southern Taurids, which are active from September 20th to November 20th, and the Leonids, from November 6th to 30th (see page 50). The Leonids travel at speeds of up to 71 kilometers per second, making them some of the fastest among annual showers, while the Southern Taurids slog along at an average velocity of 27 km/s, which puts them among the slowest. Both types of meteors, fast and slow, however, have been observed — or perceived — to behave in mysterious ways.

A dramatic rendering of the Leonid shower of 1868, as observed by French artist and amateur astronomer Étienne Léopold Trouvelot, records several types of oddball meteors. The plate shown at right appears in the 1882 edition of *The Trouvelot Astronomical Drawings Manual*. It represents an "ideal view," meaning it shows the types of meteors Trouvelot saw between midnight and five o'clock on the morning of November 13–14, 1868. In all, he witnessed more than 3,000 meteors that night, with "a dozen being sometimes in sight at the same instant." He noted that one doesn't have to look carefully to see meteors "curved, wavy, or crooked." They are, as Trouvelot stated, "in all cases depicted as they were actually observed."

Note the "crooked" meteor at the center of the plate, which could be a chance alignment of two different meteors observed near-simultaneously — that is, the Leonid emanating downward from the radiant terminates just where a sporadic meteor begins traveling in a perpendicular direction. I proffer this theory, as I've witnessed such an occurrence. But what of the fishhook appearance of some of the meteors? Trouvelot wasn't alone in seeing such peculiarity.

In a 1911 issue of *The Observatory*, British astrophysicist F. J. M. Stratton reported that he and R. H. Compton were at the South Parade Pier in Portsmouth, England, looking at Comet Brooks, C/1911 O1, near the zenith, when they saw a slow-moving, 5th-magnitude meteor overhead. "Towards the end of the path the meteor curled completely round and traced out a path in the shape of a letter J placed horizontally, the longer and upper arm of the hook being about 15° long, the lower about 3°," Stratton noted. The observers ruled out any kind of explosion or fireworks, as the object appeared near the zenith and came from the direction of the sea. "A swerve," he wrote, "which might be due to one of several physical causes, would suffice for the observed result."

What of the "wavy" meteors? In a 1949 issue of *Popular Astronomy*, Harvey Nininger, considered by many to be the father of modern meteoritics, reported seeing a very slow meteor traveling eastward from near the zenith that quickly reddened, becoming the "deepest red-orange color of all the meteors I have witnessed." He went on to say that the "most unusual feature of this meteor was its apparent deviation from a direct course, which I interpret as a spiraling motion because of its rhythmic nature." He observed "four complete oscillations" before the meteor straightened its course, though being "inclined slightly toward the vertical from the previous line of travel."

In a 1988 *Earth, Moon, and Planets* article, Martin Beech of the University of Western Ontario, Canada, found that "approximately one in every 200 of the visual meteors is likely to show a non-linear trail, and that of such trails, about 60% will be continuously curved and 40% sinusoidal." The curved trails, he suggested, may result from the *Magnus effect* — that is, if some spin is imparted to an object in flight, its path will be curved, like a curveball in baseball. However, an oblong-shaped object spinning on its long axis, like in American football, could also account for the spiral trails seen in some meteors.

Note that one doesn't need a meteor shower to see a peculiar meteor. It may occur at any time of year or even be a sporadic meteor during a shower. But meteor showers do present us with a better chance of seeing one, given the increased number of meteors visible. So good luck this November, and may the oddity be with you.

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

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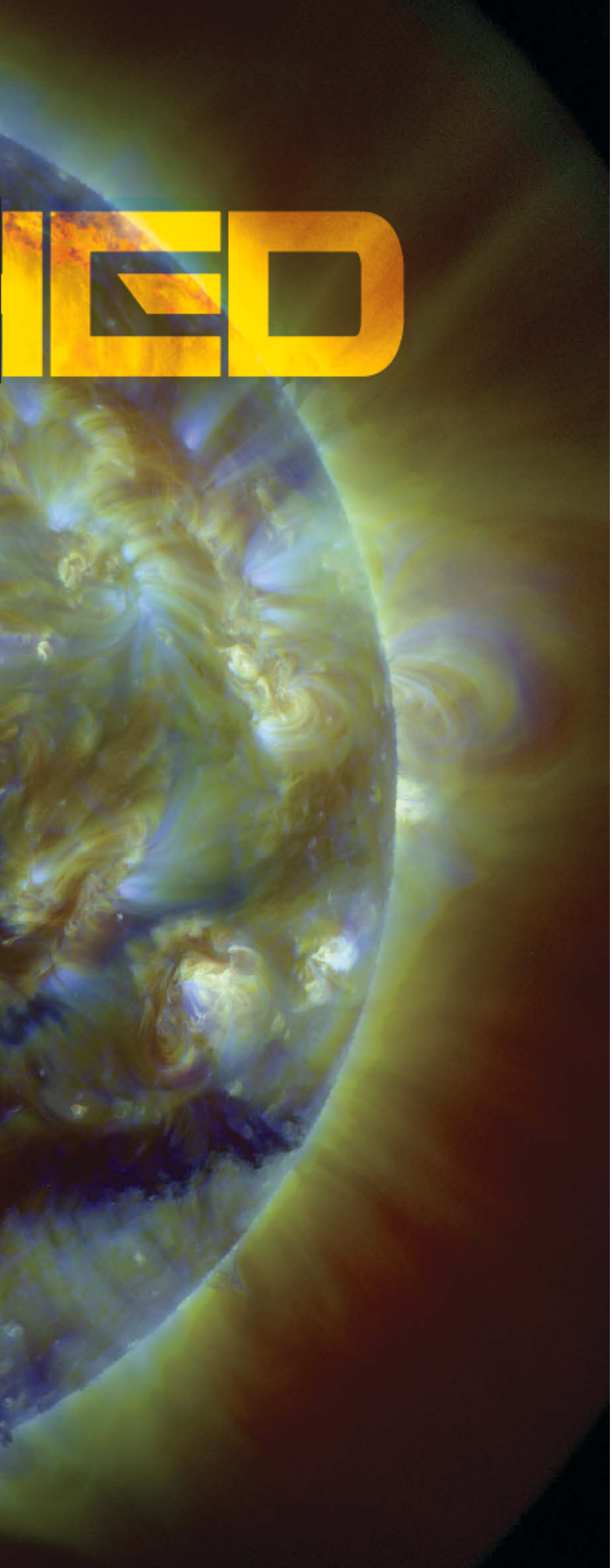
SCORCH



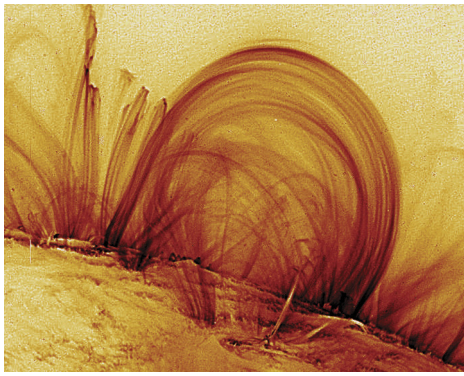


Solar physicists are pulling back the curtain on why our star's atmosphere is so hot.

The Sun is a boiling pot of hot gas. The fusion deep in its heart — where temperatures reach some 15 million kelvin, or 27 million degrees Fahrenheit — unleashes a steady torrent of energy that travels upward, transforming our star's outer zone into a giant cauldron of seething plasma. The hot, buoyant gas rises, radiates energy and cools, then sinks again, turning over in convective cells that stretch 1,000 kilometers (600 miles) across yet break up in 5 to 10 minutes.

Giant magnetic loops and streamers stick up from the cauldron's surface, called the *photosphere*, towering anywhere from 1,000 to 100,000 km high. The churning plasma below tows the magnetic strands along, wiggling, twisting, and tangling them as it drags them toward the gutters between the convective cells.

The photosphere, far from the central furnace, glows at a temperature of about 6000K. But as we climb up from that surface into the solar atmosphere, something strange happens: The temperature rises again. Some 1,000 km above the photosphere, the temperature is roughly 10,000K. As we continue outward and the plasma's density plummets, the temperature skyrockets, reaching millions of kelvins several thousand kilometers above the surface. Heavy ions up here can have energies corresponding to 100 million K, even hotter than the core.



▲ **SOLAR DRAMA** Coronal loops arch majestically along the Sun's limb in this TRACE satellite image, taken in 1999. The 17.1-nanometer band picks up plasma with a temperature of 1 million kelvin.

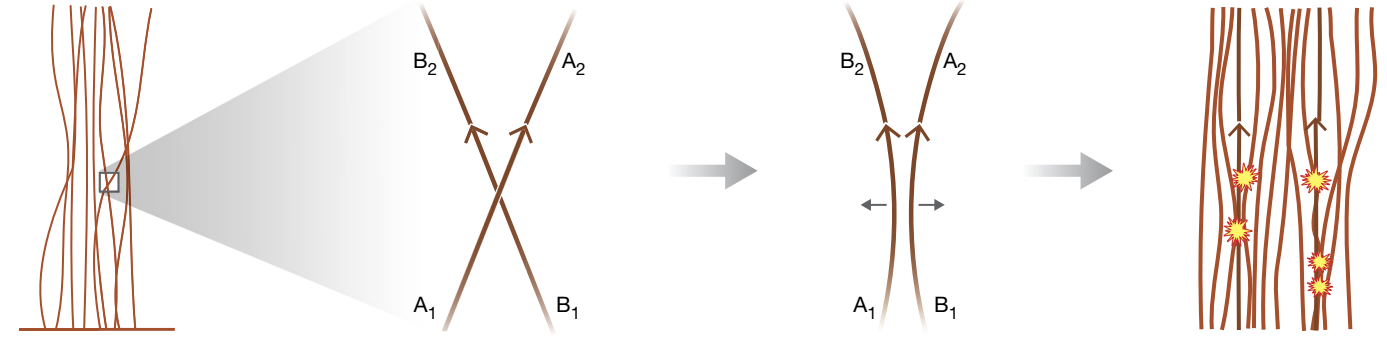
This is not how hot things on Earth behave: On Earth, the farther you stand from a bonfire, the colder you are.

Scientists have known for more than 80 years that the Sun's outer atmosphere, or *corona*, is superhot. They also know that the ultimate source for the energy behind the heating is the roiling convective motions in and below the surface, and that the soaring magnetic strands effectively serve as hoses,

◀ **SOLAR HAIR** Myriad magnetic strands fill the Sun's corona and sometimes become visible as bright loops. This image combines data taken at three wavelengths by the Solar Dynamics Observatory spacecraft, each sensitive to different plasma temperatures: 17.1 nanometers (blue), corresponding to cooler coronal plasma and the upper transition region (630,000 kelvin); 19.3 nm (green), which catches emission from both the corona and hot flares (1.3 million K and 20 million K); and 21.1 nm (red) for active regions (2 million K).

SUN: NASA / SDO AND THE AIA, EVE, AND HMI SCIENCE TEAMS; TRACE LOOP: M. ASCHWANDEN ET AL. (LMSAL), TRACE, NASA

NANOFLARES



Countless magnetic strands fill the corona, rooted in the photosphere below. Convective motions twist and tangle the strands by moving their footpoints.

When the strands are misaligned and/or twisted just right, they'll snap and reconnect in a new configuration.

The new, curved strands yank away from each other as they straighten out.

When they yank away, the strands crash into surrounding ones. The collisions heat the plasma locked to the strands.

transporting that energy up into the atmosphere.

Yet it's not enough to have a hose; the hose also needs a nozzle. Unless there's a mechanism to release it, the energy won't dump into the surrounding gas. And dump it must: Without an in situ heating mechanism, the corona would cool in about 30 minutes. Whatever the nozzle mechanism is, it must be ubiquitous and ever-active.

For many years, solar physicists have debated the nature of the nozzle. They now have the answer, at least in broad strokes. But scientists want more. Never satisfied with partial answers, they want to understand in detail what makes our star's atmosphere heat, cool, and even explode the way it does. The Sun is, after all, the primary source of light and heat on Earth. Its high-energy radiation creates our ionosphere, which affects the radio signals we use to navigate and communicate. And the Sun's hiccups can have severe consequences on our increasingly electronics-reliant society.

If we want to be able to predict our star's behavior, scientists say, then we need to understand how energy moves through its atmosphere. And part of that is knowing why the corona is so darn hot.

Lighting the Match

It all started in 1869, when astronomers pointed spectroscopes at the Sun during a total solar eclipse. For a scant few minutes, the Moon blocked our view of the photosphere, revealing the Sun's wispy, ethereal hair.

The spectra showed a green emission line that scientists didn't recognize. Thinking it came from a new element, they dubbed the substance coronium.

Not until quantum mechanics transfigured our understanding of the atom in the early 1900s did scientists realize their mistake. The green line and others found after it weren't spectral fingerprints from an alien element. Rather, the lines were emission from commonplace atoms such as iron and calcium that had been stripped of an uncommonly large number of electrons. The energy required to ionize these elements so severely meant that the corona was about 1 million K — much hotter than the photosphere.

Soon after, scientists proposed that various kinds of waves in the corona could be responsible. The most promising type, suggested by plasma physicist Hannes Alfvén, was undulations in the magnetic fields threading the Sun's ionized gas. "Initially, everyone thought the corona was heated by waves," says solar physicist James Klimchuk (NASA Goddard Space Flight Center).

There was one problem: No one saw waves in the corona.

The main challenge in studying the corona is that we cannot really observe it from the ground. It radiates most of its energy at ultraviolet and X-ray wavelengths, which Earth's atmosphere blocks. (The white halo we see during total eclipses is primarily light from the photosphere scattered off electrons and dust grains.)

The Space Age brought a breakthrough. X-ray observations revealed the corona's plasma is frozen to myriad magnetic loops of all sizes. The brightest parts of the corona corresponded with the strongest concentrations of magnetic field in the photosphere below, places where we see things like sunspots. Astronomers also realized that X-ray flashes abounded on the Sun, and that smaller ones outnumbered the big ones, all the way down to the detection limit.

In the 1980s, solar physicist Eugene Parker suggested even smaller bursts existed and that these countless, unseen *nanoflares* could heat the corona. Like their larger brethren, nanoflares would be created when magnetic strands that had been tangled by convection reconnected in new configurations, triggering a burst of energy. Many scientists favored this new solution, since nanoflares were mini versions of a familiar phenomenon.

Everything changed at the end of the 20th century, when the Transition Region and Coronal Explorer (TRACE) spacecraft gave researchers a high-resolution look at the corona.

BEATRIZ INGLESSIS / S&T

TRACE's images revealed strands undulating like plucked strings. "There was a swing in interest," says Iñigo Arregui (Canary Islands Institute of Astrophysics, Spain). When it came to heating theories, "everybody was interested in waves, and not that much in reconnection."

That changed yet again as observations and theoretical work advanced. Missions such as the Solar Dynamics Observatory, Hinode, and the rocket-borne High-Resolution Coronal Imager delivered increasingly detailed views, revealing a twisting, tangling, writhing atmosphere where the magnetic fields change over just a few hours. Flashes and jets cover regions of intense magnetism, sparked when fields reconfigure. Astronomers now know that waves are all over the Sun, and so is reconnection.

"The community is 100% convinced that physical processes that involve both kinds of mechanisms are really occurring in the solar atmosphere," Arregui says. "A debate in terms of mutually exclusive mechanisms is totally out of the question nowadays."

Nor are the two mechanisms unrelated: Reconnection can spark waves, and waves can bring magnetic strands together.

Today, solar physicists focus on when and where each process happens and what fraction of solar heating each might be responsible for. They agree that in places where the field is especially strong and snarled in loops, reconnection dominates. Conversely, in places where field lines stream out into deep space, wave heating dominates.

But that still leaves a whole lot of our star unexplained.

When Magnetic Fields Snap

Most of the corona is what's called *magnetically closed*, meaning the magnetic field arches up and back down again in giant loops tethered to footpoints in the photosphere. *Active regions* belong to the closed corona. These magnetic chokepoints sometimes sprout dark sunspots down in the photosphere, but up in the corona they're hotter than their surroundings and blaze in ultraviolet and X-rays.

Coronal loops are the building blocks of active regions, and each giant loop comprises multiple strands. A single active region can hold some 100,000 magnetic strands. Each strand heats and cools on its own, but the aggregate effect is to keep the loop hot.

Astronomers do see waves in active regions, but those waves don't carry enough energy to explain the high temperatures in the active regions' cores, which reach a few million kelvin. Instead, reconnection must be the primary instigator.

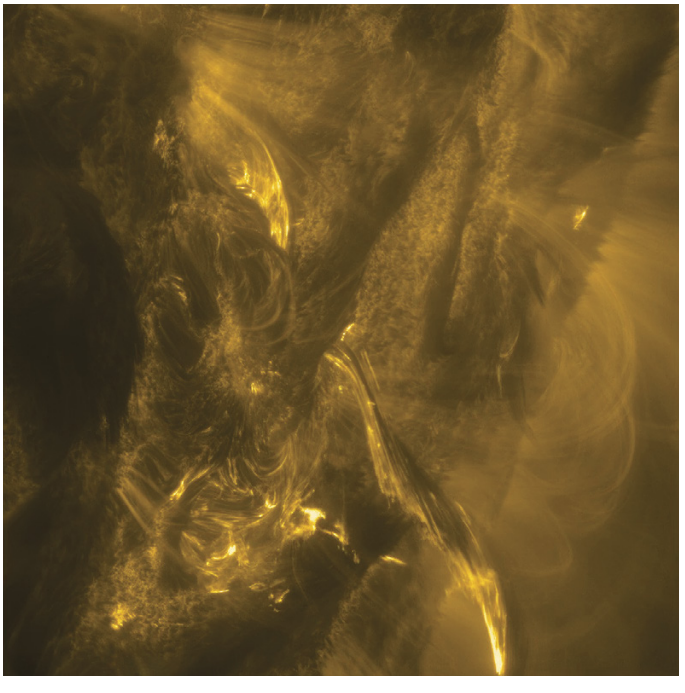
The photosphere's churning motions braid and tangle magnetic strands. This winding cannot go on indefinitely. "We twist the rubber band and keep twisting and twisting," Klimchuk says. "Eventually, it's going to snap." The only way to disentangle the strained strands is for them to break and reconnect in novel arrangements.

This rearranging creates new, curved strands that want to snap straight. The strands yank away from each other. Because the plasma particles are stuck to the magnetic field like beads on abacus wires, they go along for the ride, whipped through the corona at some 1,000 km/s (2 million mph) before they crash into surrounding material. The collisions convert all that kinetic energy into heat.

The shears, misalignments, and collapses that prompt reconnection unfold at a range of scales in the corona, creating everything from the too-tiny-to-see nanoflares to violent, large-scale plasma eruptions, Klimchuk says. Nanoflares' sporadic bursts happen endlessly in the corona's sea of strands. Unstable magnetic threads can also set off an avalanche of bursts, heating a loop and making it pop out as brighter than its surroundings.

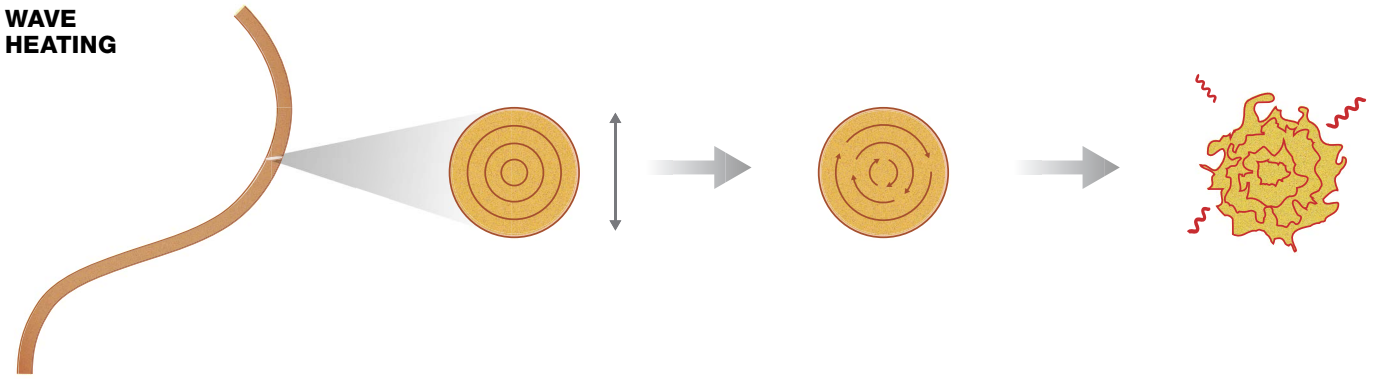
Using the European Space Agency's Solar Orbiter, Lakshmi Pradeep Chitta (Max Planck Institute for Solar System Research, Germany) and others recently watched a larger kind of magnetic avalanche unfold, catching the buildup to a major solar flare in a tangle of coronal loops. Over the course of a half hour, individual strands broke and brightened every few seconds, as though the loops were slowly unraveling. Then suddenly, one end of a thick rope broke free, swirling around for several seconds before it lit up in a surge of reconnection events, creating the flare.

Chitta says that other observations he and his colleagues have done corroborate this "controlled explosion" process. "The braided loops don't go boom," he says. "They just are progressively reconnecting with each other" in a bridled frenzy.



ESA & NASA / SOLAR ORBITER / EUI TEAM

▶ **FLARE BUILDUP** This snapshot from a video by the Solar Orbiter spacecraft shows the moment before the Sun unleashed a powerful flare. One end of a filament (extending from center) has just broken free. Bright sparks mark where magnetic field lines are snapping and reconnecting, releasing energy. About 1 minute later, an avalanche of reconnection events lit up the whole filament in a brilliant flare. Watch the video: **tinyurl.com/soflare**.



Do the Wave

Then there's the magnetically open corona. The open corona is where we find *coronal holes*, dark spots in ultraviolet and X-ray images where instead of making loops, the magnetic field stretches out into the solar system. These magnetic streamers serve as highways for particles, feeding the solar wind that billows out from our star.

The open field is also a highway for waves, Arregui says. Alfvénic waves easily travel along these seemingly endless magnetic paths, transporting energy to vast distances and heating the solar wind.

The streamers are anathema to nanoflare production, Klimchuk explains. "You have the same convection displacing the magnetic footpoints, trying to tangle and twist the field, but those tangles and twists just propagate out to space," he says. "You can't wind them up." It's like the difference between twisting a short piece of string and a long one: Twist the short string once, and it's a major change for the string; twist a long string once, and the effect is negligible.

Alfvénic waves are *transverse waves*, meaning they move along a strand like the wave of a plucked guitar string does. A string oscillates back and forth because it's been pulled out of equilibrium. As it tries to return, it overshoots, thrumming back and forth until it dissipates the energy and finally stills.

Yet unlike guitar strings' oscillations, Alfvénic waves don't die away easily. Some other mechanism must force their energy to smaller scales and release it as heat. It could be that the way the strand wriggles and writhes within itself creates turbulence and friction, which sap energy and produce heat. "This happens — at least in the computers," says Arregui, who has worked on the problem for more than 20 years.

We encounter turbulence in all sorts of places — a coffee cup, for instance. As you stir cream into coffee, the spoon's cup-size motions create smaller and smaller eddies, leading to a cascade from large to small scales that mixes everything.

In the solar atmosphere, the plasma and magnetic field are frozen together, so both become turbulent. Such turbulence likely serves as a mediator in many ways, both between scales and mechanisms. As waves propagate back and forth along strands, for instance, they'll interact with each other, producing smaller eddies of intense shear and currents that dissipate the energy. "That's widely regarded as the way that the magnetically open regions are heated," Klimchuk says.

"Turbulence is the Holy Grail in all of this, because we know that at those small scales, the dynamics become turbulent," Arregui says. "If I solve the problem of how the energy goes to these small scales, then I am done, because turbulence will do the rest of the work — even if we don't have a general theory of turbulence."

Tickled Pink

Active regions and the open corona make up only a small fraction of the solar atmosphere. Left largely unexplained is the rest of the closed corona, called the *quiet Sun*. Here, the magnetic field loops up and back down but is relatively weak.

The quiet Sun is cooler than active regions are and requires significantly less energy to heat. Solar physicists don't know how the combination of heating mechanisms plays out here. "The problem is that the quiet Sun is quiet," Arregui says.

"It does not mean that it's not changing," Chitta clarifies. "It just means that there's so much going on that you cannot really pick up any changes."

In theory, waves could (barely) provide enough energy to meet the quiet Sun's budget, although Klimchuk thinks the estimates are too optimistic. "It could be some mixture of nanoflares and wave heating," he says. "We just don't know."

The quiet Sun is not the only region scientists need to decipher in order to solve the heating problem. Another mysterious zone lies below the corona, between it and the photosphere. Here we find a jumble of plasma and magnetism that complicates the picture.

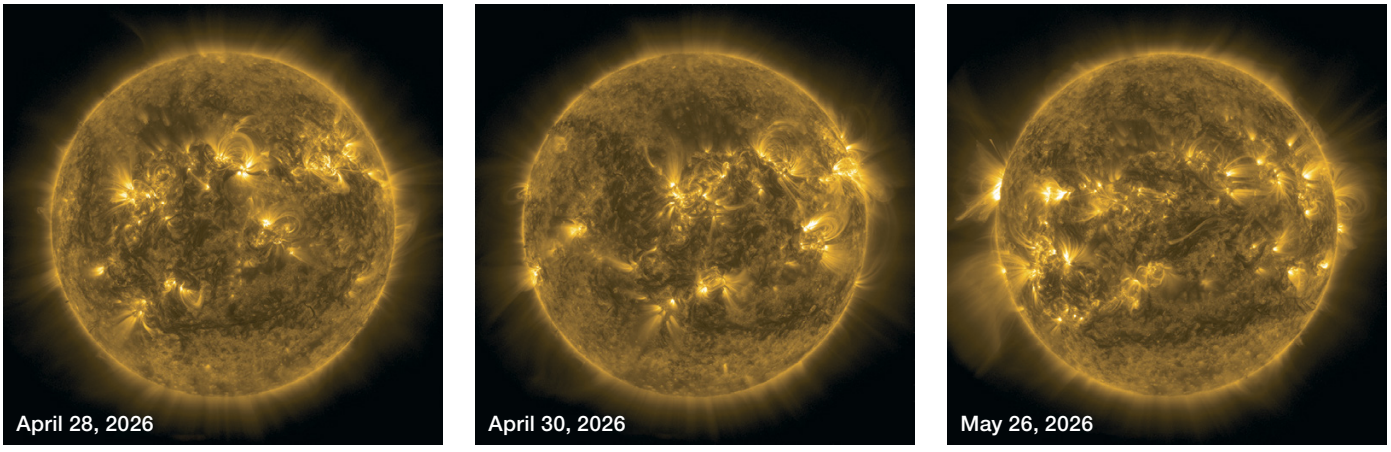
Just above the photosphere stretches the *chromosphere*, a region of middling-hot gas (ballpark 10,000K) that sometimes peeks around the edge of the eclipsed Sun's disk in

BEATRIZ INGLESSIS / S&T



CROWNING GLORY This image of the 2017 total solar eclipse combines 91 exposures of varying durations to capture the huge range of brightness in the corona. The hot plasma traces countless magnetic strands.

SEAN WALKER / *S&T*



▲▶ **CHURNING CAULDRON** The corona isn't a single temperature, so although active regions (some visible as knots of bright loops) might on average be more than 1 million K, parts of them are much cooler. These ultraviolet images capture gas of roughly 600,000K, giving scientists a look at structures in both the active and quiet Sun as well as coronal holes (darker regions) and how they all change with time. Note that the Sun takes about one month to rotate, so some of these images show the same features as they move left to right across our field of view.

rosy tendrils. The chromosphere is cool enough to have some neutral atoms, and dense enough that plasma pushes the magnetic fields around. It's so dense, in fact, that it takes more energy to heat the chromosphere than it does the more diffuse corona above it.

The chromosphere is a dynamic region, with surges of hot and cool gas and chaotic movements. It's also an energy sponge and a lousy heat conductor: Heat that goes there largely stays there. And as in the corona, whatever heats the chromosphere must happen locally.

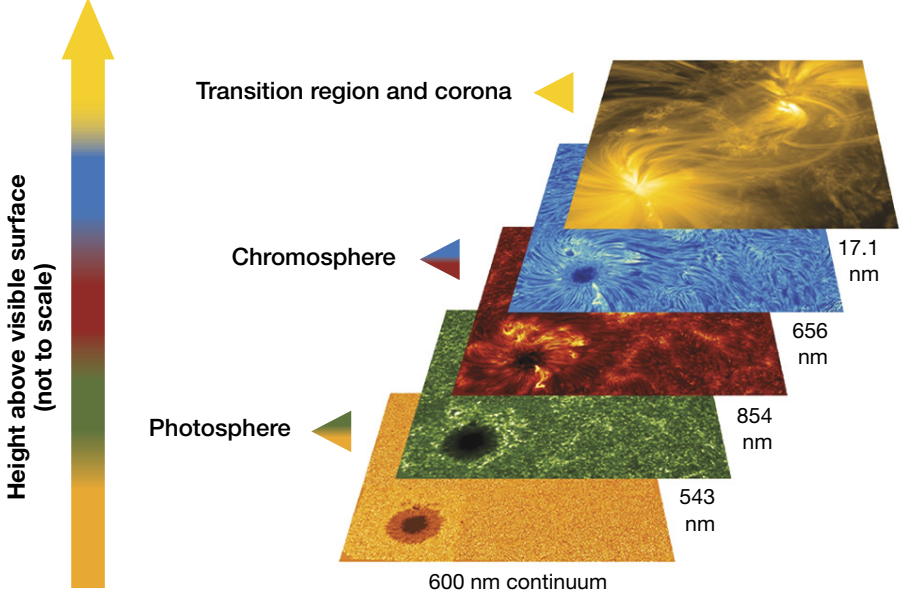
That's not the case for the transition region, an onion-skin-thin boundary that lies between the chromosphere and the corona. In a few hundred kilometers, temperatures in the transition region can soar from 10,000K to 500,000K.

"You go from the cool to the hot, from the dense to a lot less dense," says Paola Testa (Center for Astrophysics, Harvard & Smithsonian). "You go from a region where the plasma dominates to a region where the magnetic field dominates. So it's a complex region with lots of big changes."

This small layer plays an outsized role in the coronal heating problem. "It's incredibly special," Klimchuk says. The transition region is basically a dumping ground for heat from the corona. Roughly half of the energy deposited in the corona (by whatever mechanism) is radiated directly out to space. But the other half is conducted down to the transition region, heating it.

For instance, when magnetic strands reconnect in the corona, the heat travels down the new threads into the transition region. This energy pumps up the pressure of the plasma there, making it squirt back up along the strand. Such squirts help to move gas into the upper atmosphere.

All of this heating, cooling, chaotic mixing, and stymied conduction feed into why the corona has the temperatures it does. If the chromosphere didn't sap so much energy, for example, the corona would be much hotter — like "bonkers" hot, Chitta says. In a sense, the question is not, "Why is the corona so hot?" It's, "Why is the corona so cool?"

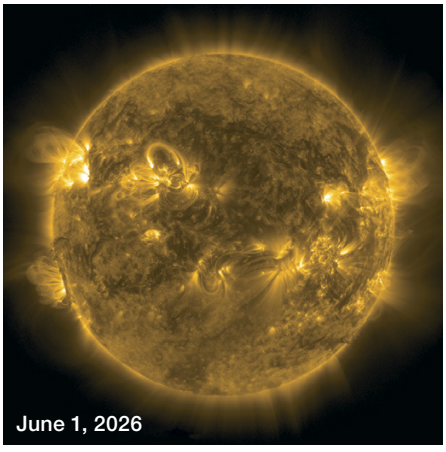


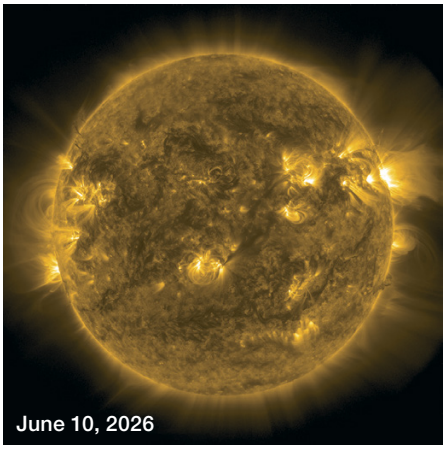
Catch Some Rays

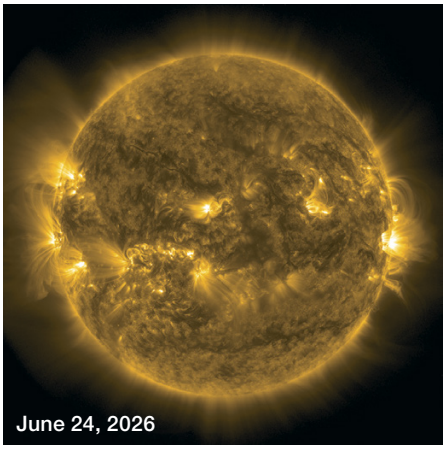
To tackle these lingering mysteries, scientists are preparing to send two spacecraft to study our star. Missions like the Solar Dynamics Observatory have given us

◀ **CHANGING VIEW** This series of images shows how an active region with a sunspot looks in different layers of the solar atmosphere. The layers do not have sharp boundaries at uniform heights — for example, although the chromosphere starts around 1,000 km up and has a thickness of roughly 2,000 km, it also has tall jets called *spicules* that can stretch several thousand kilometers higher than that.

SUN IMAGES: NASA / SDO AND THE AIA, EVE, AND HMI SCIENCE TEAMS (6); LAYERS OF SOLAR ATMOSPHERE: NSO / AURA / NSF & NASA / SDO, ADAPTED BY BEATRIZ INGLESSIS / *S&T*







beautiful, high-resolution images that catch quick changes. But these images miss a lot of the physics, Testa explains.

"I'm a spectroscopist at heart," she says. "When you look at spectra, you can actually determine the temperature, the density of the plasma, the chemical composition of the plasma, in a way that you can't with images."

If you see a specific spectral line, you know you're looking at gas with a specific temperature. Images don't have that precision. "Spectroscopy is really putting physics into astrophysics," she says.

Previous solar missions' spectrographs had narrow fields of view through a single slit; astronomers had to scan slowly across a region in order to study it. The Japanese Hinode satellite, for example, needs several minutes to construct a spectral map, blurring processes that unfold over seconds.

Instruments have also often only looked at certain parts of the solar atmosphere. Because spectral lines probe certain temperatures, different emission lines detect different layers. NASA's Interface Region Imaging Spectrograph (IRIS), for example, primarily sees gas with temperatures that correspond to the chromosphere and transition region. Testa and her colleagues have used IRIS to spot occasional, brief jets in cool coronal plasma that look like they could be created by nanoflares' tiny reconnection events. But there's currently no way to know whether these *nanojets* also happen in hotter plasma.

The new missions take complementary approaches to surmounting such shortcomings. The first, NASA's Multi-slit Solar Explorer (MUSE), combines 35 slits in its high-resolution spectrograph, focusing on three emission lines that probe the corona and transition region. With a field of view comparable to an active region's size, the instrument will be able to take spectra over the entire field within 10 to 20 seconds — on par with SDO's imaging cadence. An imager will also provide context shots with a larger field of view.

The second mission, Japan's Solar-C, will have similar resolution and fields of view. But instead of many slits, its spectrograph will have just one that covers a wide range of wavelengths, enabling it to detect gas with temperatures from roughly 10,000 to 15 million K — encompassing the chromosphere to the corona and even flares in a single glance.

The MUSE team plans to launch as early as 2027; Solar-C scientists hope for 2028. Both craft will give solar physicists new insights into how gas moves, heats, and cools in the solar atmosphere, as well as why that atmosphere sometimes becomes unstable and unleashes flares and superheated clouds of plasma at us.

Because living with a star has consequences. The solar storm that lit up Earth's skies in May 2024 also botched GPS signals guiding automated tractors, costing the agricultural industry in the U.S. Midwest more than $500 million. Changes to the Sun's everyday brightness at different wavelengths impact Earth's ionosphere, where disturbances "can royally screw up radio-signal propagation," Klimchuk says, messing with everything from weapons-guidance systems to navigation. And satellites and astronauts operate in precarious proximity to solar outbursts we can't predict.

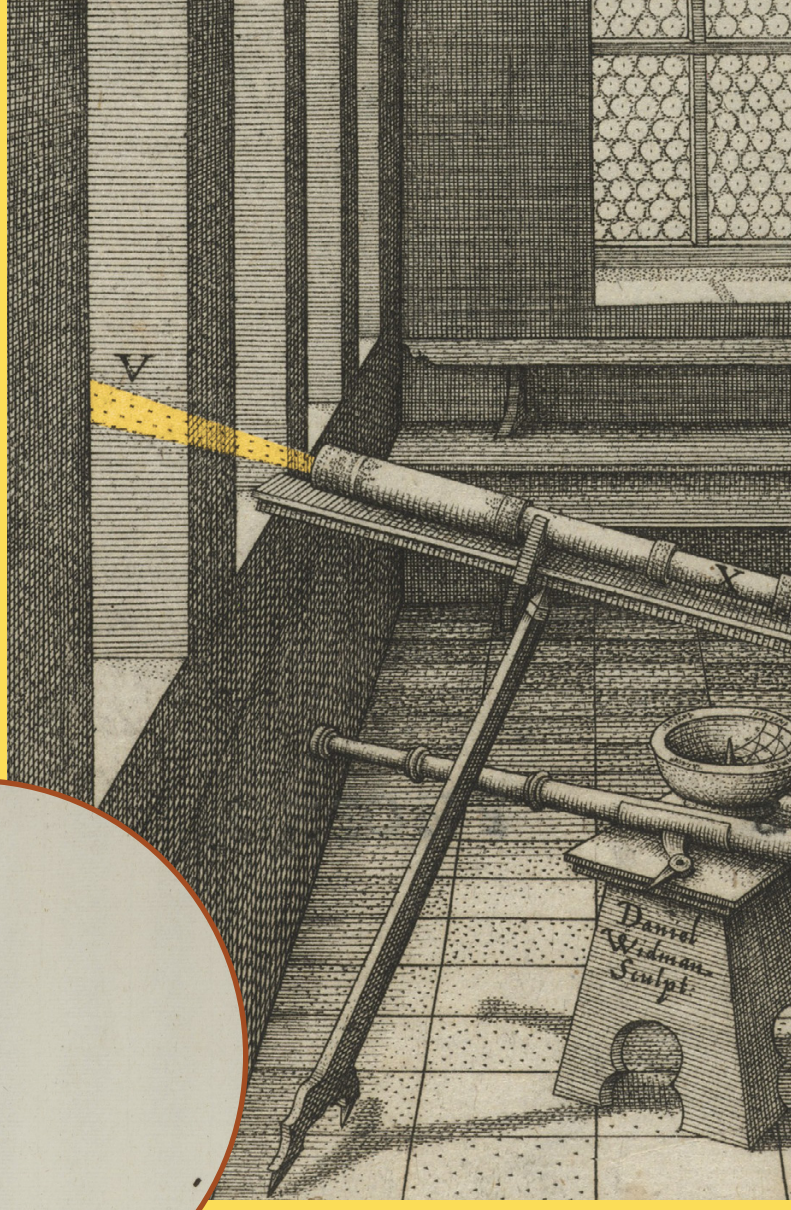
The consequences of stellar activity aren't unique to the solar system. A star's ultraviolet and X-ray radiation eats away at its planets' atmospheres. Astronomers want to understand stars' output at these wavelengths, but there's a critical range in the extreme ultraviolet that's unobservable because the interstellar medium absorbs it, Klimchuk says. Exoplanet astronomers therefore rely on what we know about the Sun's energy output — and are hampered by what we don't. "When we try to extrapolate to slightly different conditions in other stars, we can't really be confident that we're doing anything right," says Testa, who is a member of the MUSE science management team.

But the implications of understanding the corona aren't the only thing driving researchers. Science is also its own reward. As humans, when we see something strange, we want to poke it. And the solar atmosphere is strange. It's a seething ball of plasma and magnetic fields constantly trying (and failing) to settle down. It behaves unlike any bonfire we've ever huddled around. And like Moses encountering the burning bush, we can't help but stop and look to find out why it's blazing.

■ Science Editor **CAMILLE M. CARLISLE** writes about all things astronomy while carefully shielded from the Sun's rays.

Sunspots and the Dawn of Modern Science

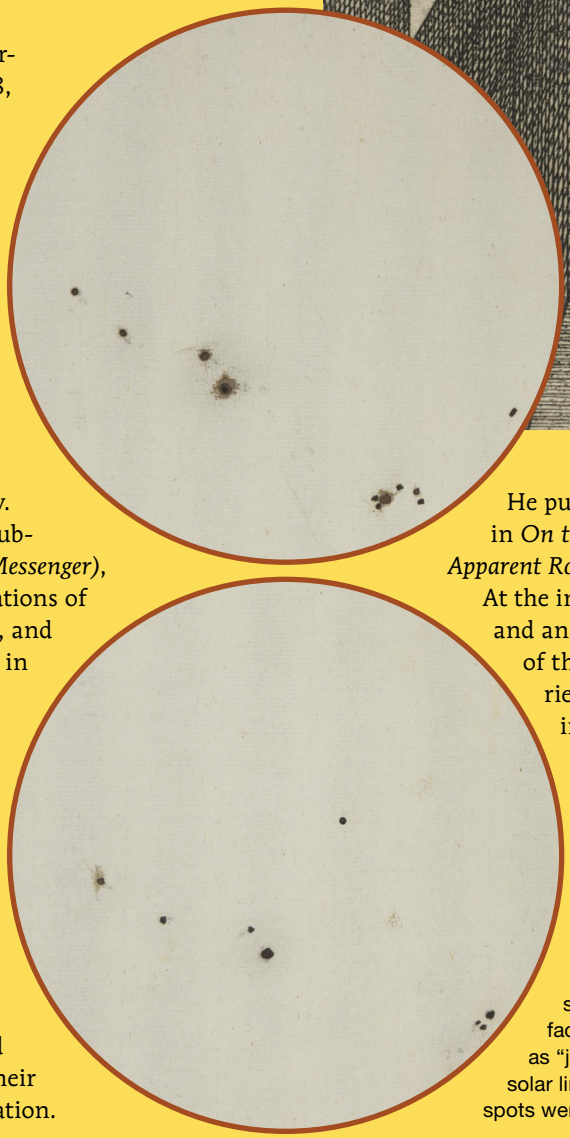
Early telescopic observations of the Sun advanced the development of astrophysics.



Our story begins in the Netherlands in the autumn of 1608, when Hans Lipperhey, a German-born optician living in Middelburg, applied for a patent on a device to view distant objects clearly — the first documented telescope. Its exact origin remains uncertain, as other local opticians like Jacob Metius made similar claims. News of the invention spread quickly across Europe, and as the design improved, the telescope was soon directed toward the sky, opening a new era in astronomy.

In March 1610, Galileo Galilei published *Sidereus nuncius* (*The Starry Messenger*), reporting his first telescopic observations of the Moon, the Milky Way, the stars, and Jupiter's satellites. At the same time in England, Thomas Harriot used his own telescope and by December was observing sunspots, though he never published his results.

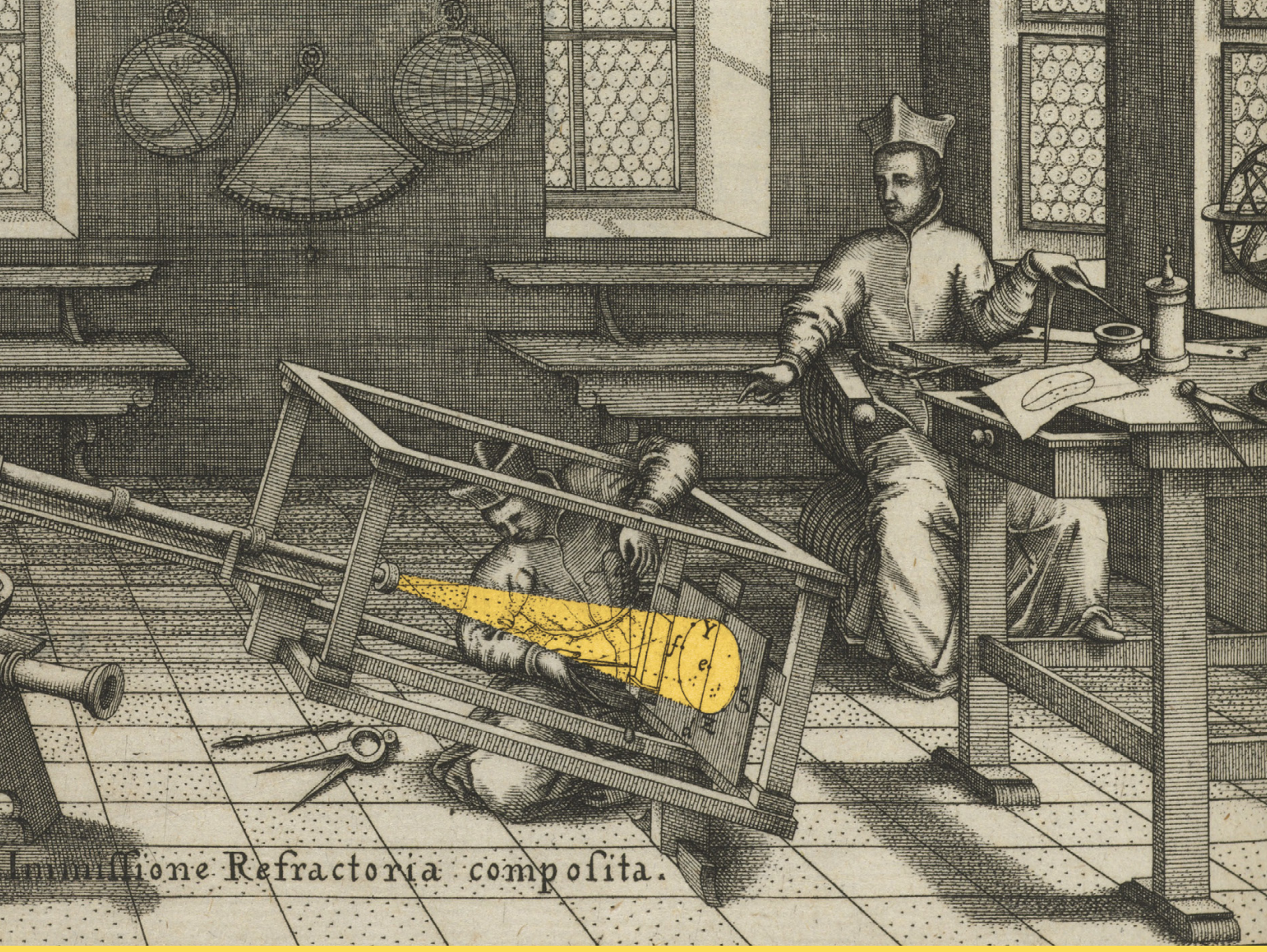
The first printed account of sunspot observations came from Johannes Fabricius, a young German astronomer trained in Leiden. Returning home to Osteel in March 1611, he studied the Sun with his father, David, noting spots that moved, vanished, and reappeared, correctly interpreting their motion as evidence of the Sun's rotation. He published his findings on June 13, 1611, in *On the Spots Observed on the Sun and Their Apparent Rotation*.



FIRST LIGHT Sunspots drawn by Thomas Harriot on July 2 and 3, 1612. His unpublished observing notebook contains 201 depictions of the solar disk from 1610 to 1613. The drawings do not clearly separate the dark umbras and lighter penumbras, and some apparent penumbral structures are probably artifacts caused by faded ink. Harriot occasionally described spots as "jagged" or "elongated," especially near the solar limb, which suggests he was aware that the spots were not strictly circular.

HARRIOT SUNSPOTS: THOMAS HARRIOT / MAX PLANCK INSTITUTE FOR THE HISTORY OF SCIENCE, LIBRARY / PETWORTH HOUSE ARCHIVES / CC-BY-SA 3.0 DE

At the intersection of observation, technology, and analysis, sunspots have served as one of the most important natural laboratories for understanding the Sun and its influence on Earth. They have provided a continuous record of solar activ-



SCHEINER'S SETUP: CHRISTOPH SCHEINER / HOUGHTON LIBRARY / HARVARD UNIVERSITY / PUBLIC DOMAIN

ity, challenging earlier ideas about the heavens and driving major advances in astronomical methods and interpretation. In fact, the study of sunspots has played a central role in the development of modern observational astronomy.

▲ **SAFE SOLAR OBSERVING** To study our star without injuring their eyes, astronomers in the 17th century observed the Sun low on the horizon, through clouds or colored glass filters, or by projection. This engraving from Christoph Scheiner's *Rosa Ursina* shows the priest and an assistant recording sunspots in Italy in 1625 using the projection method.

The 17th Century

The years following 1610 were decisive for the study of sunspots. In 1612, the Jesuit priest Christoph Scheiner wrote three letters to the German banker and astronomer Mark Welser, later published as *Three Letters on Sunspots*. Welser shared them with Galileo, who replied with three letters of his own, collected in *Letters on Sunspots* (1613). These two works offered radically different views.

Scheiner, faithful to Aristotelian cosmology, explained sunspots as clouds or bodies passing before the Sun; Galileo, though unaware of their true nature, argued that they belonged to the Sun itself and deduced its axial rotation from their motion.

Scheiner pursued solar studies for more than 15 years, culminating in his monumental *Rosa Ursina* (1626), one of the most discussed works of the Scientific Revolution. There he abandoned his earlier hypothesis and came to regard sunspots as features associated with the solar surface rather than independent orbiting bodies — a shift in interpretation that would later be fully integrated into 19th-century solar physics.

Meanwhile, in 1619, Simon Marius — a German mathematician, physician, astronomer, and calendar compiler — published his pamphlet *An Astronomical and Astrological Description of the Comet*, mainly devoted to the Great Comet of 1618. In it, he observed a noticeable decline in the number of sunspots compared with earlier telescopic records, becoming one of the first to recognize a temporal variation in their occurrence.

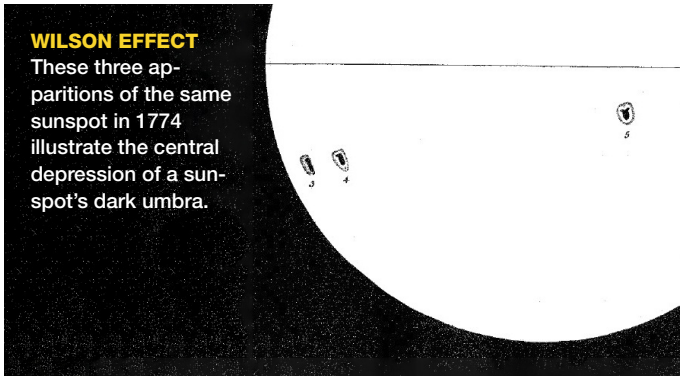
Among the great observers of the 17th-century Sun, though, Johannes Hevelius stands out. Hevelius, a wealthy

brewer and city councilor from Gdańsk — a city on the Baltic coast of northern Poland — is best remembered as an astronomer. He made significant contributions with his *Selenography* (1647) and *Celestial Machines* (1679), which contain systematic sunspot observations recorded between 1642 and 1645. These were the last continuous records before a prolonged period of exceptionally low solar activity from 1645 to 1715 left our star's face essentially blank (see box on page 25).

The Dawn of Astrophysics

As sunspots gradually reappeared in the early 18th century, observational interest was renewed. Among the scholars who embarked upon systematic study, the Danish astronomer Christian Horrebow (1718–1776) suggested that sunspot numbers might vary in a regular cycle, while the Scottish astronomer Alexander Wilson (1714–1786) examined their structure in detail. He discovered that a sunspot's dark, central *umbra* sat below the level of the surrounding photosphere — a phenomenon now known as the Wilson effect. Considered together, Horrebow and Wilson's work marked a transition from simple description to careful, interpretative observation, laying the groundwork for modern solar physics.

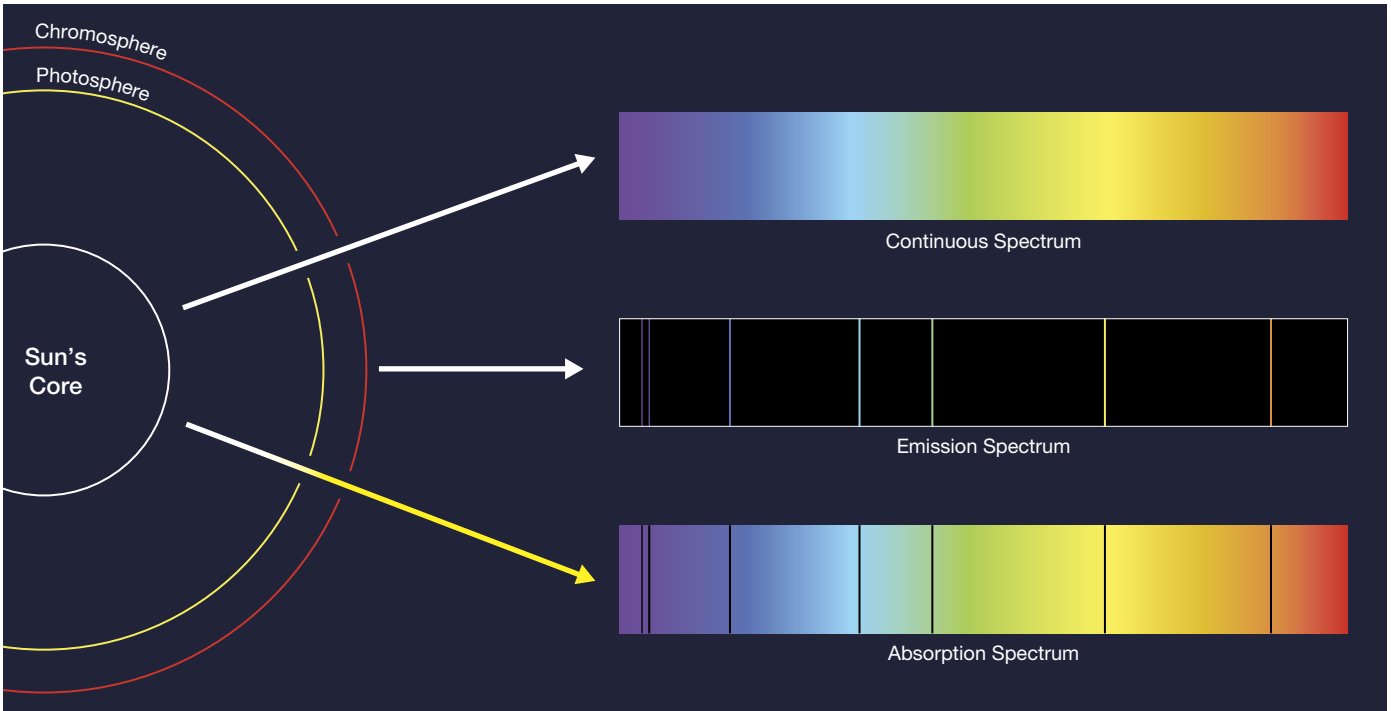
This shift was part of a larger change in the works. Astronomical observation between the late 18th and early 19th centuries underwent a profound transformation, poised between the legacy of the past and the birth of modern astronomy.



WILSON EFFECT These three apparitions of the same sunspot in 1774 illustrate the central depression of a sunspot's dark umbra.

At the beginning of the 19th century, astronomy was mainly concerned with determining the positions of celestial bodies, rather than understanding their nature. As telescopes and observational instruments improved, measurements became increasingly precise, enabling astronomers to trace the structure of the Milky Way and compile ever more detailed and comprehensive star catalogs.

By mid-century, however, the situation began to change with the rise of astrophysics — a new branch of science devoted to uncovering the nature, composition, and inner workings of celestial objects. Astronomers began to inves-



KIRCHHOFF'S LAWS When astronomers use a spectroscope to study the Sun, the incoming light is broken up into its different wavelengths, and we see the spread as a spectrum. There are three different kinds of spectra, and each tells us about the light being radiated. (1) A hot, dense gas like the Sun's core produces a continuous spectrum. (2) A thin gas like the Sun's chromosphere produces bright *emission* lines, wavelengths emitted by the atoms. (3) A continuous spectrum passing through a tenuous gas produces a spectrum with dark *absorption* lines, when the gas's atoms absorb certain wavelengths. The bright and dark lines are unique to each element and can reveal an object's composition. The Sun, its prominences, and sunspots all have distinctive spectral fingerprints.

WILSON EFFECT: A. WILSON / *TRANS. ROYAL SOC.* 64, 1, 1774 / PUBLIC DOMAIN; KIRCHHOFF'S LAWS: BEATRIZ INGLESSIS / *S&T*; *SOURCE:* GRIFFITH OBSERVATORY

tigate the Sun as a celestial body in its own right, endowed with physical, chemical, and dynamic properties to be measured. Our star ceased to be only an object of contemplation and became a genuine natural laboratory whose observation presented scholars with unprecedented challenges.

These early steps were uncertain and lacked solid theoretical foundations. Yet they opened the way to a new understanding of the universe.

Decoding Sunlight

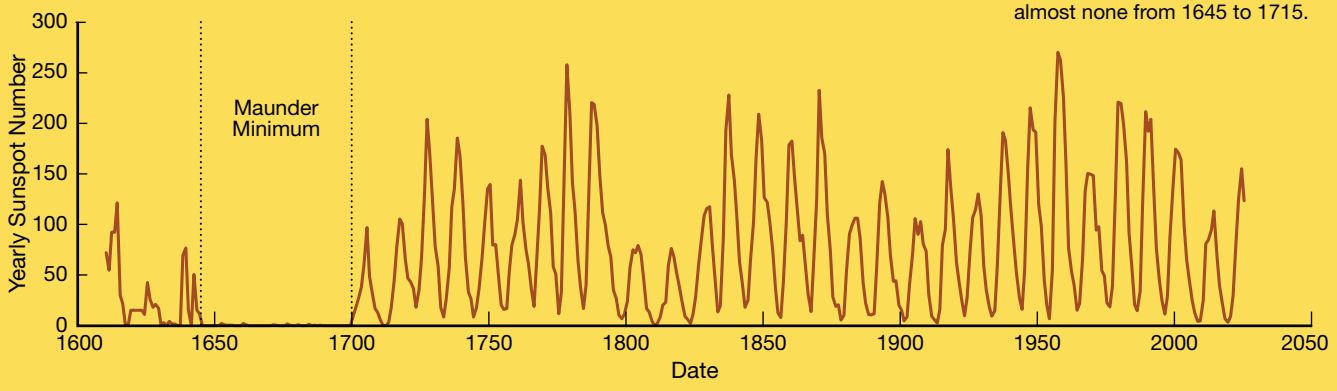
The history of spectroscopy begins with Joseph von Fraunhofer, who in 1814 discovered mysterious dark lines within the solar spectrum. Today we know that these lines correspond to the absorption of specific wavelengths by atoms in the Sun's atmosphere, superimposed on the radiation emitted by its hotter inner layers. At the time, however, their nature was a mystery: Some thought they were defects in telescopes, others that they originated in Earth's atmosphere, and still others suggested solar atmospheric origins.

Only a few decades later, Gustav Kirchhoff (1824–1887) and Robert Wilhelm E. Bunsen (1811–1899) demonstrated that each chemical element produces a unique set of spectral lines. Researchers then used that discovery to begin to learn what the Sun was made of.

The scientific community, and astronomers in particular, now learned to view celestial bodies as objects capable of revealing their internal structure, much like terrestrial ones. Over time, it became clear that even their invisible properties could be observed and analyzed using experimental tools, often requiring complex choices in a context still uncertain in terms of theories and methods.

Kirchhoff's laws of spectroscopy, while not providing a theoretical justification for observed phenomena — being merely a summary of experimental results — nonetheless made it possible to interpret astronomical observations. In practice, the spectrum alone was sufficient to determine the composition and temperature of the Sun and more distant stars, and a goal that had seemed unattainable just 20 years earlier had now been reached. Spectral analysis showed that the Sun's photosphere and sunspots have distinct temperatures, with sunspots being about 1500°C (2700°F) cooler. As a result, they emit less light and appear dark in contrast to the surrounding solar surface.

This period represents an epochal change, comparable to that of Kepler's laws in the 17th century. In 1888, the physicist and astronomer Samuel Pierpont Langley published *The New Astronomy*, a title deliberately recalling Kepler's 1609 *Astronomia Nova* to emphasize the revolutionary significance of 19th-century advances. Just as Kepler's laws were later incorporated into Newtonian mechanics, Kirchhoff's laws would eventually find theoretical explanation in the framework of 20th-century quantum mechanics.



SPOTLESS The 400-year history of sunspot observations shows almost none from 1645 to 1715.

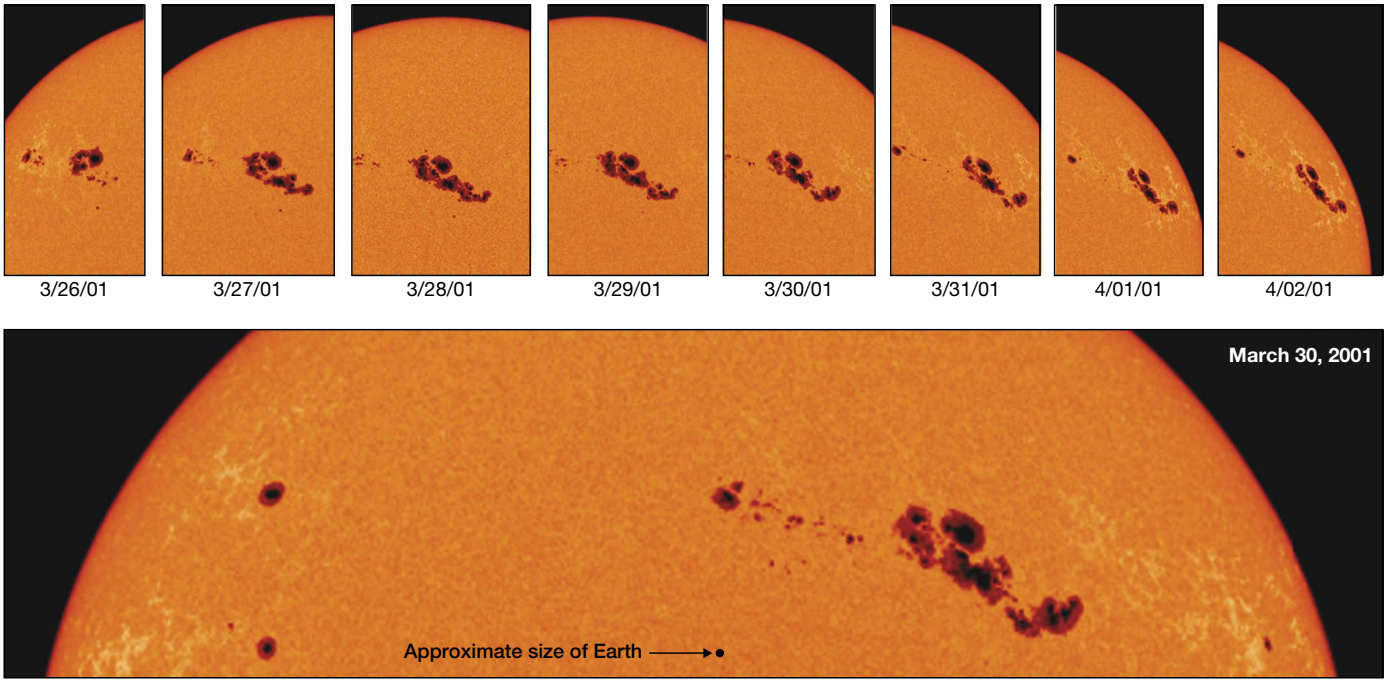
BEA INGLESSIS / S&T; SOURCE: DAVID H. HATHAWAY / NASA

A Slumbering Sun

For centuries, sunspots and the 11-year solar cycle were thought to follow a stable and predictable rhythm. Yet observations made in the late 17th and early 18th centuries hinted at something unusual: long periods when sunspots all but disappeared. These records were eventually forgotten, and the idea of a constant Sun prevailed.

It was not until the late 19th century that astronomers realized the Sun had, in fact, experienced significant fluctuations in activity. In 1887 and 1889, Gustav Spörer drew attention to an extended episode of diminished solar activity spanning the 1600s and 1700s. Edward Walter Maunder then promoted Spörer's findings, first in 1890 with a note to the Royal Astronomical Society, "Professor Spoerer's researches on sun-spots", and later in 1894 in the illustrated magazine *Knowledge*.

Although Spörer was the first to identify the anomaly, it became associated with Maunder due to his English publications and wider dissemination, and the period is now known as the Maunder Minimum.



▲ **SOLAR ROTATION** This sequence of photographs shows sunspots moving across the Sun's visible surface. On March 30, 2001, the sunspot chain shown here produced numerous flares and coronal mass ejections. The group's shape changed noticeably over time and was visible with the (protected) naked eye.

From Sunspot Cycles to Solar Storms

As the physical foundations of solar science were being established through spectroscopy and radiation theory, observational studies of the Sun were making their own decisive progress. In February 1844, the journal *Astronomische Nachrichten* published a brief article by the German pharmacist and amateur observer Samuel Heinrich Schwabe. In it, he presented his regular solar observations from 1826 to 1843 and proposed an approximately 10-year cycle of solar activity.

Inspired by Schwabe, Johann Rudolf Wolf, professor of mathematics and astronomy in Bern, Switzerland, began regular sunspot observations in 1847. In addition, he analyzed historical records, confirming that the cycle had been regular at least since 1700.

Largely overlooked at first, Schwabe's work gained recognition after the renowned German naturalist and geographer Alexander von Humboldt incorporated it into the third volume of *Kosmos* (1850). Meanwhile, Sir Edward Sabine, superintendent of the British magnetic observatories, noticed a strong correlation between sunspot numbers and geomagnetic storms. In an 1852 article Sabine demonstrated that the link between sunspot activity and terrestrial magnetic disturbances was both significant and undeniable. Not long after he published his results, a dramatic demonstration of the Sun-Earth magnetic connection occurred.

On September 1, 1859, at 11:18 a.m., English astronomer Richard Carrington observed two intense flashes within a large sunspot group, lasting about five minutes in total — the first direct observation of a solar flare in white light. A massive coronal mass ejection, a cloud of magnetized plasma ejected from the Sun, reached Earth 17 hours and 40 minutes later, triggering one of the strongest geomagnetic storms ever recorded. Aurorae appeared at tropical latitudes (Cuba, Hawai'i, and southern Italy, among others). Telegraph systems were severely disturbed due to currents induced in Earth's atmosphere.

Carrington detailed the event in a November 11, 1859, article in the *Monthly Notices of the Royal Astronomical Society*, noting the remarkable coincidence between the flare and the storm.

The Magnetic Sun

Thanks to the Sun's brightness, its spectrum could be examined in fine detail — something that was, at the time, impossible for fainter stars. By the second half of the 19th century, the idea had taken hold that the Fraunhofer lines originated within the Sun itself. In 1868, researchers identified helium in solar prominences. Its discovery remains the only case in which a chemical element was identified first in the Sun and only subsequently on Earth.

Still, at the dawn of the 20th century, sunspots remained mysterious features on the solar surface, known only by their dark, fleeting appearance. Their origin was largely a puzzle until 1908, when the American astrophysicist George Ellery Hale made a groundbreaking discovery: Sunspots are not mere blemishes but regions dominated by powerful magnetic fields, revealing a hidden dynamism in the Sun's surface.

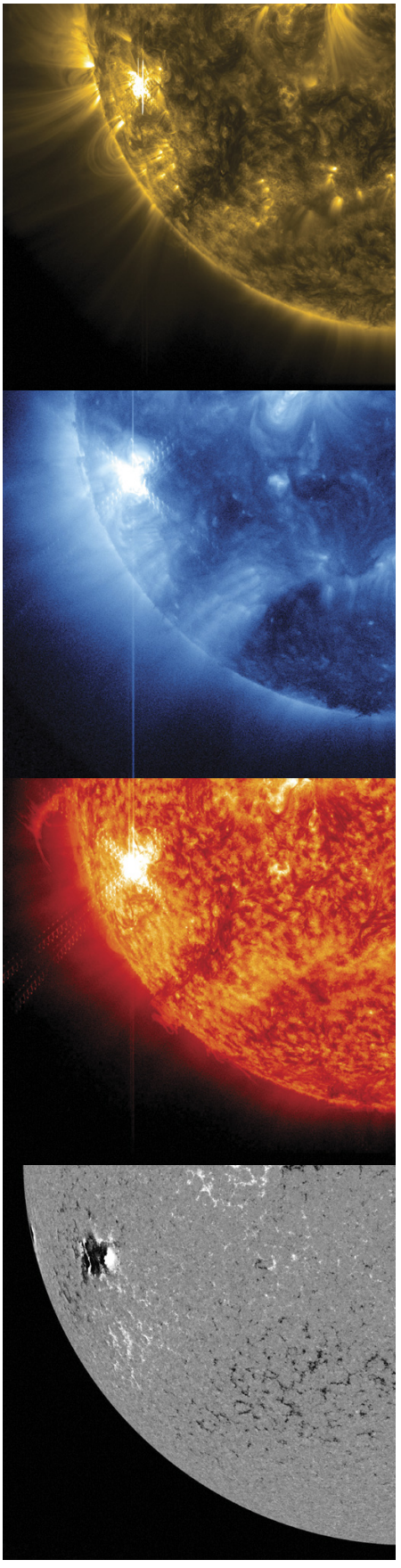
Using a *spectroheliograph*, Hale observed that spectral lines split in sunspots, a phenomenon explained by the earlier work of the Dutch physicist Pieter Zeeman (1865–1943), who had

SOHO / ESA / NASA

shown the same effect in the presence of magnetic fields. From these observations, Hale measured sunspot magnetic fields far stronger than those normally observed on Earth. Subsequent studies by Hale and his colleagues Ferdinand Ellerman, Seth B. Nicholson, and Alfred H. Joy examined *bipolar sunspot groups* — paired sunspots with opposite magnetic poles. They demonstrated that the leading and following spots in a binary group are aligned with each other by hemisphere, and that groups in one hemisphere have the opposite polarity of those in the other hemisphere. This pattern persists throughout the approximately 11-year solar cycle, after which polarities reverse in the subsequent cycle, indicating that the Sun's magnetic field evolves according to a 22-year cycle. These results were published in two articles in *The Astrophysical Journal* in 1908 and 1919.

During the 1960s, scientists recognized that the Sun's magnetism extends beyond sunspots to the entire solar surface. In 1961, the American astrophysicist Horace W. Babcock published a model in which the Sun's global magnetic field reverses periodically, explaining both the sunspot cycle and the magnetic cycle. Later, in 1969, Robert B. Leighton demonstrated how convective motions and large-scale plasma flows reorganize the magnetic field, completing the theoretical picture of the solar cycle. These processes form the basis of the Babcock–Leighton model, which links the Sun's periodic magnetic reversal to dynamic plasma motions on its surface.

While the photosphere is where magnetic structures appear as dark sunspots and bright *faculae*, the roots of the Sun's "magnetic heartbeat" lie in the *convection zone* just below, where differential rotation and convective motions stretch and amplify magnetic field lines. When strong enough, these fields emerge as sunspot pairs with opposite polarities. During the 11-year sunspot cycle, convective motions and surface flows reorganize the magnetic field, and around solar maximum, the Sun reverses its global magnetic field and repeats the sunspot cycle with opposite polarity, completing the 22-year magnetic cycle (see *S&T:* Nov. 2025, p. 34).



NASA / SDO / GSFC (4)

▶ **MULTIWAVELENGTH SUN** By observing the Sun at a number of different wavelengths, orbiting telescopes can tease out different aspects of features on our star. These four Solar Dynamic Observatory images of a solar flare on October 22, 2012, reveal *(from top)*: light from the Sun at a wavelength of 17.1 nanometers, which shows the structure of loops in the corona; 33.5 nm, which highlights light from active regions in the corona; 30.4 nm, which picks up light from the middle part of the solar atmosphere, where flares originate; and a magnetogram, which shows magnetically active regions.

New Eyes on the Sun

For centuries, the study of sunspots was limited by atmospheric turbulence, weather, and the day-night cycle. Recent decades have seen these obstacles partially overcome through advanced observational techniques, but space exploration has truly revolutionized solar studies. Satellites enable continuous monitoring and access to wavelengths in the ultraviolet and X-ray parts of the spectrum, revealing the energetic and magnetic processes of the Sun and helping forecast dangerous solar eruptions. More recently, artificial intelligence has transformed data analysis, handling vast data sets and detecting patterns invisible to humans. Together, these advances open entirely new horizons in the study of sunspots and solar physics.

Ever since the first telescopic observations of sunspots more than four centuries ago, we have embarked on a remarkable journey to understand our star and its place in the universe. Sunspots have repeatedly opened new paths of discovery — from revealing the Sun's rotation and magnetic nature to advancing stellar physics — playing a fundamental role in modern astronomy and in our understanding of the physical universe.

■ **NICOLA CUSANELLI** is a physicist based in Naples, Italy, with interests in science communication and the history of astronomy.



M76

The Not-So-Little Dumbbell Nebula

There's more to this planetary than meets the eye.

Our corner of the Milky Way is full of wonderful things, and M76 is one of them. Tucked away in northwestern Perseus, near the border with Andromeda and Cassiopeia, M76 — also known as the Little Dumbbell Nebula — is a marvelous object no matter how you look at it, and it has something to offer anyone fascinated by planetary nebulae. But before we explore M76, let's first delve a little bit into its history.

The 19th-century French astronomer Charles Messier is known today for his catalog of 110 deep-sky objects. However, the 76th object on his list was actually discovered by his younger friend and collaborator, Pierre Méchain, using a 3-inch refractor. Like Messier, he was primarily interested in discovering comets. All told, Méchain found eight and co-discovered another three, making him the second most successful comet hunter of his time, just behind Messier.

On October 21, 1780, Messier acknowledged his friend's find: "Nebula at the right foot of Andromeda, seen by M. Méchain on September 5, 1780, & he reports: 'This nebula contains no star; it is small and faint.'"

In all, Méchain made 25 original discoveries of deep-sky objects in Messier's catalog, and M76 was his fifth. By comparison, Messier discovered 44 of the entries on his list. The rest were either found by other astronomers of their era

▲ **PERSEUS GEM** At 2.7′ by 1.8′, M76 is apparently smaller than M27, the (big) Dumbbell Nebula in Vulpecula, at 6.7′ in diameter. But M76 is also more than twice as far away (3,000 versus 1,250 light-years), so their actual diameters (1.2 versus 1.4 light-years) are almost the same. M76's apparent size is also larger than better-known M57, the Ring Nebula in Lyra, which has an apparent diameter of 1.3′ and an actual diameter of 1.3 light-years. A 60-cm (24-inch) Hypergraph and SBIG STL-11000M CCD camera captured this view of M76. North is up in all images.

STEFAN HEUTZ / STEFAN BINNEWIES / JOSEF PÖPSEL

or in antiquity. It's more accurately the "M catalog" than Messier's catalog.

M76 also goes by the nicknames Cork Nebula, Butterfly Nebula, and Barbell Nebula. We settled on the Little Dumbbell Nebula only after several iterations. In the 1880s, British astronomer T. W. Webb described M76 as a "Pearly white nebula, double; curious miniature of M27 . . . ." An observing report by American astronomer Zaccheus Daniel published in the 1903 issue of *Popular Astronomy* was titled "The Miniature Dumb-bell Nebula, Messier 76." Finally, *S&T* columnist Leland S. Copeland coined the Little Dumbbell moniker in his article, "An Amateur's Tour of Planetary Nebulae" (*S&T:* Feb. 1960, p. 214).

I have a hunch the Little Dumbbell nickname may be part of the reason it's not considered one of the top-tier Messier objects. Although unintentional, the adjective "little" somehow diminishes the appeal of M76. Sure, it looks somewhat similar to, but smaller than, the big Dumbbell Nebula, M27, but would it be more sought out if its moniker were something more fanciful like Méchain's Butterfly Nebula or the Double Bubble Nebula?

Also, it doesn't help that its sometimes-quoted magnitude of 12.2 is actually a photographic value. The correct visual magnitude is 10.1, which means M76 is accessible to nearly anyone with a telescope. Remember, Méchain discovered it with a 3-inch refractor.



PORTRAIT OF PIERRE MÉCHAIN: NARCISSE GARNIER (1824) / MUSÉE D'ART ET D'ARCHÉOLOGIE DE LAON / PUBLIC DOMAIN

◀ **M IS FOR MÉCHAIN** Charles Messier's contemporary, Pierre Méchain (1744–1804), usually doesn't get the recognition he deserves for his discoveries, which include about two dozen deep-sky objects and 11 comets.

A Little More History

After Messier added Méchain's discovery to his catalog in 1780, William Herschel saw it with his 18.7-inch reflector seven years later as: "Two close together, their nebulosities run into each other; distance of their centers is 1½ or 2 arc minutes." Because Herschel saw M76 as two separate nebulae, they each ended up with their own NGC designations — NGC 650 and NGC 651. M76 properly consists of both, with NGC 650 being the southern half and NGC 651 the northern half.

In 1866, Irish astronomer Robert Stawell Ball observed M76 with Lord Rosse's 72-inch reflector, describing it as a:

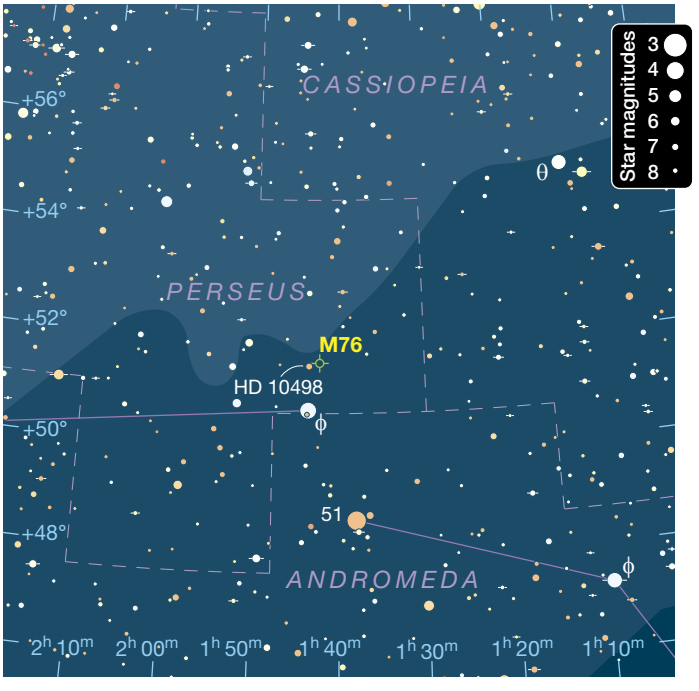
> *. . . remarkable object; a new spiral possessing details of interest. . . . It consists principally of the two B* [bright] *knots which according to Herschel are the pair of double nebula, and third much fainter knot p* [preceding] *the other two. Form compared to a reaping hook. Sketched by Lord Oxmantown* [Lord Rosse]. *The nebulosity terminates very suddenly on the s* [southern] *edge where there is a star, probably distinct from, though very close to the nebulosity. A branch of nebulosity in the following* [eastern] *direction was suspected by both observers preceding from between the two knots.*

This "branch of nebulosity" was probably the first sighting of M76's butterfly wings. At practically the same time, English amateur astronomer William Huggins examined M76 with a spectrograph and determined it has a gaseous spectrum, demonstrating it was a nebula.

Welsh-born amateur astronomer Isaac Roberts photographed M76 in 1891 and suggested that its appearance was probably due to a broad ring seen edge-on, which is exactly right. In 1918, American astronomer Heber Doust Curtis noticed the planetary's central star based on a new photo he made with the 36-inch Crossley reflector at Lick Observatory on Mount Hamilton, California, and estimated it as magnitude 16. The current cataloged value is 15.9.

A Modest Amount of Astrophysics

Planetary nebulae are often featured in *Sky & Telescope* (for a recent example, see the September 2026 issue, page 20), but a quick recap will give M76 some context. Overall, a planetary nebula is a type of emission nebula consisting of expanding,



▲ **STAR-HOPPING IN PERSEUS** M76 is located at a right ascension and declination of 1h 42.3m, +51° 35′. To find it, start at M31, the Andromeda Galaxy (outside the chart), and star-hop 7½° northeast to 4.3-magnitude Phi (φ) Andromedae. From there, shift 5° east-northeast to 3.6-magnitude 51 Andromedae, and then 2¼° north-northeast to 4.1-magnitude Phi Persei. M76 would be a short, 55′ hop to the north-northwest. A 7th-magnitude star, HD 10498, lies 12′ to the east-southeast of the Little Dumbbell Nebula.



▲ **BIG-EYE VIEW** This Hubble Space Telescope image shows that M76's central bar is actually an elliptical ring seen nearly edge-on. The bipolar bubbles or lobes expanding east and west from the ring's perimeter are commonly referred to as "butterfly wings." The red color is from ionized nitrogen emission, while the blue is from ionized oxygen.

ionized shells of gas created by red giant stars as they enter the *asymptotic giant branch* phase (AGB; see the sidebar below).

After only a few thousand years, nuclear reactions within the core cease and the star starts cooling into a white dwarf. The fast but tenuous wind from the central star clears the area around it of gas, compressing the material that had been ejected earlier in the star's life. Ultraviolet light emitted by the white dwarf ionizes this material, causing it to glow.

This is true for M76, but the object is even more interesting because it's a *bipolar* planetary — that is, it has significant outflow from the central star's north and south poles that creates a symmetrical set of beautiful "butterfly wings."

The first thing we see through an amateur-size telescope is an elongated, north-south rectangle of nebulosity with a slightly pinched waist, which I'd always assumed was the bipolar part of the nebula. Nope! This is actually an elliptical, equatorial ring we're seeing nearly edge-on at an angle of approximately 75° from our perspective. In the literature, it's sometimes referred to as a "napkin ring." It's estimated to be about 8,000 to 9,000 years old, and its ends appear brightest because we're looking through more (denser) material. If we could see all this face-on, it would probably look similar to M57, the Ring Nebula, in Lyra.

The bipolar butterfly wings — the ends of the "napkin" being pinched by the napkin ring — are actually bubbles billowing out from the equatorial ring, where emission is concentrated and the wings are most conspicuous. Several high-density bright and dark patches are visible within the wings. The wings begin to form as the progenitor star loses its outer layers through mass loss during the AGB phase's super stellar-wind process. This superwind concentrates mass loss along the star's equatorial plane, creating the circumstellar ring. Then, just before the planetary nebula phase, the evolving central star produces a tenuous and hot fast wind, ionizing the equatorial ring. The ring forces the fast wind to channel its flow in both polar directions, creating the butterfly wings, which are actually bubbles in 3D.

M76's central star is classified as a pre-degenerate star — meaning it's transitioning from the post-AGB stage to a white dwarf. It's estimated to have an extremely hot temperature of about 200,000 kelvin. When the star was on the main sequence, it had somewhere between 3 to 7 solar masses.

Perhaps the most compelling aspect about M76 is that we can see almost all the nebula features in a backyard telescope. At about 3,000 light-years away, M76's actual diameter is approximately 1.2 light-years. Its proper motion indicates a velocity of 34 km/s, moving nearly parallel and below the plane of the Milky Way by about 550 light-years. It's also moving toward us in an east-southeast direction. With all this background information, will your next telescope view of M76 be more interesting? I hope so!

The Asymptotic Giant Branch (AGB) Phase

This is a stage that low- to intermediate-mass stars enter as they evolve into a red giant, when the nuclear reactions in their core wind down. This causes the star's core to contract and heat up while its outer layers cool and expand, leading to mass loss. Eventually, the star ends up as a white dwarf. Much of the mass lost by the star on its way to becoming a white dwarf then becomes part of the planetary nebula, as the intense ultraviolet radiation from the white dwarf causes this surrounding material to fluoresce.

My Short List of Observations

I've observed M76 through telescopes ranging from 80 mm to 48 inches and found that what I see depends not only on the size of the scope, but also on the quality of the observing conditions. Below I outline my observing experiences in my telescopes in order of increasing aperture.

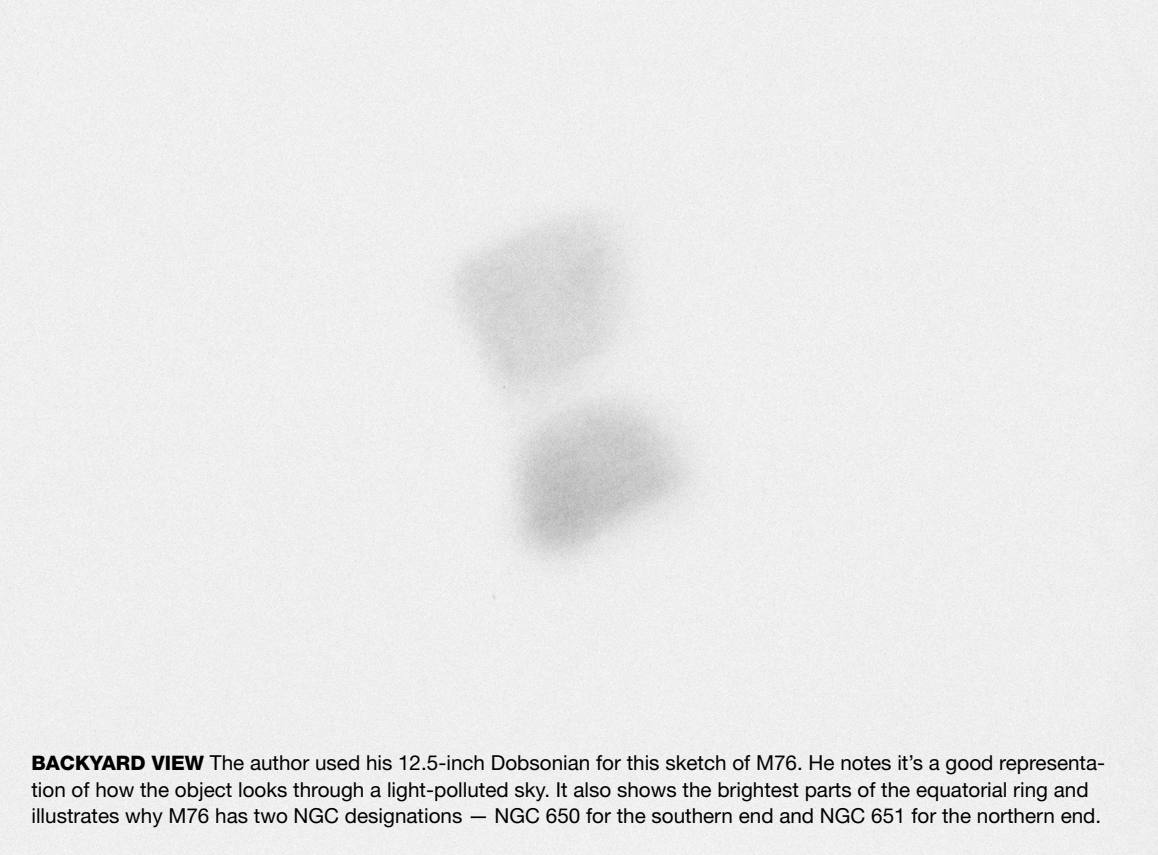
80-mm: I used a zoom eyepiece on my 80-mm (3.1-inch) finderscope. As Méchain and Messier had demonstrated, M76 is visible in a scope this size, and indeed it wasn't difficult at all. At my highest magnification of 40×, it appeared as a small fuzzy spot in a sea of stars. Seeing M76 much like Méchain did when he discovered it was pretty exciting.

8-inch: My first recorded sighting of M76 was in September 1982 with my homemade 8-inch f/4 Newtonian. On a "dark" night from my suburban backyard, I used the object as a warmup before searching for M33. I wrote:

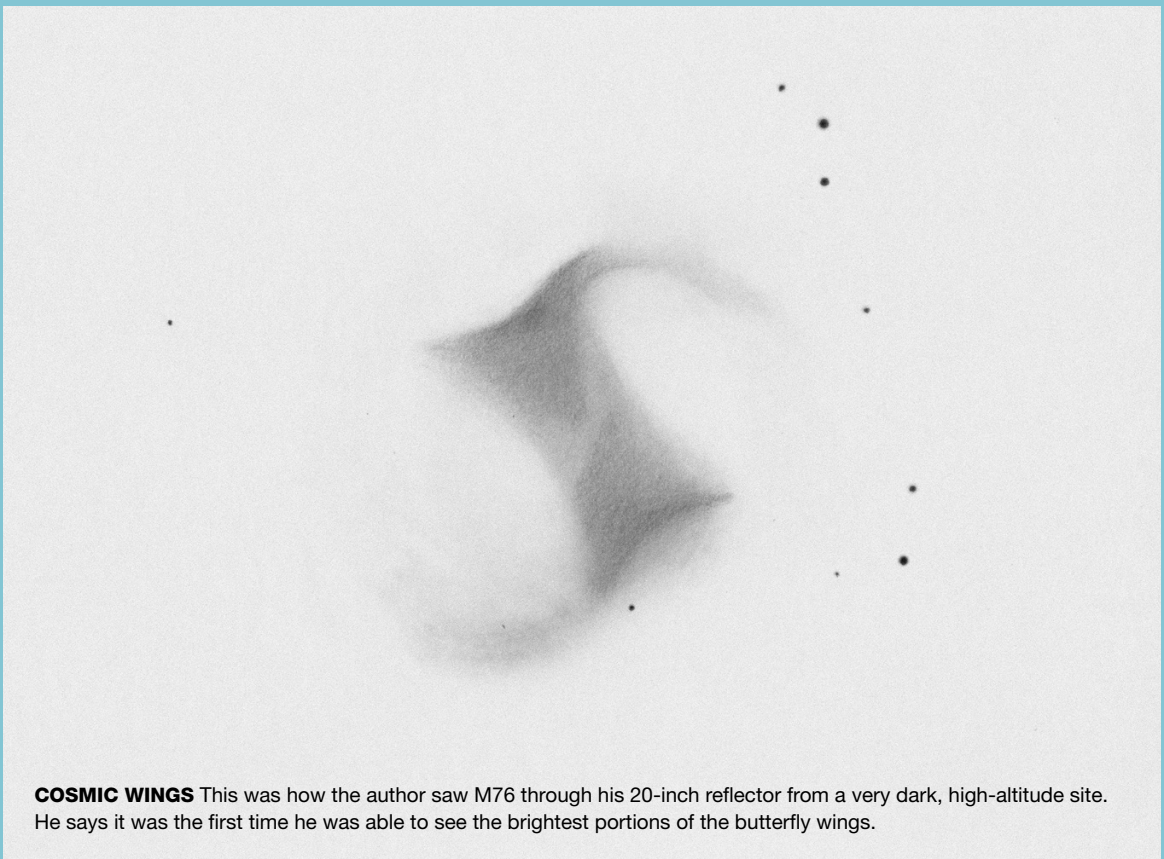
> *A bit of sweeping netted the faint patch of gray against another starry crisp field.*

Unfortunately, I didn't note the magnification.

NASA / ESA / STScI

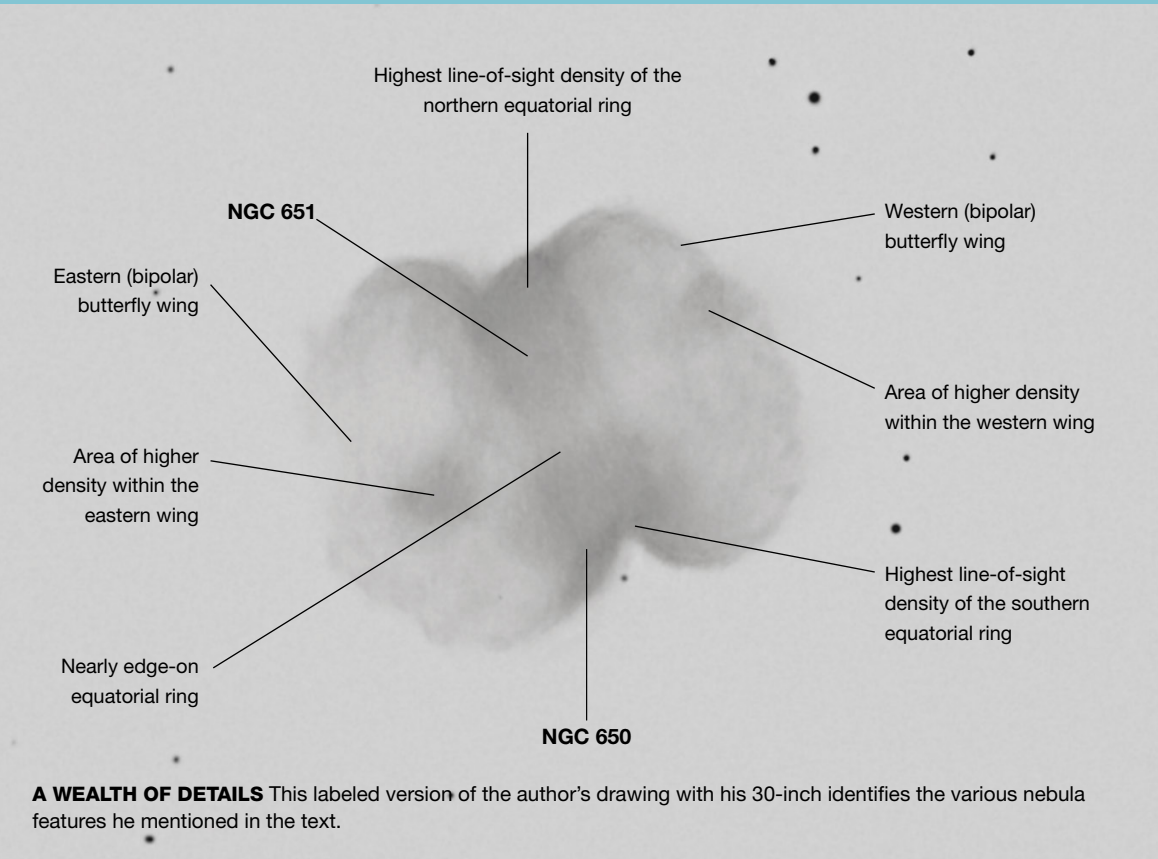


BACKYARD VIEW The author used his 12.5-inch Dobsonian for this sketch of M76. He notes it's a good representation of how the object looks through a light-polluted sky. It also shows the brightest parts of the equatorial ring and illustrates why M76 has two NGC designations — NGC 650 for the southern end and NGC 651 for the northern end.

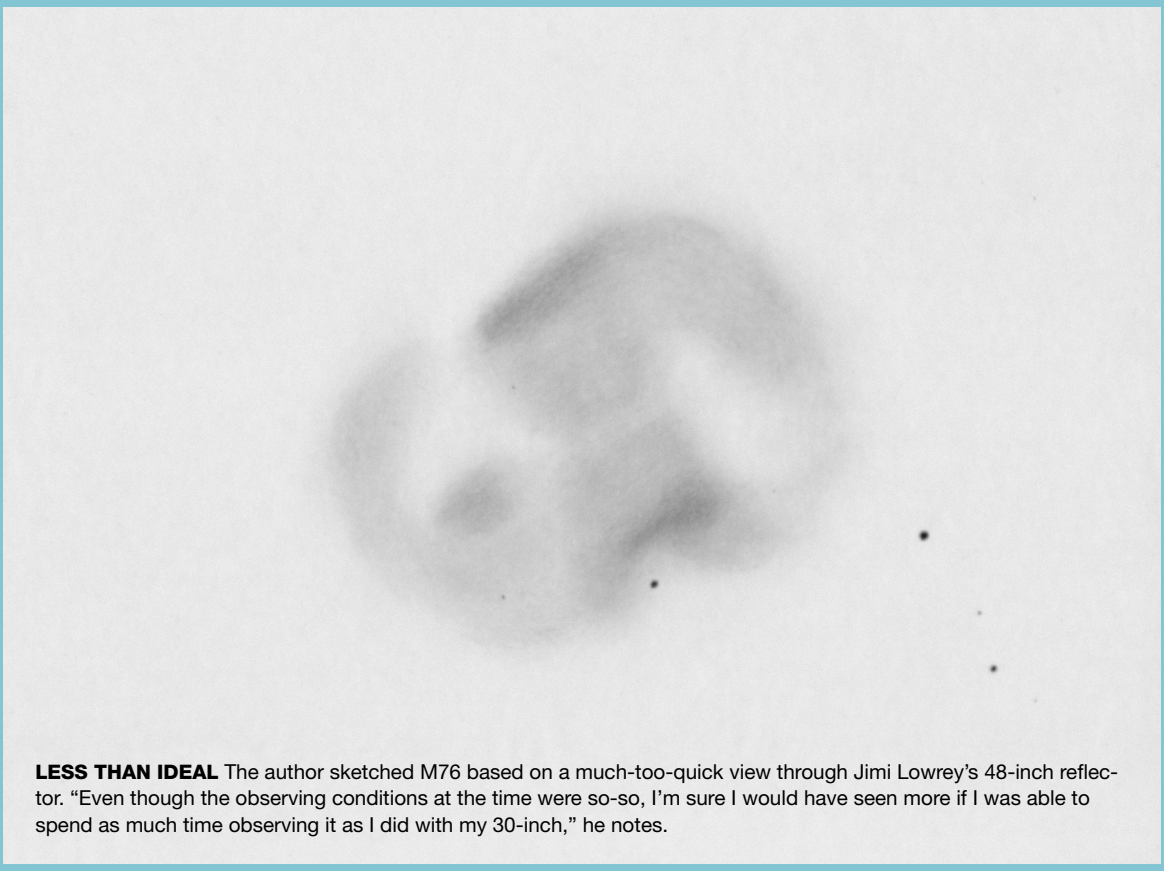


COSMIC WINGS This was how the author saw M76 through his 20-inch reflector from a very dark, high-altitude site. He says it was the first time he was able to see the brightest portions of the butterfly wings.

HOWARD BANICH (2)



A WEALTH OF DETAILS This labeled version of the author's drawing with his 30-inch identifies the various nebula features he mentioned in the text.



LESS THAN IDEAL The author sketched M76 based on a much-too-quick view through Jimi Lowrey's 48-inch reflector. "Even though the observing conditions at the time were so-so, I'm sure I would have seen more if I was able to spend as much time observing it as I did with my 30-inch," he notes.

HOWARD BANICH (2)

12.5-inch: October 1989 was my next recorded observation, this time with my homemade 12.5-inch f/7.8 Dobsonian. My suburban sky was fairly bright — I'd already failed to spot several galaxies in Pegasus before trying my luck on M76:

With direct vision, it appeared as a long rectangular glow with one end brighter, but no gap in the middle. Only with averted vision could the gap be seen, and the brightness differences between the two ends were more apparent. 260×, O III filter.

This is probably similar to what Herschel saw when he described it as two nebulosities close together. Many observers will view it like this, especially under light-polluted skies. If you're disappointed you can't detect the butterfly wings, just remember that you're still seeing a nearly edge-on nebulous ring that's slightly more than 1 light-year across.

20-inch: From a high-altitude site in 1992, I viewed M76 for the first time in a dark, pristine sky:

A wonderful view of an old favorite — looks much like a barred spiral galaxy. Very near the zenith right now . . . 359× (no filters).

28-inch: From my moderately light-polluted home in September 2019, I had a surprisingly detailed view of M76 on a rare night of rock-steady seeing:

Quite the sight, especially considering this is from my backyard! The NPB [narrow passband] *and O III filters brought out the two side loops, but this may be my first glimpse of the central star — steady seeing and 695× gave me several good pops.*

M76 is a wonderful sight, and I can't decide whether I like the NPB or O III filter best. Slightly more detail with the O III, but a more natural view with the NPB. 253×, 408×, and 695×. 20.38 SQM [Sky Quality Meter reading].

Its central star is listed as magnitude 15.9, but there's an apparently unrelated star of similar brightness right next to it. That should make both stars — which appear as one — easier to see, but the surrounding bright nebulosity makes this a challenging observation that requires steady seeing and high power. In my experience, M76's central star was more difficult to detect than that of M57, the Ring Nebula.

30-inch: In March 2026, I had two excellent nights at a dark-sky site in central Oregon. I didn't think I'd see much of M76 because it wasn't very high in the northwest that time of year, so I was mostly curious about how it would look so low in the sky. Incredibly, I got an absolutely fabulous view instead!

The best observations with my other telescopes were when M76 was near the zenith. So how did I get such a great view when it was only about 30° degrees above the horizon? In a word, transparency. Or just good luck. Sometimes the atmosphere is clearer than predicted, and that makes an enormous difference in the views through the eyepiece. I'd driven five hours to observe in what I knew would be a dark sky, but the transparency exceeded the already excellent prediction. Top-notch transparency is about as rare as super-steady seeing, and they both usually show up unexpected. So yeah, luck.

As pleasing as M76 was in my 80-mm finderscope, most of my excitement was through my 30-inch reflector. That night, there was a light, intermittent breeze, with soft quacks from the ducks floating on the reservoir a short distance away, wafting my way every so often. The temperature was in the low 50s. It was exceptionally pleasant.

The Little Dumbbell was my first observation of the night, but between the extremely bright zodiacal light, blazing Jupiter, and the brilliant winter stars lighting up the sky and my surroundings, it didn't look very dark. Just spectacular. There was a small light dome to the east, but it was too small to matter.

At 140×, I could immediately tell this was a special view, so I quickly bumped up the magnification. The seeing was remarkably steady this low in the sky. I flipped back and forth between the NPB and O III filters, then compared each to the non-filtered view. Just like in my 28-inch scope, the NPB gave the best contrast and more natural view than the O III. The non-filtered view wasn't far behind though, but the subtle details were more difficult to see. I sketched for an hour or so. In my combined 80-mm and 30-inch observing notes, I wrote:

For being so low in the northwest, this is a kick-butt view! Easily seen in the 80-mm finder as a little direct vision smudge, in the 30-inch it's a totally awesome sight. I really didn't expect to see so much detail. The sketch says it all really, but I'll add that seeing the full 'butterfly' wings is a special treat. 140× to 396×, 21.72 SQM.

A sky like this is why the five-hour drive was worth it.

48-inch: We observed M76 one night in November 2025 with Jimi Lowrey's famous 48-inch reflector in West Texas. Unfortunately, conditions were relatively poor, but I was still impressed with this quick observation:

This is a wonderful view! Nearly 3D, very bright with a large knot in the (northern) spiral. But the (southern) spiral is brighter overall. Interesting asymmetrical structure in the 'bar,' especially on the ends. 488×, 21.57 SQM.

Former *S&T* columnist Sue French once said, "Part of the beauty of observing is in knowing that there's always more to see." M76 is a perfect example of an enchanting object in the sky that offers observers many layers of detail, depending on telescope aperture and sky conditions. So, why not take a look the next clear night?

Contributing Editor **HOWARD BANICH** hopes to get another chance to see M76 through the 48-inch. He can be reached at **hbanich@gmail.com**.



On Approach to Phobos

Japan is launching its Martian Moons Exploration mission to sample Phobos and fly past Deimos — and finally settle the moons' origin.

NASA's Apollo program was the grandest geological field trip ever made. Its six crewed landings returned 382 kilograms (842 pounds) of lunar dirt, called *regolith*, and revealed unknown chapters of Earth's deep past and our Moon's violent origin.

Without those samples, we would not know that a Mars-size protoplanet collided with Earth roughly 4.5 billion years ago. The crash melted both bodies, launching massive amounts of debris into orbit that eventually coalesced to form the Moon (*S&T:* Aug. 2018, p. 26). This event led to the formation of specific types of rocks, preserved on our natural satellite's ancient, airless surface. Astronauts picked up these records of the past and brought them home for us to study.

The same principle — visiting a moon to learn more about its host planet — now guides a flagship mission led by the Japan Aerospace Exploration Agency (JAXA) that's headed to Mars. Our rusty neighbor has two small, potato-shaped moons, Phobos and Deimos, still unsullied by any spacecraft's touch. Scientists have conflicting ideas about how these bodies might have formed. By analyzing the samples JAXA's Martian Moons Exploration (MMX) mission will retrieve from larger Phobos, they hope to determine whether these moons are captured asteroids or result from a massive impact similar to the one that formed our own Moon.

Secret of the Moons

While Mars has been a primary exploration target for decades, spacecraft have largely left its two small moons alone. Most of what we know about them comes from side glances during occasional flybys. The most recent occurred in 2023, when the Emirates Mars Mission orbiter performed a series of close-range passes of Deimos.

The Martian moons are tiny and weird. Phobos is just 27 kilometers (17 miles) along its longest axis and orbits Mars faster than the planet rotates, completing a full revolu-

▲ **ARRIVAL** Upon insertion into orbit around Mars, the Martian Moons Exploration (MMX) spacecraft will explore and ultimately land on the larger, inner moon Phobos, sampling its surface for clues to its origin.

JAXA

tion every 7 hours and 39 minutes. As a result, from the Martian surface, it appears to rise in the west and set in the east — counter to the direction the Sun and the outer moon, Deimos, travel across the sky.

The two moons' orbits are also evolving in opposite ways. Phobos orbits just 6,000 kilometers above the surface, more than 60 times closer to Mars than our Moon is to Earth, and it's slowly creeping lower. In tens of millions of years, it will crash into Mars — if the planet's gravity doesn't rip the moon apart first. Smaller Deimos, just 15 kilometers at its widest point and much farther away, is doing the reverse, slowly receding from the planet.

The origin of these moons remains a mystery. After Mariner 9 returned the first close-up images in 1971, researchers thought the satellites could be captured asteroids or comets, based on their dark color and cratered surfaces. Their spectra, which lack distinctive features, resemble those of primitive asteroids common to the outer asteroid belt.

While this theory still has supporters, it also has some problems. Moons have been captured in this way elsewhere in the solar system, but their orbits are highly elongated and tilted relative to their planet's spin (*S&T:* Feb. 2026, p. 14). Phobos and Deimos, however, circle Mars's equator in almost perfectly round orbits.

Furthermore, for a planet's gravity to catch a passing asteroid, the asteroid must first slow down enough to let itself be caught. Otherwise, it would just zoom by. Spacecraft use rockets to slow down when entering orbit, "but an asteroid doesn't have rockets," says planetary scientist Sébastien Charnoz (Institute of Earth Physics of Paris).

"The main problem for capture is that you haven't just captured one object; you've captured two objects, Phobos and Deimos, and they are exactly in the same orbital plane," Charnoz says. "How to explain that is very difficult."

This dynamical problem, combined with the realization that large impacts were likely common in the young solar system, led to an impact-origin hypothesis for the two moons. Similar to the collision that formed Earth's Moon, this model suggests that a sizeable object struck Mars, ejecting a disk of debris that eventually coalesced into satellites, which would naturally form along the equator.

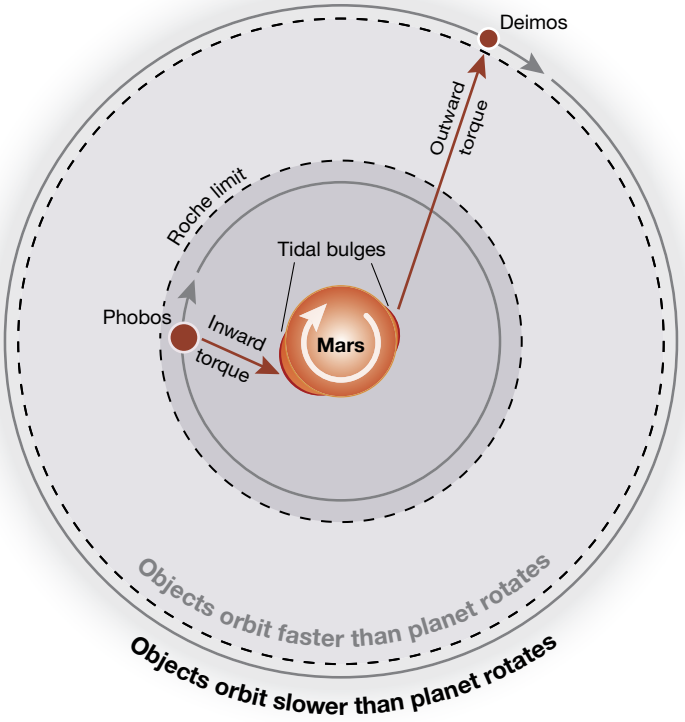
The impact would have been much smaller than the one that created our Moon, though. A hit from a body similar to the dwarf planet Ceres could have been enough. "The Earth's Moon is 1% of Earth's mass, and to make an object that is 1% of Earth's mass, the impact must be massive," Charnoz says. "But Phobos is about 1 in 60 million times the mass of Mars." And Deimos is even lighter.

An impact could explain other puzzling Martian features, such as the difference in elevation between the planet's southern and northern hemispheres. Several researchers argue that a large impact could have excavated the planet's northern half, forming the large basin there. Depending on the geometry of the impact, the hit could have also increased Mars's spin rate to its current 24 hours and 39 minutes.

Missed Landings

Previous attempts to land on Phobos have notoriously failed. In 1988, the Soviet Union launched the ambitious Phobos 1 and Phobos 2 missions; the former was lost en route due to a command error, and the latter failed just as it hovered 50 meters above the moon. A more recent attempt, Russia's Phobos-Grunt, failed to leave Earth's orbit in 2011.

Proposed in 1994 by Robert Craddock (Smithsonian Institution), the impact hypothesis was met with years of skepticism. It wasn't until 2011 that a peer-reviewed journal accepted his work. Other researchers have expanded on this model since then, some suggesting that an impact could have created additional moons that have since been destroyed by tidal forces. Phobos and Deimos could either be the last survivors or second-generation moons, formed from the debris of a larger predecessor. Deimos might have been the only one to form beyond the *synchronous orbit* — the distance where a moon's orbital period matches the planet's rotation — and because it's farther out, it has slowly been receding from Mars ever since.



▲ **CLOSE ORBITS** Phobos orbits so close to Mars, within its *Roche limit*, that the tiny tug of the planet's tidal bulges will ultimately pull the moon in for a crash landing. Deimos orbits farther out, so its path is more stable, though the planet's tidal forces still act to push the smaller moon farther away every year.

GREGG DINDERMAN / S&T; SOURCE: E. ASPHAUG / *NATURE GEOSCIENCE* 2016

Researchers hope the material MMX brings home from Phobos will settle the question for both moons. If the sample contains dark, claylike materials similar to those found on Ryugu, then they will know that Phobos is a captured asteroid. On the other hand, the presence of melted glass and dry minerals such as pyroxene or olivine would be the smoking gun for a high-speed impact.

Or, "maybe it's another scenario that nobody has thought about," Charnoz says. "The only way to make any progress on that is to have a piece of Phobos in a laboratory."

Take Pictures!

MMX is scheduled to leave Earth from Japan's Tanegashima Space Center in late 2026. The four-ton spacecraft will take about a year to reach the Red Planet, arriving in 2027.

The spacecraft will adapt to each part of the mission, shedding components when they are no longer needed. It will ditch the main propulsion module upon arrival at Mars. The exploration module, which hosts most of the science instruments as well as the landing legs, will carry out the bulk of the observations and sample collection. But ultimately, it too will be left behind. Samples will be stowed on a return module, which also carries the communications equipment and is propelled by a smaller set of engines. The exploration and return modules will lift off from Phobos together, exploring the Martian system for another year and a half (including close flybys of Deimos). Then the return module will detach to take its precious cargo to Earth.

Each step of the mission is carefully choreographed. Once in the vicinity of Phobos, the spacecraft will first maneuver to match the satellite's path. Phobos has almost no gravity and sits so close to Mars that the planet's gravitational pull overwhelms that of the moon. As a result, MMX will orbit Mars, not Phobos, while still following the moon closely.

"What we do is called a *quasi-satellite orbit*, so we go into orbit around Mars but on an elliptical orbit," Charnoz says. Since the moon is tidally locked, with the same face always looking at the planet, this offset between trajectories will make it seem like the probe is circling Phobos.

MMX will study Phobos from orbit in unprecedented detail using a sophisticated suite of instruments. Over the course of a year, it will map the surface in 3D using a wide-angle camera and a laser altimeter, in order to identify a landing site both safe and scientifically interesting. Three spectrometers will simultaneously begin unraveling the moon's elemental composition and surface mineralogy, while a dust sensor will monitor particles escaping from Mars and Phobos.

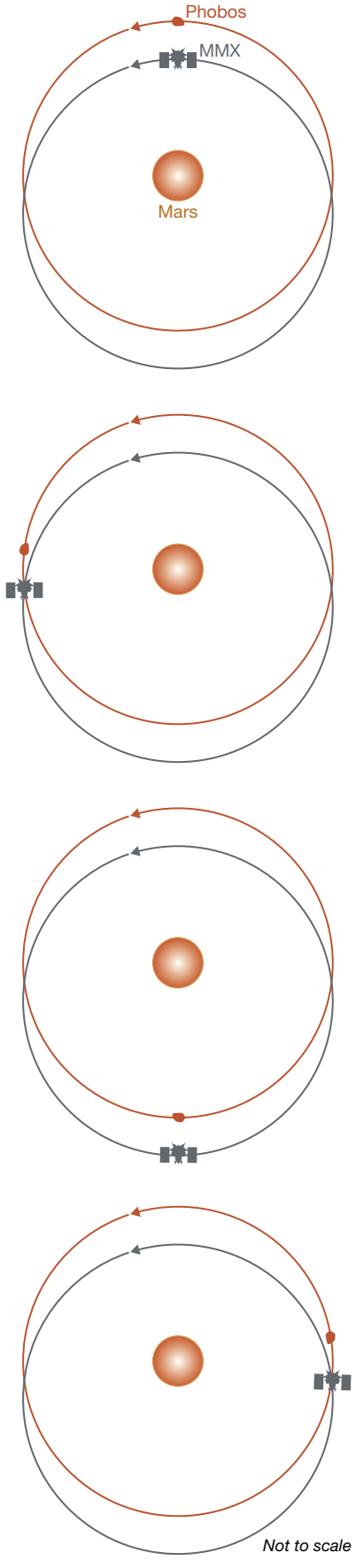
The orbital data will tell scientists a lot about Phobos's composition, maybe even enough to reveal the moons' origin and fulfill the mission's primary goal. "Of course, the sample return will be the highlight of the mission, there's no doubt about that," Charnoz says. But remote observations will reveal details about Phobos that samples can't give, such as the moon's density and internal structure. From orbit, MMX can assess whether the moon has a solid core or is an assemblage of multiple pieces. "The internal structure will tell you a lot about the formation process," Charnoz adds.

A persistent mystery has been the moons' lack of clear spectral features, especially at near-infrared wavelengths. Researchers think space weathering has darkened surface materials to the point that their true composition is undetectable. But as it observes the moon from close quarters, the spacecraft's near-infrared spectrometer could reveal new details.

To capture good images throughout the mission, the Japan Broadcasting Corporation provided a pair of ultra-high-resolution video cameras that will take

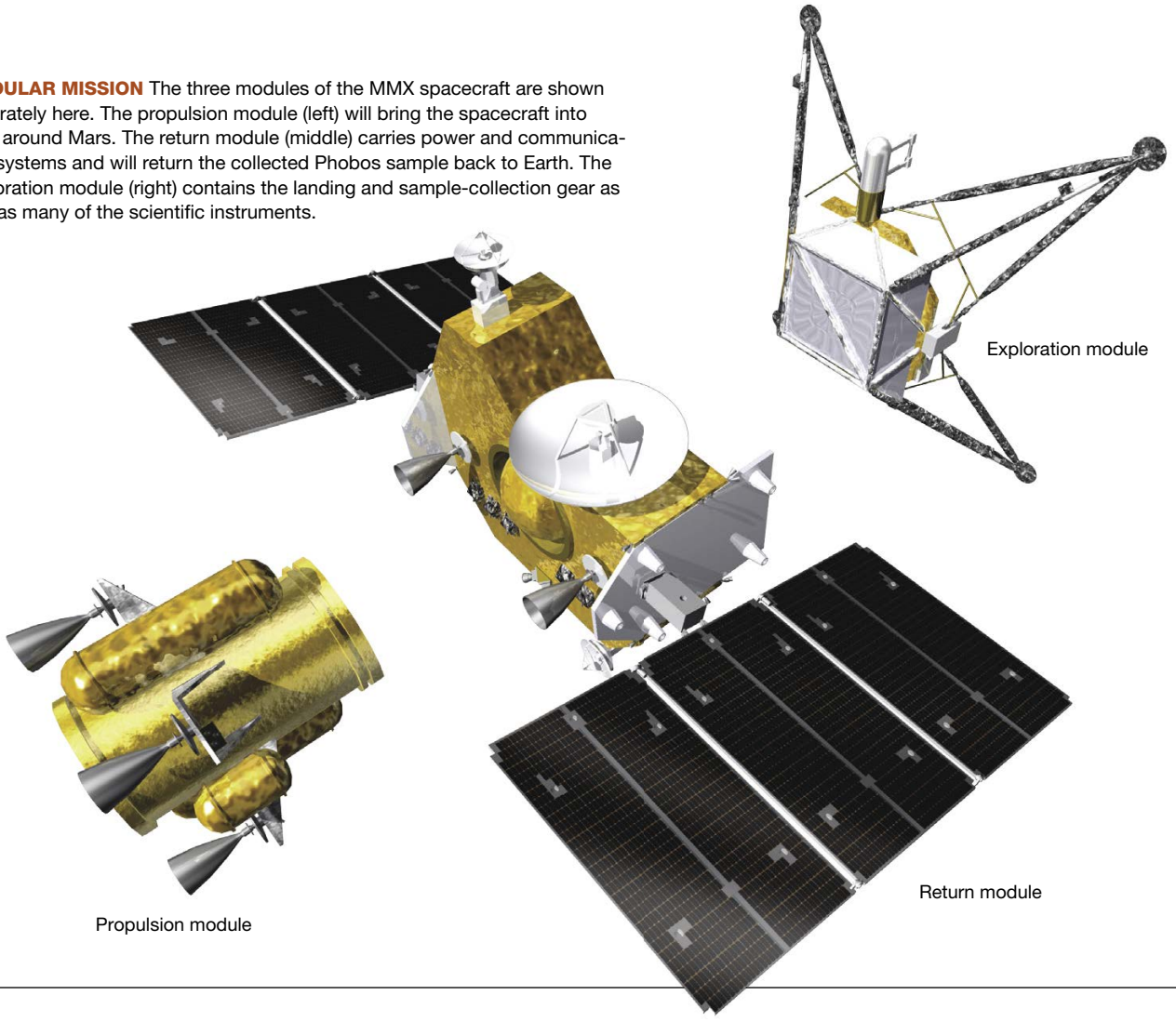
Lunar Views

From the surface of Mars, Phobos rises in the west, travels across the sky in 4 hours and 15 minutes, and sets in the east, completing its journey three times every Martian day.



◀ **LOOP-THE-LOOP** MMX will orbit Mars, but due to its elliptical trajectory (relative to Phobos's nearly circular path), it will appear to orbit Phobos.

JAXA / NAOJ



MODULAR MISSION The three modules of the MMX spacecraft are shown separately here. The propulsion module (left) will bring the spacecraft into orbit around Mars. The return module (middle) carries power and communication systems and will return the collected Phobos sample back to Earth. The exploration module (right) contains the landing and sample-collection gear as well as many of the scientific instruments.

detailed footage of Mars and its moons. While some of these images will be sent to Earth during the mission, the bulk of this data-intensive footage will be stored in the sample-return capsule, to be recovered on Earth.

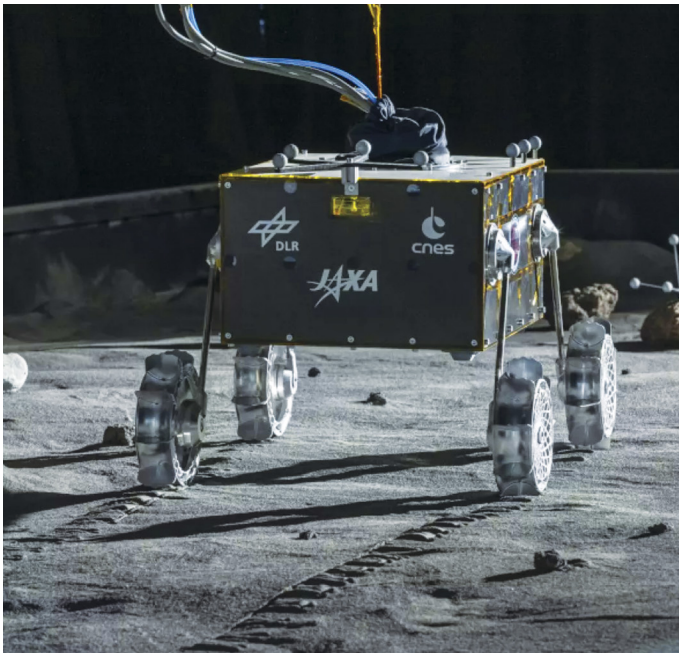
A Tiny Rover

Hitching a ride to Phobos is a four-wheeled rover designed to scout the surface ahead of the mothership's landing. A black box that's about 50 centimeters (20 inches) to a side with a bundle of solar panels folded on top, it almost looks like a child's toy — but it's about to go on a wild journey.

Named Idefix — a nod to the charismatic dog in the French comic *Asterix* — the rover was developed by the French and German space agencies.

The mothership will drop Idefix onto Phobos from an altitude of 40 meters (130 feet). "Falling from 40 meters on a low-gravity body is not so bad," says Stephan Ulamec (German Aerospace Center), the rover's principal investigator. "You still reach the surface at a very low velocity." In the moon's weak gravity, the rover will hit the surface at about 1 meter per second — less than normal walking speed.

Nevertheless, the rover is expected to bounce several times, traveling maybe a dozen meters before it comes to rest.



▲ **IDEFIX** A prototype of the rover went for a test drive on a patch of simulated Phobos terrain in 2025.

MMX: JAXA; IDEFIX ROVER: DLR

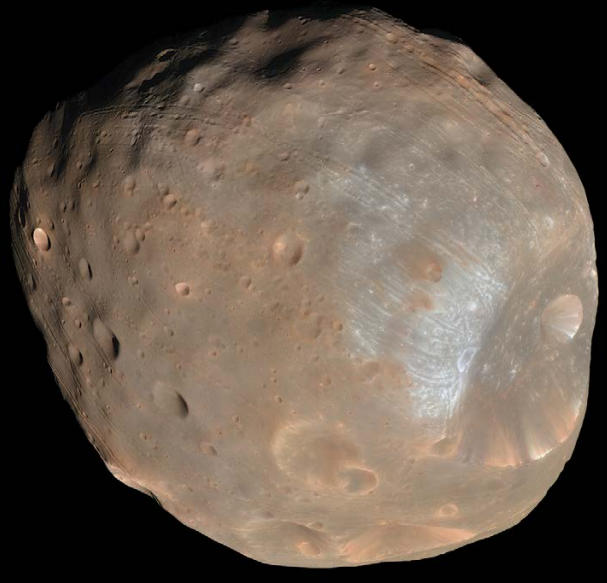
Then it will have to flip itself into driving position and unfold its solar panels to recharge its batteries. "If this doesn't work, the rover mission is over," adds Ulamec.

The low gravity will create other challenges. With a mass of 25 kilograms, Idefix will be light as a feather on Phobos, reducing the traction that enables the wheels to push forward. Speed will be restricted to a quasi-comical 1 millimeter (0.04 inch) per second. At this pace, it will take a full minute to travel just 6 centimeters. Still, the rover is expected to operate for at least 100 days, meaning there's time to travel hundreds of meters out from its landing site.

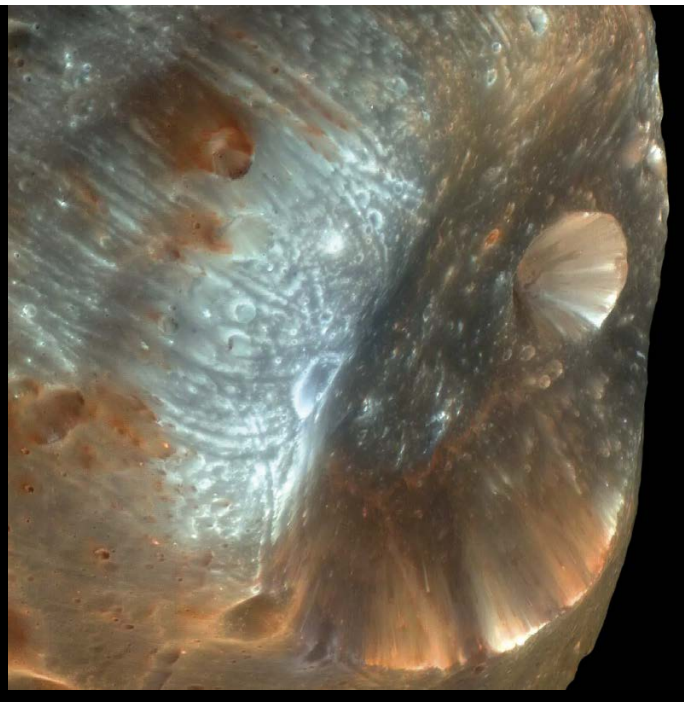
Driving commands will reach the rover from Earth using the mothership as a communications relay. But operators will be able to communicate with the rover only every 8 hours or so, due to Phobos's revolution around Mars. They will send instructions, maybe to advance a few centimeters, then wait to see the outcome. "It is not a racing car," Ulamec says, "but it will be the fastest car on Phobos." An autonomous driving feature is available, but only as a technology demonstration.

Idefix is a rolling laboratory. Two navigation cameras will look forward, while two additional cameras will point downward to observe how the wheels interact with the regolith — crucial not only for navigation but also to study the dirt's physical properties. A radiometer will measure surface temperatures to determine the moon's thermal properties, which indirectly reveal details about the density and interior.

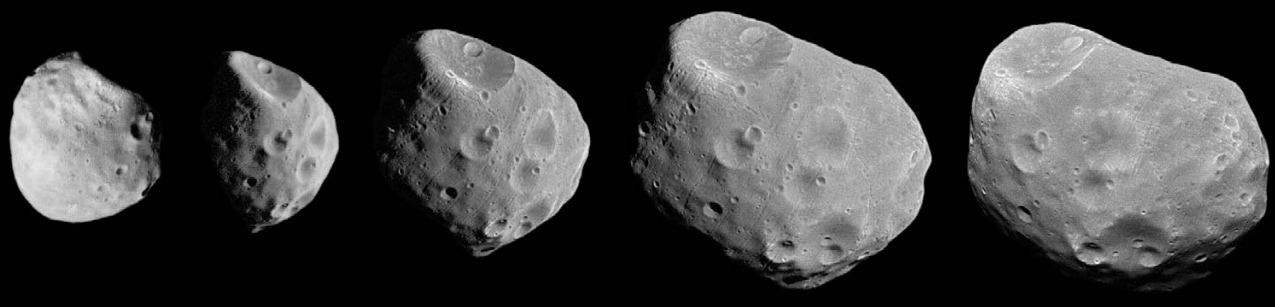
The most sophisticated instrument on the rover is a Raman spectrometer, designed to identify the regolith's



▲ **PHOBOS** Potato-shaped Phobos, imaged here by NASA's Mars Reconnaissance Orbiter, is 150 times smaller than our Moon and, due to its porosity, much less massive. Grooves extending from Stickney Crater at right might be signs of tidal stress threatening to rupture the moon.



▲ **MIGRATING MATERIAL** This image of Stickney Crater, the most prominent feature on Phobos, reveals fine dust left behind by boulders sliding down sloped surfaces. While this region of the moon changes more over time, other areas are more stable.



▲ **ZOOMING IN** The European Space Agency's Mars Express took these photos of Phobos as it passed ever closer over several orbits. The different views give a better sense of Phobos's 3D shape.

PHOBOS AND STICKNEY CRATER: NASA / JPL-CALTECH / UNIVERSITY OF ARIZONA (2); VIEWS OF PHOBOS ON SUBSEQUENT ORBITS: ESA / DLR / FU BERLIN (G. NEUKUM)

mineralogical composition. Because the instrument has a short working range, the rover must perform an awkward crouching maneuver, lowering its chassis until the sensor is near the ground. The process is slow and energy-intensive, meaning the team will have to be selective about where they perform these scans. These measurements are particularly valuable for investigating two distinct regions on Phobos with slightly different overall colors, either due to composition or merely texture. Raman spectroscopy can also determine how representative the mothership's samples are of the moon's overall makeup.

"You cannot get any of this information from orbit or from the samples," Ulamec says.

Even if Idefix works for longer than planned, its mission will end when the MMX mothership leaves Phobos and the communication link breaks. The rover will be left alone on the surface, unable to call home.

Chasing Regolith

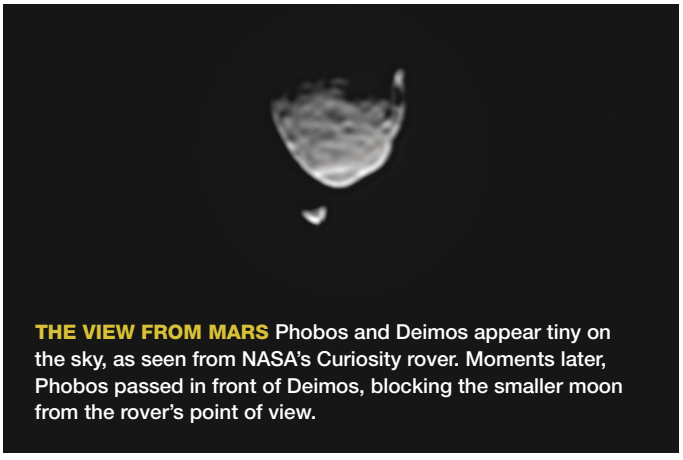
The sample gathering is the mission's highlight, but also a hair-raising maneuver for engineers and scientists alike. While previous asteroid missions performed touch-and-go procedures, bouncing away immediately after grabbing regolith, MMX will actually land on Phobos, remaining on the surface for several hours before collecting a sample.

No agency has ever attempted landing on a small body, and the act is made riskier by limited current knowledge of the terrain. The best images available now have a resolution of several meters per pixel, so it remains unknown whether there are any flat and smooth areas that are safe for landing, or if the whole place "is just cliffs and big rocks," Ulamec says. Mission planners are counting on the images gathered from orbit to help them plan the descent.

Regardless of the rocks' sizes, Phobos's regolith is likely loose, like dry beach sand, says MMX science team member Isabel Herreros (Center for Astrobiology, Spain). It should thus be subject to a shifting tug-of-war, due to the competing forces from (among other things) the moon's weak gravity, its rotation, and Martian tides.

The configuration of these forces varies with location. At the *sub-Mars point* — the location on Phobos that directly faces the planet — Martian gravity pulls "up" toward the planet, as does the centrifugal force from the moon's rotation, while the moon's own gravity pulls back toward the moon. At the poles, centrifugal forces disappear, leaving Martian gravity and self-gravity. On the anti-Mars side, both gravities combine to pull down towards Phobos's center, while the centrifugal force "pushes" up.

This gravitational mambo is further complicated by Phobos's slightly eccentric, near-synchronous orbit. As the moon circles Mars, the direction of the planet's pull "wiggles," causing the moon to sway back and forth, destabilizing regolith on the slopes. This causes grains to creep across the surface in a slow but constant migration. Thermal stress, internal fractures, and a constant rain of micrometeorites further destabilize the terrain, keeping the regolith on the move.



THE VIEW FROM MARS Phobos and Deimos appear tiny on the sky, as seen from NASA's Curiosity rover. Moments later, Phobos passed in front of Deimos, blocking the smaller moon from the rover's point of view.

Herreros has mapped how this material would move and where it would accumulate. Her work could help MMX avoid risky landing zones and it provides important context for any samples collected. A grain of sand collected in a valley might have rolled down from a nearby cliff, for example, while areas stripped of material might expose fresher layers that have been buried for eons.

Areas where material builds up are more likely to contain a diverse mix of grains — including ejecta blasted off the surface of Mars. But these ejecta might be easier to find in areas where grains are neither escaping nor building up. "If you want Martian material, it is better to go to a stable zone," Herreros explains. In such a spot, space weathering might have degraded Martian ejecta, but at least the pieces won't be buried under the shifting Phobos regolith.

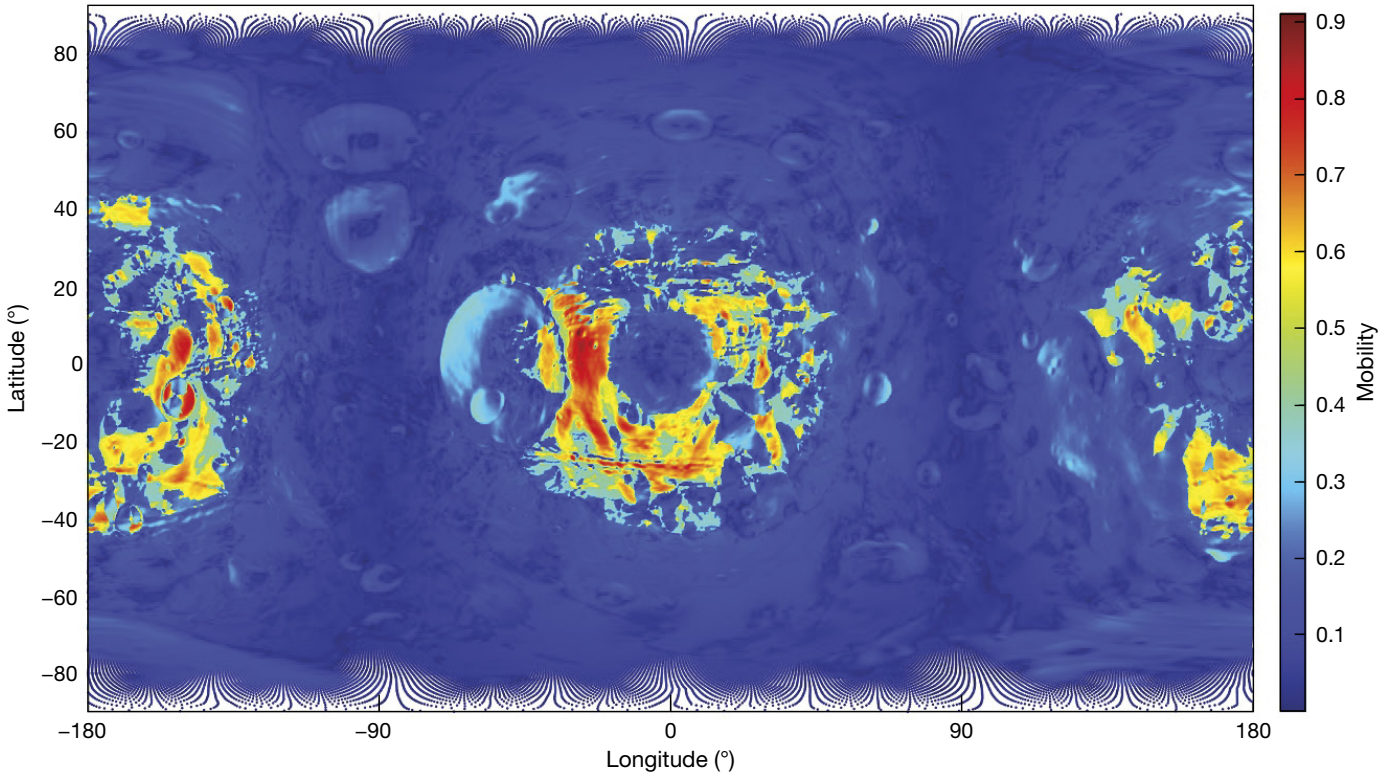
Because the physical properties of the surface — whether hard, sandy, or powdery — remain unknown, MMX carries two different sampling systems. The core or C Sampler consists of a drill mounted on a robotic arm. It's designed to bore up to 10 cm beneath the surface, to recover relatively pristine material that has been shielded from space weathering. Such samples are potentially representative of the moon's original building blocks.

In contrast, the P Sampler is a pneumatic system that uses a gas jet to collect loose material from the surface. This surface regolith is heavily impacted by radiation and, as Herreros's research suggests, likely contains a mix of nomadic grains that come from all over the moon's surface.

MMX researchers expect to collect approximately 10 grams (0.4 ounce) of material from Phobos. For comparison, Hayabusa 2 was expected to collect only 0.1 gram of material from the asteroid Ryugu but instead returned 5.4 grams. Some mission members are optimistic that MMX might similarly exceed their expectations.

After the sample has been collected, the spacecraft will take off again and return to orbit, where it will continue observations for another year or so. It remains to be seen whether the spacecraft will attempt a second landing to collect more samples from a different region. Mission plan-

NASA / JPL-CALTECH / MALIN SPACE SCIENCE SYSTEMS / TEXAS A&M UNIV.



▲ **LANDING SITES** This map of Phobos shows where material migrates a lot (red) or very little (blue). Stickney Crater is just to the left of center. Green areas, where grains are neither escaping nor building up, might make for the best sampling sites.

ners are waiting to see how everything goes during the first attempt before they decide.

Once the sampling is finished and the orbital observation campaign is deemed completed, perhaps sometime in 2029, MMX will start spiraling out from Mars, paying a visit to Deimos on the way. Whether this is a hasty flyby or a longer rendezvous will depend on how much propellant is left. Lastly, to further economize fuel, the return module will detach from the exploration module, leaving most of the instruments and landing gear behind, before powering on its engines to start the long journey back home.

As in previous missions, JAXA plans to safely crash the return capsule in the Australian outback. It should land in 2031. From there, the capsule will travel to the Extraterrestrial Sample Curation Center in Sagamihara, Japan, which hosts the samples from Itokawa, Ryugu, and Bennu. Only a single gram of the sample will be shared with Japanese and international scientists for immediate analysis; the rest will be stored for later study.

"Once you have the sample, it is kept for the future generation," Charnoz says. Keeping it safely preserved ensures that, when technology improves decades from now, scientists can perform analyses "that we cannot even imagine today."

Countdown

As the MMX launch date approaches, team members are finalizing preparations. For years they have squinted at low-resolution images of the moons taken from afar. MMX represents a new era of discovery, of seeing with clarity. "You imagine things one way," says Herreros. Now, she adds, "I want to go and see it."

"My hope is that when we go super, super close, Phobos will finally reveal itself," Charnoz says. "Is there water? Is there carbon? We might finally see the real spectral signature" that the darkened surface hides.

Another critical moment will be the first contact, led by the Idefix rover — that is, if it survives the landing. "Those first data beyond the pure 'housekeeping,' those first images, will be the most exciting," Ulamec says. "How is the rover? Is it working? What's the terrain? Are there rocks around?" The torrent of questions continues. "The excitement will continue as you drive and see how the driving works, and you get the first spectra. It will be a very fascinating 100 days."

For all of them, the mission is more than images and data; it's the possibility to move from theory and ideas to real evidence of the moons' histories — especially if they can finally study a sample face-to-face. "It's about curiosity," Herreros says. "For me, it will be spectacular if at some point I can truly see a sample that we have taken from there. That will be an experience that goes far beyond science."

■ Contributing Editor **JAVIER BARBUZANO** is a science journalist from Spain. A lifelong fan of the Asterix saga, he is already rooting for Idefix.

I. HERREROS & S. CHARNOZ / EPSC-DPS 2025 / CC BY 4.0

SKY AT A GLANCE
November 2026



1 **DAYLIGHT-SAVING TIME ENDS** at 2 a.m. for most of the U.S. and Canada.

2 **MORNING:** Face east to catch the delightful sight of the waning crescent Moon leading Mars, Jupiter, and Regulus above the horizon. The quartet forms a ragged line some 13° long. Turn to page 46 for more on this and other events listed here.

3 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:45 p.m. PST (see page 50).

6 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:34 p.m. EST (7:34 p.m. PST).

7 **DAWN:** Venus rises in the east-southeast shepherded by the almost-new Moon about 1½° lower right and Spica, Virgo's lucida, 1¼° left.

9 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 7:23 p.m. EST.

10 **DAWN:** Venus leads Spica by 1° as they rise above the east-southeastern horizon.

16 **MORNING:** After clearing the east-northeastern horizon, Mars and Jupiter climb together into the south, with a little more than 1° separating the pair.

16–17 **ALL NIGHT:** The Leonid meteor shower is expected to peak. The nearly first-quarter Moon won't interfere with viewing opportunities. Turn to page 50 for details.

24 **MORNING:** High in the west the full Moon hangs around 2° lower right of the Pleiades. Binoculars will help you tease out the cluster stars from the dazzle of the nearby Moon.

26 **MORNING:** In the east, Mars and Regulus pair up to form an isosceles triangle with Jupiter, spanning a bit less than 4°.

26 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:17 p.m. PST.

27 **EVENING:** The waning gibbous Moon, Pollux, and Castor form a line about 10° long. Look to the east to take in this sight.

29 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:06 p.m. EST (6:06 p.m. PST).

30 **MORNING:** Low above the eastern horizon, the waning Moon, just shy of last quarter, Jupiter, and Mars cluster around Regulus. The separation between the Moon and Mars is some 6°.

—DIANA HANNIKAINEN

▲ M33, the Triangulum Galaxy, is a great target for binoculars on November nights and can even be visible to the unaided eye under the best conditions. BRETT BOLLER

Lunar Almanac
Northern Hemisphere Sky Chart



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

MOON PHASES

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

LAST QUARTER
November 1
20:28 UT

NEW MOON
November 9
07:02 UT

FIRST QUARTER
November 17
11:48 UT

FULL MOON
November 24
14:54 UT

DISTANCES

Apogee
405,619 km

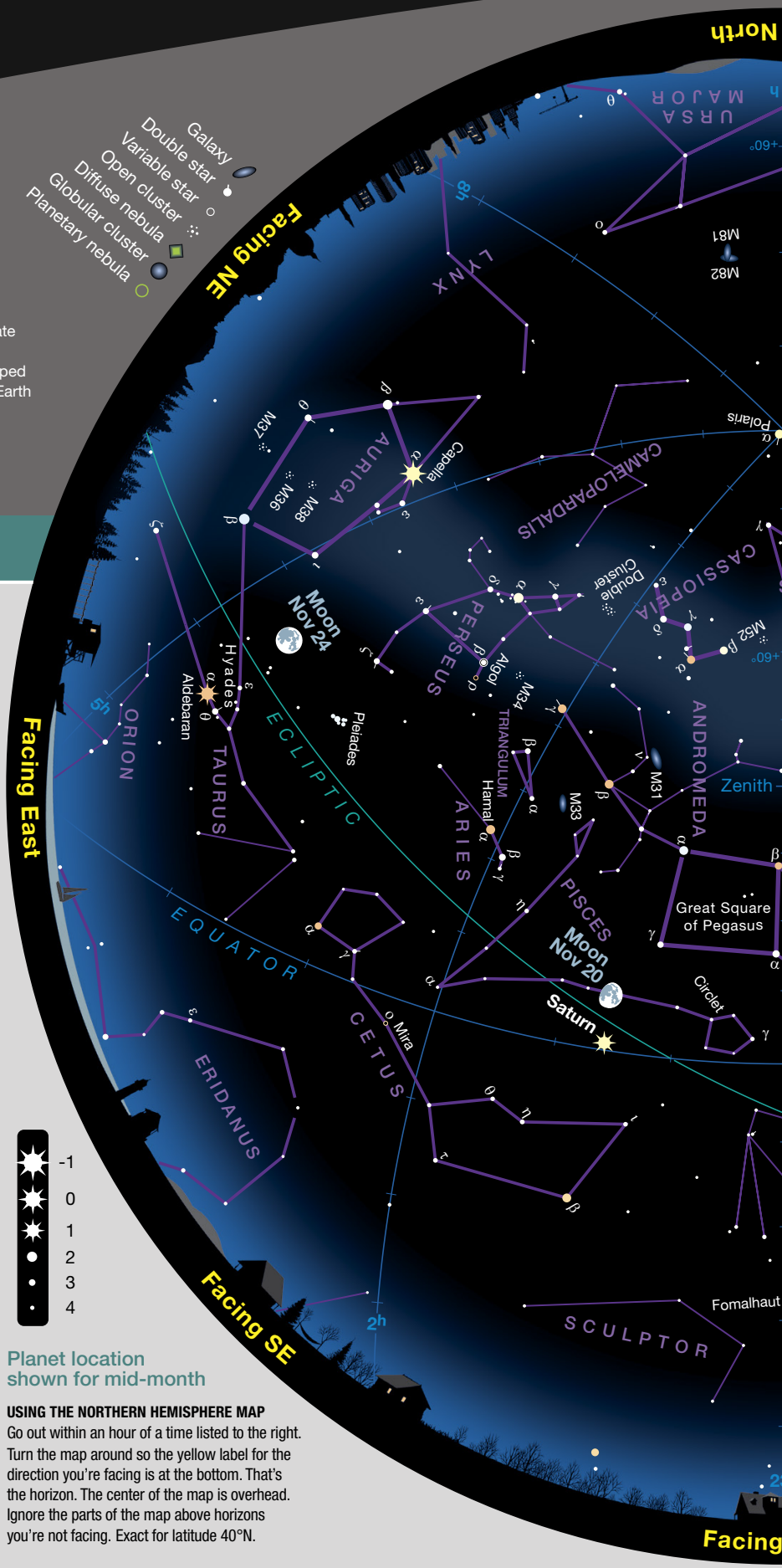
November 13, 18^{h} UT
Diameter 29′ 28″

Perigee
359,347 km

November 25, 21^{h} UT
Diameter 33′ 15″

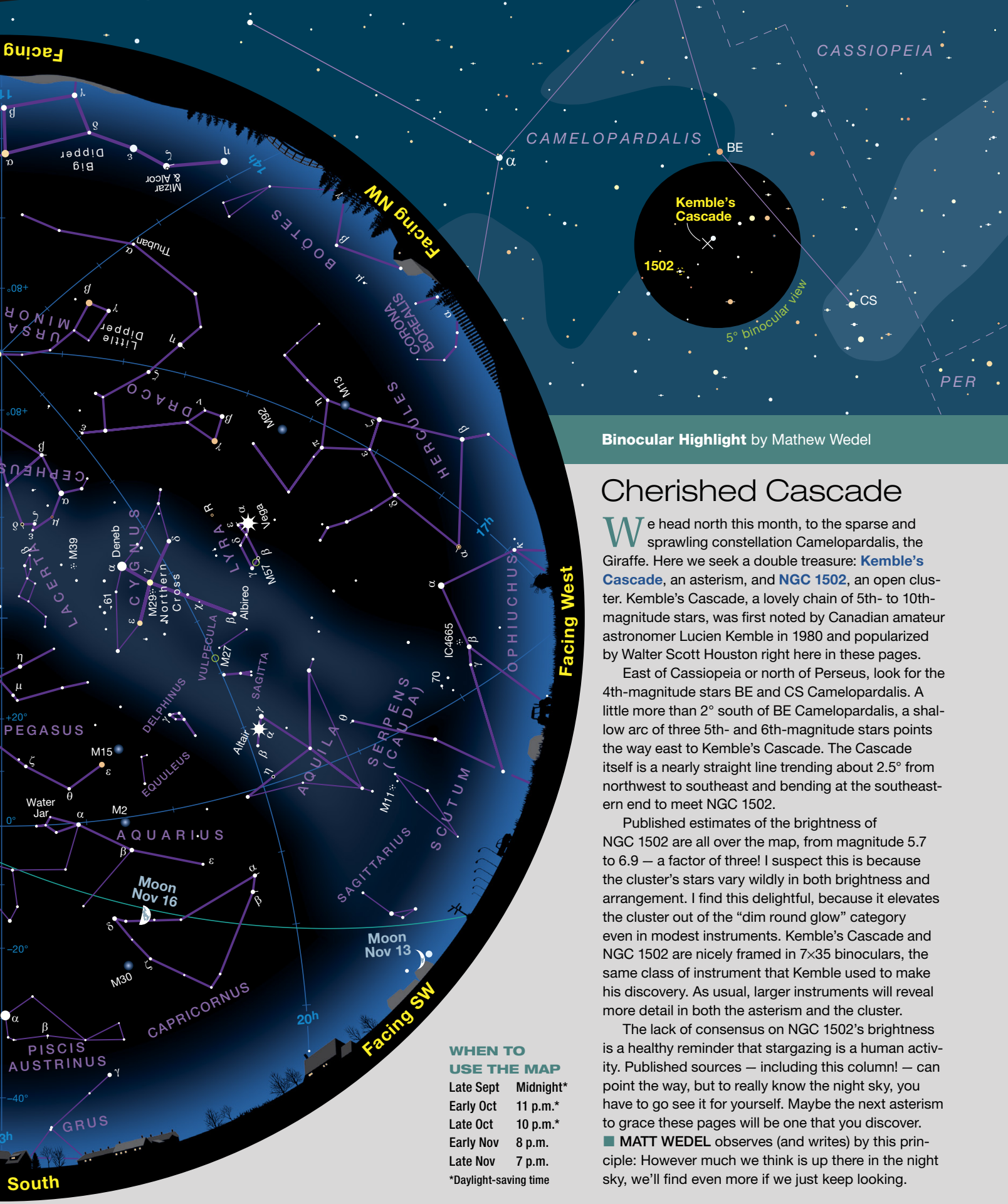
FAVORABLE LIBRATIONS

- Inghirami Crater — November 23
- Pingré Crater — November 24
- Le Gentil Crater — November 25
- Schomberger Crater — November 26



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

Cherished Cascade

We head north this month, to the sparse and sprawling constellation Camelopardalis, the Giraffe. Here we seek a double treasure: **Kemble's Cascade**, an asterism, and **NGC 1502**, an open cluster. Kemble's Cascade, a lovely chain of 5th- to 10th-magnitude stars, was first noted by Canadian amateur astronomer Lucien Kemble in 1980 and popularized by Walter Scott Houston right here in these pages.

East of Cassiopeia or north of Perseus, look for the 4th-magnitude stars BE and CS Camelopardalis. A little more than 2° south of BE Camelopardalis, a shallow arc of three 5th- and 6th-magnitude stars points the way east to Kemble's Cascade. The Cascade itself is a nearly straight line trending about 2.5° from northwest to southeast and bending at the southeastern end to meet NGC 1502.

Published estimates of the brightness of NGC 1502 are all over the map, from magnitude 5.7 to 6.9 — a factor of three! I suspect this is because the cluster's stars vary wildly in both brightness and arrangement. I find this delightful, because it elevates the cluster out of the "dim round glow" category even in modest instruments. Kemble's Cascade and NGC 1502 are nicely framed in 7×35 binoculars, the same class of instrument that Kemble used to make his discovery. As usual, larger instruments will reveal more detail in both the asterism and the cluster.

The lack of consensus on NGC 1502's brightness is a healthy reminder that stargazing is a human activity. Published sources — including this column! — can point the way, but to really know the night sky, you have to go see it for yourself. Maybe the next asterism to grace these pages will be one that you discover.

■ **MATT WEDEL** observes (and writes) by this principle: However much we think is up there in the night sky, we'll find even more if we just keep looking.

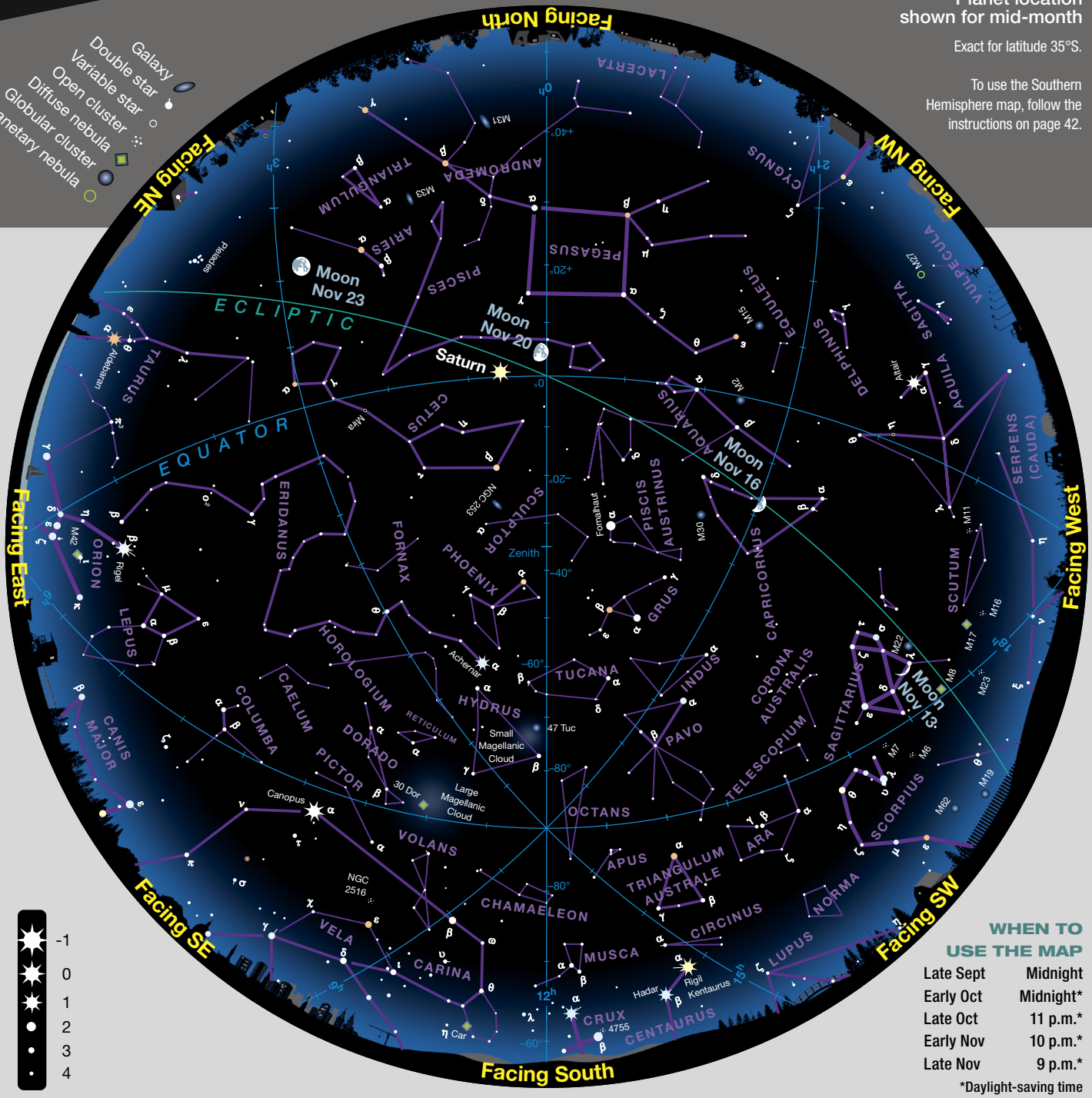
WHEN TO USE THE MAP

Late Sept	Midnight*
Early Oct	11 p.m.*
Late Oct	10 p.m.*
Early Nov	8 p.m.
Late Nov	7 p.m.

*Daylight-saving time

Southern Hemisphere Sky Chart

by Jonathan Nally



WHEN TO USE THE MAP

Late Sept	Midnight
Early Oct	Midnight*
Late Oct	11 p.m.*
Early Nov	10 p.m.*
Late Nov	9 p.m.*

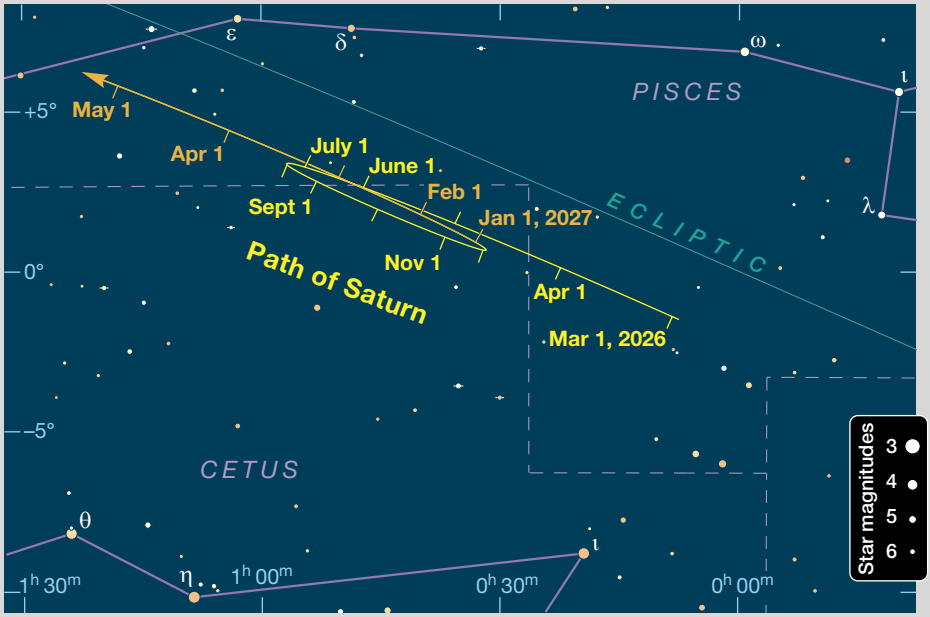
*Daylight-saving time

THE CONSTELLATION Horologium, the Clock, was devised by Nicolas Louis de Lacaille in the mid-18th century and is one of 13 he introduced that represent the tools of science, art, and navigation. Its brightest star, Alpha (α) Horologii, is at the far left-hand end of the outline on the chart above. This 3.9-magnitude *K*-type giant is about 10 times the size of our Sun and has a distinct orange appearance.

The other five stars in line as we move along the constellation are Iota (ι), Eta (η), Zeta (ζ), Mu (μ), and Beta (β). All of them are faint, between magnitudes 5.0 and 5.4. Beta, at 5.0, is actually the fourth-brightest star in the constellation after Alpha, Delta (δ; not shown, but just next to Alpha), and sometimes R Horologii (near Iota), a Mira variable with a range of nearly 10 magnitudes. ■

A Zodiacal Wonder in Cetus

Venture into the lair of the Sea Monster with Saturn.



This month, the ringed wonder Saturn and its menagerie of satellites harbors in Cetus, the Sea Monster. Read that sentence again. Notice anything odd? Saturn . . . in *Cetus*? When's the last time you heard someone say that they were born under the sign of Cetus? So what's a planet doing there?

Before we begin, look at the Northern Hemisphere Sky Chart on pages 42–43. Note the position of Saturn. It lies just south of the teal line representing the ecliptic, the apparent path that the Sun, Moon, and planets move along against the stars — sometimes on it, occasionally a little north of it, and at times a little south of it. Note, too, Saturn's proximity to Pisces, the Fishes, which *is* a zodiacal constellation. Cetus lies a bit farther to the south. So why isn't Saturn in Pisces?

The answer lies in the boundaries that we do not see in the sky, though they are there. It's no different than the astronauts looking down on Earth. They don't see the imaginary lines "fencing-in" its countries, states, towns, or villages. On Earth, these invisible fences are generally highly irregular, and it's no different with constellations in the sky.

Between 1922 and 1930, the International Astronomical Union (IAU) met several times to create order out of the chaos in the sky. Namely, before then, there was nothing to prevent astronomers from continually inventing new figures between the existing ones. They agreed to divide the entire night sky into 88 *areas* with "official" boundaries, which differ greatly in size and shape. For instance, Aries, the Ram, inhabits an irregular area of 441 square degrees, while Virgo, the Virgin, occupies an abnormally shaped expanse of 1,294 square degrees. As these fences are invisible, they are useless to the casual stargazer — until something comes up, like hearing that Saturn is in Cetus.

As shown on the chart above, Saturn first moved from Pisces into Cetus this year on April 10th. The planet remained in Cetus until June 3rd, when it returned to the Fishes. We then saw the planet reverse its forward progress (from west to east) and reenter Cetus on September 5th. This *retrograde motion* (from east to west) is an optical illusion caused by the different speeds at which Earth and Saturn orbit the Sun. When Earth overtakes slower-moving Saturn, we see Saturn appear to travel backward — just as a car driving slower than yours seems to recede from view. The ringed wonder will remain in Cetus until February 22, 2027, when the planet resumes its *prograde motion* and returns to Pisces. By then, Saturn will have spent a total of about eight months in the celestial Sea Monster — at least according to the IAU.

Ancient Babylonians, creators of the first astronomical coordinate system, didn't have this irregular boundary issue, as they had the Sun, Moon, and planets moving through twelve equal-length zodiacal signs, each 30° wide. It was that simple.

Cetus isn't the only square peg in the round hole of the zodiac. For instance, the Sun and planets pass through a portion of Ophiuchus, the Serpent Bearer, too. Some astrologers even try to call it the 13th zodiacal sign. I wonder if they'll try to add Cetus to that list now as well? By the way, though you won't find them plotted in this month's star chart, two of the largest asteroids — Vesta at magnitude 7.0 and Pallas at 8.7, which also circle within the Sun's orbital plane — lie in Cetus all month as well. Like Saturn, these asteroids are currently a celestial feint to some practitioners trying to provide insights into human affairs.

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

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

Glorious Morning Gatherings

Early risers are amply rewarded with a series of spectacular planetary gatherings.

MONDAY, NOVEMBER 2

Although winter doesn't officially begin in the Northern Hemisphere until the December solstice, November nights can be downright frigid. In most locations, the temperature bottoms out in the hours just before sunrise. But this morning offers a conjunction that should warm skywatchers to the core: a tight grouping featuring the **Moon**, **Mars**, and **Jupiter**. The waning lunar crescent (about 43% illuminated) is approaching the Red Planet, so the later you look, the narrower the gap between the pair will be. As twilight brightens the sky, they're just 1° apart, while the Moon is positioned a bit more than 5½° upper right of Jupiter. Big Jove gleams at magnitude –2.0, greatly outshining +0.9-magnitude Mars. Completing the picture is Leo's leading light, **Regulus**, flickering away some 5½° lower left of Jupiter. At present, Mars is half a magnitude brighter than the star. Can you perceive the difference? Their color contrast makes the comparison more challenging than you might expect. If you revisit the scene the following morning (the 3rd), the Moon will be about 2¼° below Regulus, creating another fine conjunction. As lovely as all this is, just wait until the end of the month!

SATURDAY, NOVEMBER 7

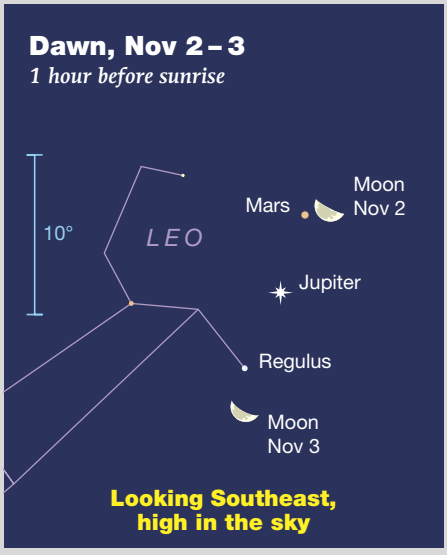
The eastward trek of the **Moon** across the dawn sky brings it near **Venus** today. And what a sight this is! The Morning Star is a bright beacon at magnitude –4.6, while the slender lunar crescent (3% illuminated) is awash with *earthshine* — sunlight reflecting off Earth toward the Moon's surface. The duo is just a bit more than three Moon diameters apart. For observers in the Americas, this is the best nighttime conjunction between them for 2026, and closer than they'll get in all of 2027.

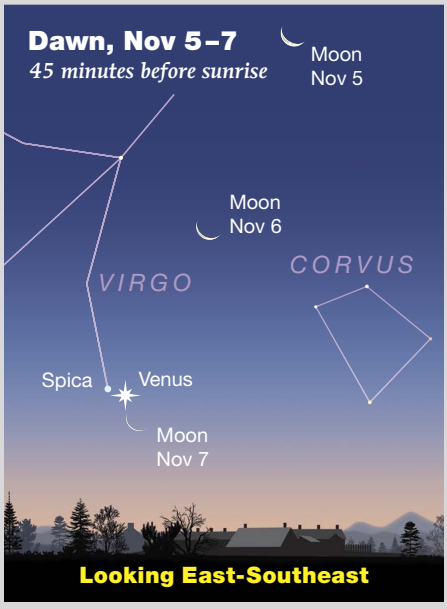
Given the spectacle of Venus and the Moon together, you'd be forgiven for not noticing that they're parked near **Spica**, Alpha (α) Virginis. Despite being a 1st-magnitude star, Spica is almost overwhelmed by its showy neighbors. Nonetheless, you should be able to easily spot its glint even without optics, though binoculars will make the star more obvious and enhance the visibility of earthshine on the Moon, especially as dawn approaches. It's also worth checking back the next few mornings to watch Venus as it slowly passes Spica. On the 9th, they'll be separated by just a bit more than 1°.

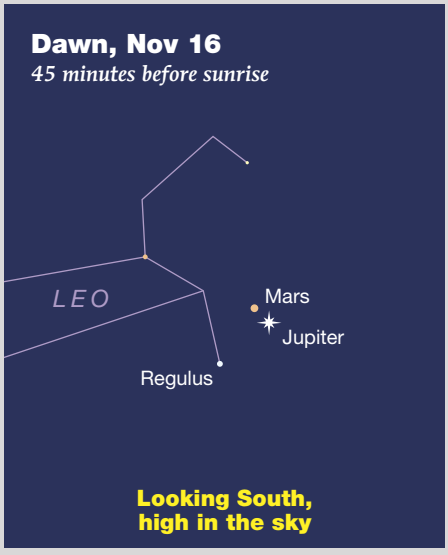
MONDAY, NOVEMBER 16

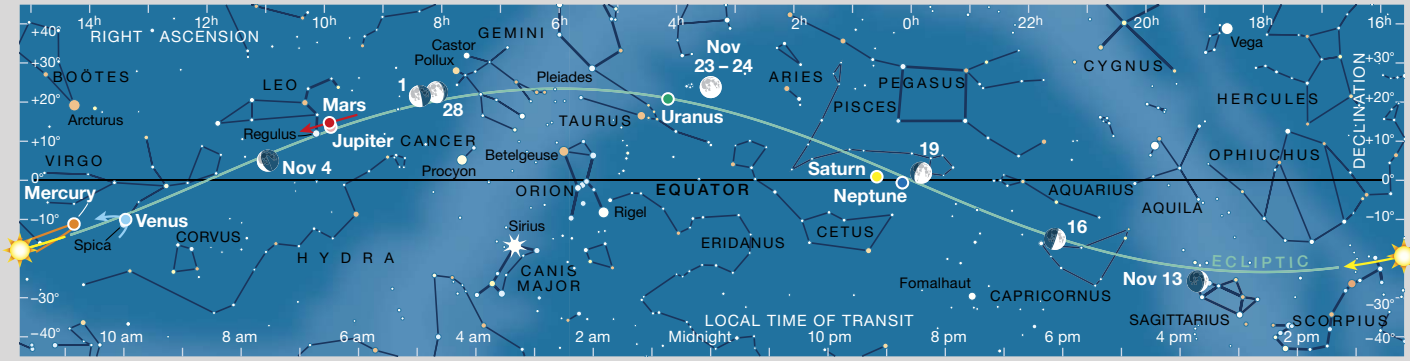
If you've been keeping an eye on Leo the past two weeks, you've probably noticed

▼▶ 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.



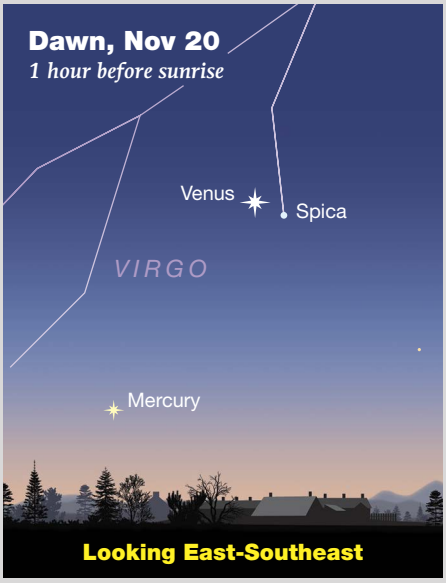






▲ The Sun and planets are positioned for mid-November; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

that speedy **Mars** has been creeping up on plodding **Jupiter**. Early this morning, they're at their very closest. As they rise together in the east-northeast roughly half an hour before midnight (when the night of the 15th ticks over to the morning of the 16th), the two worlds appear 1.2° apart. That's close enough that they can be seen together in the low-power field of most telescopes. The Red Planet passes less than 2° north of **Regulus**, on the morning of the 26th. Mars will visit Jupiter once more this apparition, but not for a few months. In January it stops moving eastward and begins to retrograde westward back toward Jupiter. But when the two meet again in April, they'll be much farther apart than this morning. All the more reason to observe them now.



FRIDAY, NOVEMBER 20

Of the three dawn **Mercury** apparitions in 2026 the current one is the best, comparable to one that took place at dusk in February. This morning Mercury is at greatest elongation (20° west of the Sun) at the same time it's at greatest elevation, thanks to the ecliptic's steep angle to the November dawn horizon. Indeed, this is Mercury's best morning showing until November 2027. The little planet pops up roughly 100 minutes before sunrise and glows brightly at magnitude –0.6. It should be an easy catch so long as you have a reasonably unobstructed east-southeastern horizon. At the same time, you can't help but notice brilliant **Venus** positioned some 15° upper right of Mercury. Although Venus has continued to drift away from Spica since the 9th, it still remains less than 2° from the star.



MONDAY, NOVEMBER 30

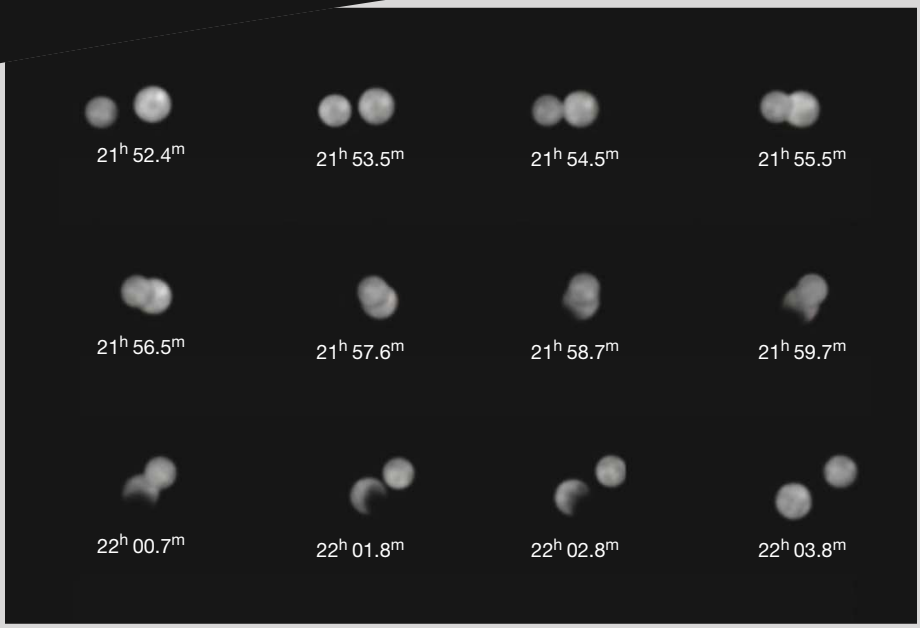
The November sky has saved the best for last! And given all the striking conjunctions that have already occurred this month, that's really saying something. On this final November morning, a remarkable gathering takes place in Leo, where the **Moon**, **Jupiter**, **Mars**, and **Regulus** clump together in a field that spans just a bit more than 5°. That's compact enough that you can view the entire quartet in 7×50 binoculars. The most conspicuous members of the bunch are Jupiter, which now shines at magnitude –2.2, and the waning gibbous Moon (about 59% illuminated) sitting roughly 1° lower left of the bright planet. (For observers in southernmost South America, the lunar disk actually eclipses Jupiter today.) The Moon also anchors a 4°-long line leading upper left that includes Mars, with Regulus in the middle. Both the Red Planet and the Moon are about 2½° to either side of Regulus, Mars having had its closest approach to the star only four days earlier.

Meanwhile, as morning twilight begins to lighten the sky, **Venus** and **Spica** sit together while **Mercury** hovers low in the east-southeast. So, if you're only going to pick one morning this month to brave the November chill, this is the one to choose!

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

Jupiter's Moons Take After Dear Old Dad

Mutual-event season is upon us.



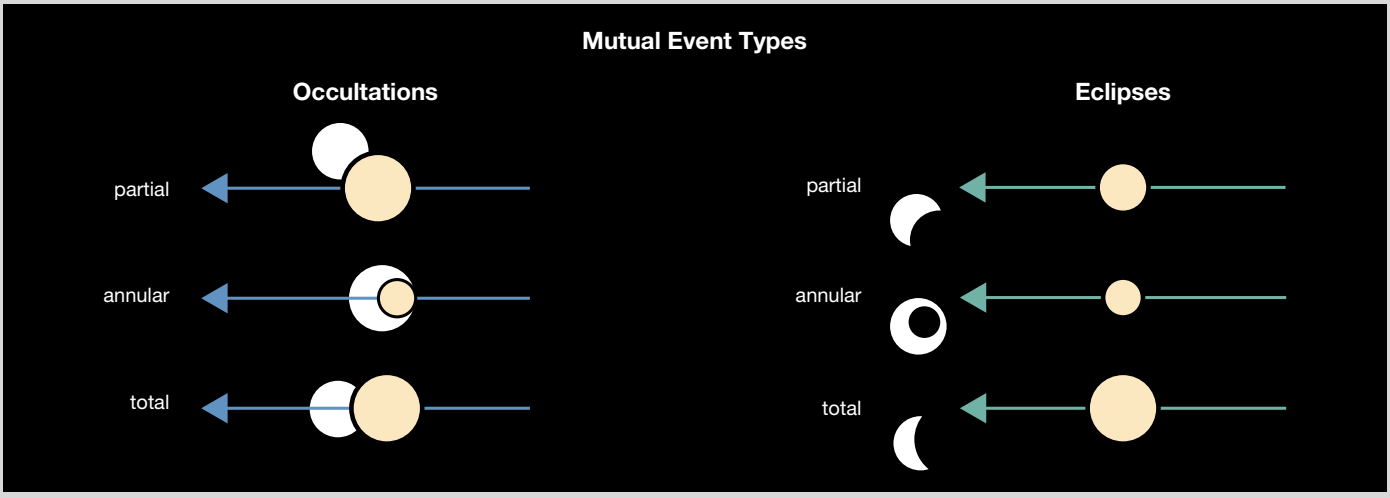
▲ During a mutual-event season, the orbits of the Galilean moons are practically edge-on from our perspective on Earth. Under these infrequent circumstances we get to see them eclipse and occult one another. In this sequence, made on February 7, 2015, Europa first occults Io and then partially eclipses it!

Every six years, the orbital plane of Jupiter's four brightest moons aligns edge-on with respect to both the Sun and Earth, and we get to see the satellites interact in a series of *mutual events*. The 2026–2027 mutual-event season began in May and heats up with Jupiter's return to the early morning sky.

From now until next August, observers will see the Galilean satellites *occult* and *eclipse* one another. During an occultation, one moon passes in front of another. They appear to merge and then part over the course of 5–10 minutes. In excellent seeing at high magnification, you may even detect their individual disks as they overlap. Eclipses, where one moon casts a shadow on another, are more nuanced: One fades while the other maintains a steady brightness.

You'll find all the information you need at the Time-Space Laboratory (LTE) website at **ssp.imcce.fr/forms**. Click the Satellites Phenomena link and under ***Epoch***, type the start date, number of days, and your geographic coordinates (western longitude is negative). Next, tap the green ***Compute*** button for a list of events. Then click the small, blue gear icon and filter the list to show only mutual phenomena of the four Galilean moons by unchecking ***By Planet*** and all moons listed except the Galileans.

The handy Documentation link on this page explains the terminology used in your list. Key parameters for planning an observing session are the altitudes of Jupiter and the Sun (H and H☉, respectively) at the time, and what's called *impact* (I), which ranges from 0 (total) to 1 (partial). The smaller the impact value, the deeper and more striking the event (see the diagram below). Although some of these mutual events are subtle, I think you'll find it captivating to watch the moons take on roles normally reserved for Jupiter alone.



▲ During a mutual event, one Jovian moon blocks another from view, either directly or with its shadow. Visually, the occulted or eclipsed moon dims depending on the satellites' alignment. The more centrally aligned the moons, the more obvious the event.

EUROPA & IO: JOHN SUSSENBACH; MUTUAL EVENTS GRAPHIC: BEATRIZ INGLESSIS / S&T

Prime Time for Uranus

THIS IS A GREAT TIME to observe the seventh planet. Not only is it north of +20° declination this observing season, it shuttles between the bright Hyades and Pleiades star clusters. Opposition occurs on November 25th, when Uranus and Earth will be closest at 2.8 billion kilometers (1.7 billion miles) apart. Its light takes 2.6 hours to reach us, or about the time it takes to watch the sci-fi movie *Project Hail Mary*.

Uranus is moving westward in retrograde motion, starting the month about 5° southeast of the Pleiades and 1.6° southeast of the 4th-magnitude star 37 Tauri. The latter acts as a stepping-stone to the planet: Start at the Pleiades and star-hop about 4° east-southeast to 37 Tau. Uranus dangles between 1.4° and 1.6° south of the star through mid-December. On February 8, 2027, the blue-green planet pulls to within 4° of the Pleiades before turning back east in direct motion.

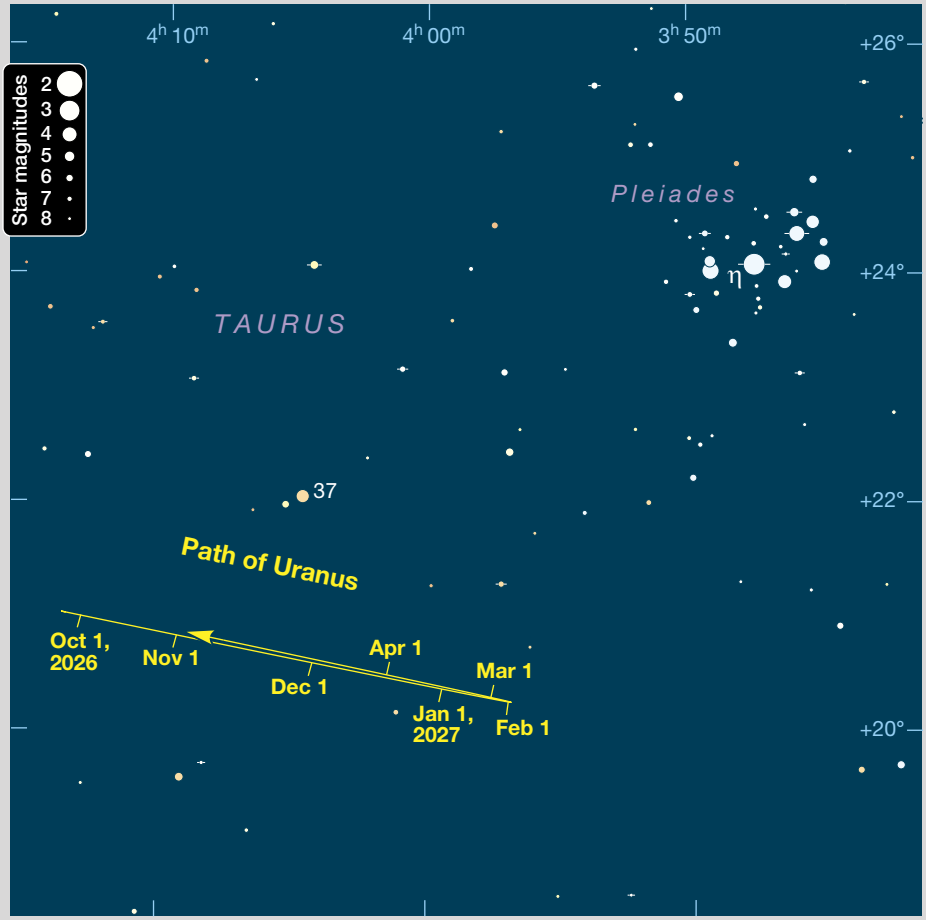
At magnitude 5.6, Uranus is fair game to spot without optical aid from a rural sky, especially this season when it tops out around 70° altitude for observers in the mid-northern latitudes. That said, binoculars make it much easier to see and track the planet, plus you can take optional side tours to the aforementioned star clusters. A 3-inch telescope will show the planet's 3.8″-wide disk at magnifications of around 100×. What's the lowest magnification *you* need to distinguish it from a star? Both Uranus and Neptune have similar colors for the same reason — the presence of methane in their atmospheres. The gas absorbs red light, reflecting a bluish hue.

As far as spotting disk detail, Uranus is a tough nut. But if you're going to attempt this difficult feat, now is the time to do it. Observers using 10-inch and larger scopes and magnifications of 300× to 500× have occasionally glimpsed faint banding and the planet's brighter equatorial zone. Astrophotographers will likely have more success than visual observers. But again, larger instruments and high magnifications are required. Red and IR (infrared) filters that probe more deeply into Uranus's atmosphere have a better chance at features otherwise invisible to the human eye. Right now we're facing the planet's bright (and occasionally stormy) north polar "cap" almost square-on. The cap may be visible at high magnification as a large, brighter, round patch slightly offset to the west of disk center.

Our pole-on perspective is the same reason the orbital planes of Uranus's brightest moons are nearly face-on. They appear to circle around the planet rather than move from side to side. Happily, that means the whole crew's essentially at greatest elongation no matter when you look. Titania and Oberon are the brightest moons at magnitudes 13.8 and 14.0, respectively, as well as being the farthest from the planet. Thus, they're the easiest of the Uranian moons to catch — visible in scopes as small as 8 inches in good seeing.

Since the satellites look like very faint stars, a map showing their positions at your observing time is essential to identify them. We've got you covered there. Go to *Sky & Telescope*'s *Moons of Uranus* observing tool (**bit.ly/4atedQh**) and set the time of your observation for a diagram showing Titania and Oberon plus the more challenging targets Ariel (magnitude 14.2), and Umbriel (14.9). These fainter moons orbit even closer to the planet. A 10-inch scope will reveal them under the calmest seeing and highest allowable magnifications.

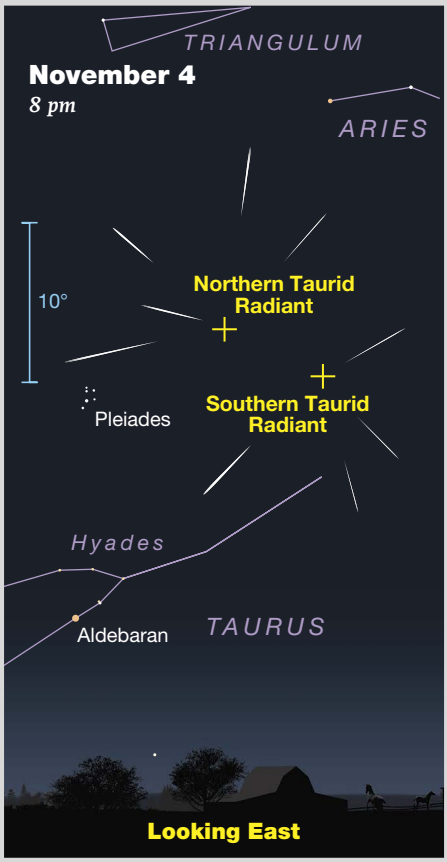
Uranus is a cold and windy planet, traits it shares with the coming winter season's weather. As you soak in the sight of the frosty blue orb through the telescope, don't be surprised if a shiver runs down your spine.



▲ Uranus reaches opposition on November 25th while moving westward in retrograde motion across Taurus. The Pleiades and 4th-magnitude 37 Tauri will help point you to it. Uranus resumes direct motion on February 8, 2027.

Three Minor Meteor Showers

TUCKED BETWEEN October's modest Orionids and December's abundant Geminids, three minor showers keep the meteor pipeline flowing through November. They include the Northern (NTA) and Southern (STA) Taurid streams and the well-known Leonids. All of them occur under dark, nearly moonless circumstances this year.



▲ The Southern and Northern Taurids both stream from near the Pleiades. The former is active through about November 20th and the latter through early December. The Leonids (not pictured) stream from Leo's Sickle asterism and reach maximum the night of November 16-17.

The Southern Taurids have two components, the second of which reaches maximum on the night of November 4–5. The Northern Taurids get their turn the night of November 11–12. Both streams have wide windows of visibility from 9 p.m. to 5 a.m. and feature bright, slow fireballs traveling at around 27 kilometers per second (61,000 mph), half the speed of the Perseids.

The showers' average hourly rate in a pristine sky is a mere five per hour, so try netting meteors with a tripod-mounted digital camera and an intervalometer. I use a 16-mm or 20-mm wide-angle lens set to its maximum aperture, an ISO of 1600 or 2500, and exposures between 20 and 30 seconds.

The Leonid meteor shower is famous for its *meteor storms*, which recur approximately every 33 years, the orbital period of its parent comet, 55P/Tempel-Tuttle. Unfortunately, astronomers expect a dearth of storms until 2099. Meteor counts in these off years drop to around 15 or fewer per hour. The Moon is near first quarter on the night of maximum, November 16–17, so best viewing will be from 1 a.m. till dawn. Should you manage to observe the full trifecta, you'll be ready for what could be the year's most spectacular meteor display — December's Geminids.

Minima of Algol

Oct.	UT	Nov.	UT
3	17:48	1	9:56
6	14:37	4	6:45
9	11:26	7	3:34
12	8:15	10	0:23
15	5:03	12	21:12
18	1:52	15	18:01
20	22:41	18	14:50
23	19:30	21	11:39
26	16:18	24	8:28
29	13:07	27	5:17
		30	2:06

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457675.72 + 2.867343E (where E is any integer) as listed in the AAVSO Variable Star Index. For a comparison-star chart and more info see **skyandtelescope.org/algol**.

Action at Jupiter

THE BIG PLANET is making its move into the late evening sky, rising earlier each day. Its best views, though, are still just before dawn when it reaches an altitude in the high 50°s. Jupiter has a lot going for it in November, including a mid-month close encounter with brother Mars and several mutual occultations and eclipses of its brightest satellites (see page 48). Our own Moon enters the field of view at month's end.

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

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

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

November 1: 2:16, 12:11, 22:07; **2**: 8:03, 17:59; **3**: 3:54, 13:50, 23:46; **4**: 9:42, 19:37; **5**: 5:33, 15:29; **6**: 1:24, 11:20, 21:16; **7**: 7:12, 17:07; **8**: 3:03,

12:59, 22:54; **9**: 8:50, 18:46; **10**: 4:42, 14:37; **11**: 0:33, 10:29, 20:24; **12**: 6:20, 16:16; **13**: 2:12, 12:07, 22:03; **14**: 7:59, 17:54; **15**: 3:50, 13:46, 23:42; **16**: 9:37, 19:33; **17**: 5:29, 15:24; **18**: 1:20, 11:16, 21:12; **19**: 7:07, 17:03; **20**: 2:59, 12:54, 22:50; **21**: 8:46, 18:41; **22**: 4:37, 14:33; **23**: 0:29, 10:24, 20:20; **24**: 6:16, 16:11; **25**: 2:07, 12:03, 21:58; **26**: 7:54, 17:50; **27**: 3:45, 13:41, 23:37; **28**: 9:33, 19:28; **29**: 5:24, 15:20; **30**: 1:15, 11:11, 21:07.

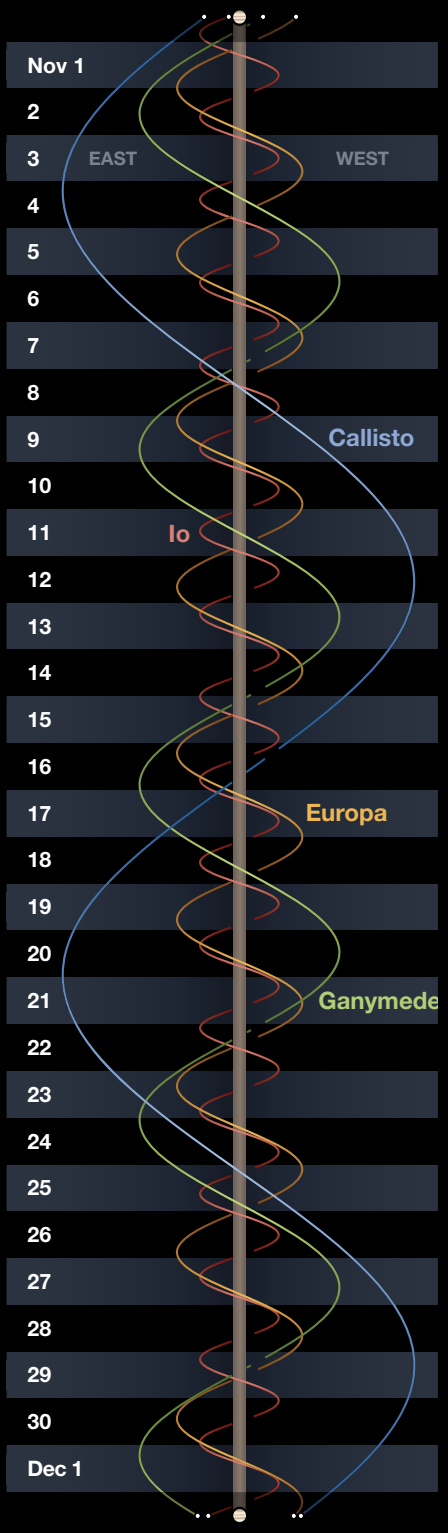
These times assume that the spot will be centered at System II longitude 94° on November 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 94° and 1²/₃ minutes later for each degree more than 94°.

Phenomena of Jupiter's Moons, November 2026

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

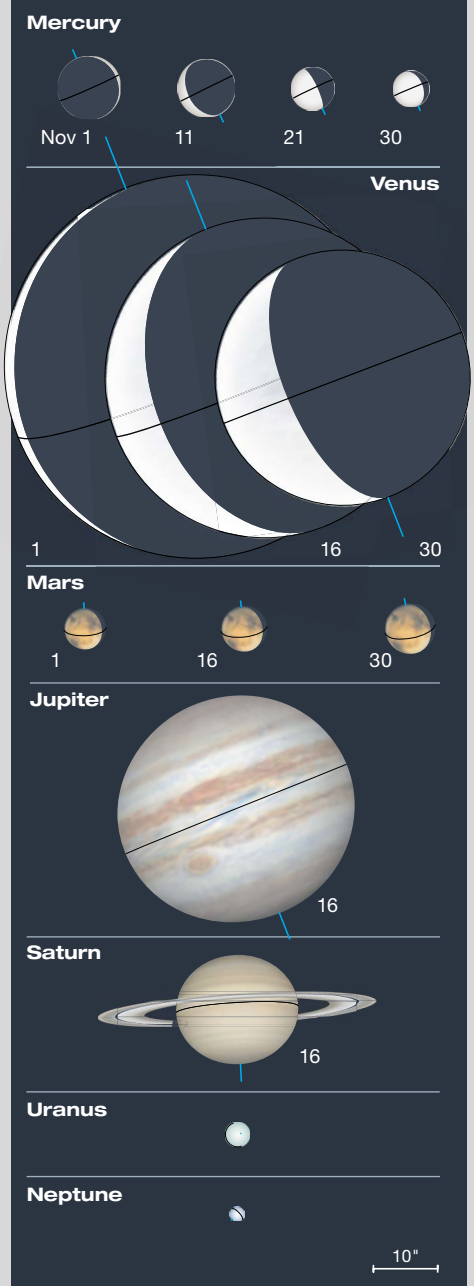
Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede,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

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn starting on the 11th • **Venus** visible at dawn • **Mars** and **Jupiter** rise around midnight and visible to dawn • **Saturn** visible at dusk and sets early morning.



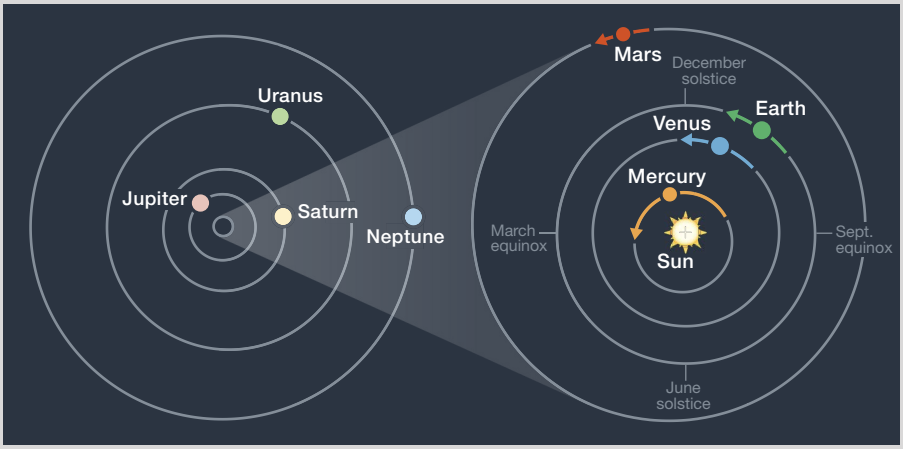
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

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

November Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$14^h\ 23.3^m$	−14° 14′	—	−26.8	32′ 13″	—	0.993
	30	$16^h\ 22.4^m$	−21° 33′	—	−26.8	32′ 26″	—	0.986
Mercury	1	$14^h\ 53.4^m$	−18° 11′	8° Ev	+3.4	9.9″	5%	0.682
	11	$14^h\ 14.3^m$	−11° 49′	13° Mo	+1.4	8.9″	15%	0.753
	21	$14^h\ 28.9^m$	−12° 12′	20° Mo	−0.6	6.7″	60%	1.001
	30	$15^h\ 13.0^m$	−16° 12′	17° Mo	−0.6	5.6″	83%	1.200
Venus	1	$13^h\ 28.7^m$	−14° 31′	13° Mo	−4.2	59.6″	3%	0.280
	11	$13^h\ 20.3^m$	−11° 02′	26° Mo	−4.7	53.5″	10%	0.312
	21	$13^h\ 26.5^m$	−9° 16′	35° Mo	−4.8	45.9″	19%	0.363
	30	$13^h\ 42.4^m$	−9° 12′	40° Mo	−4.9	39.7″	27%	0.420
Mars	1	$9^h\ 24.8^m$	+16° 53′	80° Mo	+0.9	6.5″	90%	1.433
	16	$9^h\ 53.3^m$	+14° 53′	88° Mo	+0.7	7.2″	89%	1.307
	30	$10^h\ 16.2^m$	+13° 11′	96° Mo	+0.5	7.9″	90%	1.186
Jupiter	1	$9^h\ 46.0^m$	+14° 11′	74° Mo	−2.0	35.8″	99%	5.500
	30	$9^h\ 55.5^m$	+13° 29′	101° Mo	−2.2	39.0″	99%	5.049
Saturn	1	$0^h\ 36.9^m$	+1° 04′	151° Ev	+0.5	19.4″	100%	8.548
	30	$0^h\ 32.2^m$	+0° 39′	120° Ev	+0.7	18.7″	100%	8.881
Uranus	16	$4^h\ 06.9^m$	+20° 45′	170° Mo	+5.6	3.8″	100%	18.459
Neptune	16	$0^h\ 07.5^m$	−0° 43′	128° Ev	+7.8	2.3″	100%	29.256

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



Explore the Treasures of Cassiopeia

Here's a mixed bag of easy and challenging celestial targets.

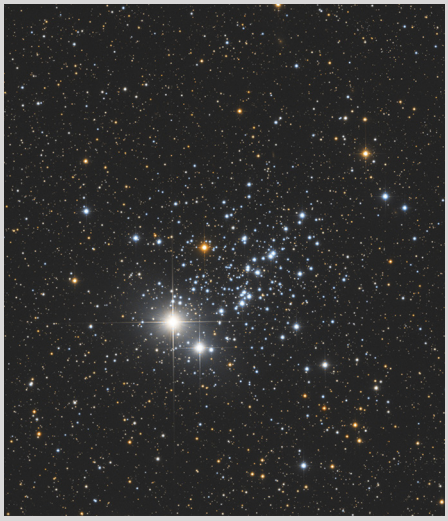


HEART AND SOUL NEBULAE: RON BRECHER; NGC 457: CHUCK AYOUB

▲ **DOUBLE GLOWING CLOUDS** Dive into Cassiopeia's trove of celestial gems, including IC 1805, the Heart Nebula (upper right) and IC 1848, the Soul Nebula. This vast expanse of intricate nebulosities represents one of the richest regions of the northern Milky Way. Here, hydrogen gas is collapsing to form a new generation of stars. North is up in all images.

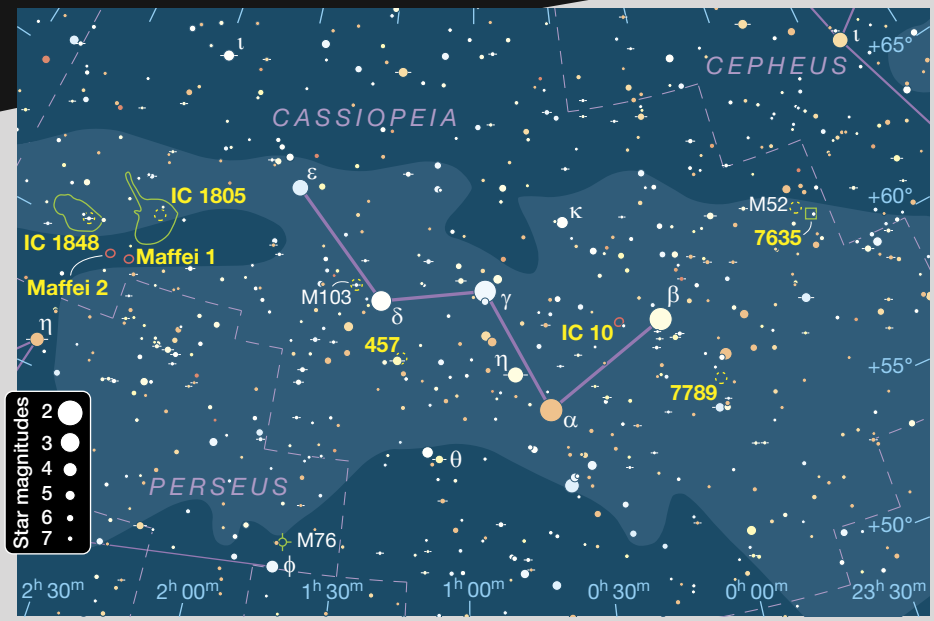
This month, I'm commencing to write the Deep-Sky Wonders column for which I'm deeply honored. The legendary observer Walter Scott Houston (1912–1993) wrote the column in this magazine from September 1946 until July 1994, and I was blessed to become Scotty's friend when I was young and producing *Deep Sky Monthly*. Now, I'm excited to carry on the tradition in the footsteps of the man who was a big inspiration for me all those years ago.

For my inaugural column, I'll focus on the ancient constellation Cassiopeia, the Seated Queen. This wonderland for deep-sky aficionados contains many bright stars, a significant number of open clusters, and an array of interesting nebulae. It represents one of the bright signposts along the glistening path of the Milky Way, the northernmost one for many observers. Additionally, it holds a couple of unusual galaxies that are significantly obscured by the Milky Way's blanket of stars and cosmic dust. As viewed from our closest neighboring star, Proxima Centauri, the Sun would appear as a dazzling, +0.4-magnitude star smack in the middle of Cassiopeia.



◀ **STELLAR AGGREGATION** The bright open cluster NGC 457, variously known as Caldwell 13, the Owl Cluster, or the E.T. Cluster, offers a dramatic view in binoculars and wide-field backyard telescopes.

My favorite object in the constellation is the bright open cluster **NGC 457**, located about 2° south-southwest of the 3rd-magnitude eclipsing binary Delta (δ) Cassiopeiae, one of the bright luminaries that forms the constellation's distinctive W (or M) shape. When I was a young observer, I zeroed in on NGC 457 with my 8-inch Schmidt-Cassegrain telescope at low power and the cluster's form immediately struck me. It looked like an



▲ **NAVIGATING CASSIOPEIA** Few constellations in our sky are so immediately recognizable as Cassiopeia, whose brightest stars form a giant W or M, depending on its rotational position. You can use this chart to star-hop to this month's targets. North is up and east is to the left.

owl, with two bright "eyes" and a body supporting arcs of stars that seemed to form its "wings." So, I dubbed it the Owl Cluster, and this name (among several others) stuck with observers.

Situated some 7,800 light-years away, the Owl Cluster is bright enough (at magnitude 6.4) and large enough (it spans 13′) to be an impressive sight in any small telescope or even a pair of binoculars, its sparklers set against a rich Milky Way field. Binoculars reveal about 150 stars, most of which range from magnitudes 9 to 13, as a concentrated knot surrounding the brightest suns. Scopes 12 inches or larger provide a spectacularly starry field, especially at low to medium powers, which encompass all the stars in this group.

Phi (φ) Cassiopeiae, the more conspicuous of the two stars that represent the eyes, is a 5th-magnitude multiple-star system with its next-brightest component at magnitude 7.0 and at a separation of 134″. Just 2′ southwest of Phi is HD 7902, a 7th-magnitude sun that marks the other eye. Two 9th-magnitude orange stars are also visible within the cluster, but most of the members appear bluish white. NGC 457 is one of the easiest open clusters to find and one of the most colorful in the northern sky, making it a favorite for many observers.

About 6½° west-northwest of 2.3-magnitude Beta (β) Cassiopeiae, or Caph, lies the spectacular emission nebula **NGC 7635**, nicknamed the Bubble Nebula. Its enormous, bubble-shaped shell contained within a molecular hydrogen cloud is formed by the stellar wind from 8.7-magnitude SAO 20575, an extremely hot, massive O-type star whose intense ultraviolet radiation ionizes the gas, creating a 10th-magnitude glow that's visible in a 6-inch scope under dark skies. A 12-inch aperture at high magnification shows the bubble shape nicely, and an envelope of gently glowing gas appears as a slightly squashed rectangle surrounding the bubble. The overall size of the nebula stretches more than 41′ to its faintest parts.

Also tucked in the western reaches of Cassiopeia is **NGC 7789**, one of the most remarkable open clusters in the sky, which you'll find just shy of 3° southwest of Beta Cassiopeiae. Also known as Caroline's Rose and sometimes called Caroline's Haystack, Caroline Herschel discovered the object in 1783. Novice skywatchers often overlook NGC 7789 as it's not included in Charles Messier's famous catalog of deep-sky objects and yet it's accessible in small instruments. This impressively rich cluster holds more than 1,000 stars, many of which are faint, giving the object the appearance of spilled salt grains against an inky black background. Among NGC 7789's members are a large number of yellow dwarf stars, red giants, and blue stragglers (relative latecomers in stellar evolution). This multicolored population provides a nice viewing experience for users of large backyard scopes. Lying about 6,800 light-years away, the cluster

The Queen's Treasure Chest

Object	Type	Mag	Size	RA	Dec.
NGC 457	Open cluster	6.4	13′	01h 19.5m	+58° 17′
NGC 7635	Emission nebula	~10.5	15′ × 8′	23h 20.8m	+61° 12′
NGC 7789	Open cluster	6.7	16′	23h 57.3m	+56° 44′
IC 1805	Open cluster/ emission nebula	6.5	100′ × 80′	02h 32.8m	+61° 28′
IC 1848	Open cluster/ emission nebula	6.5	100′ × 50′	02h 51.4m	+60° 25′
Maffei 1	Galaxy	11.1	3.4′ × 1.7′	02h 36.6m	+59° 39′
Maffei 2	Galaxy	~16	15.2′ × 7.0′	02h 41.9m	+59° 36′
IC 10	Galaxy	10.4	6.3′ × 5.1′	00h 20.3m	+59° 18′

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

glows with a total magnitude of 6.7 and spans some 16′ across, about half the size of the full Moon.

Observers armed with binoculars will be pleased viewing NGC 7789, seeing it as a smooth rise in the dense Cassiopeia stellar background, and even small apertures make it appear richly populated. Owing to the cluster's fairly large apparent size, observers with 4-inch or 6-inch scopes should employ low to moderate powers to obtain the best views. Eight-inch and larger scopes really start to expose some of the stars' wide range of colors, particularly on nights of steady seeing and transparency, making this cluster a relatively little-known gem of the northern Milky Way.

Eastern Cassiopeia, approaching the border with Camelopardalis, the Giraffe, holds the extraordinary pair of combined emission nebulae and open clusters cataloged as **IC 1805** and **IC 1848**. Scan for them roughly 6° southeast of 3rd-magnitude Epsilon (ε) Cassiopeiae. Popularly known as the Heart Nebula and the Soul Nebula, respectively, due to their unique shapes, these sprawling, faint regions are challenging for visual observers with small telescopes, but they're longstanding darlings of astro-imagers. The Heart Nebula's open cluster contains several dozen stars glowing with a total magnitude of about 6.5 and stretching across 13′. Situated about 6,500 light-years away, the cluster is the central piece of the Cassiopeia OB6 Association — a vast, star-forming complex that contains multiple nebulae, open clusters, and even a planetary nebula.

From the center of IC 1805, just 2½° to the east-southeast is IC 1848, the Soul Nebula, a wispy nebulosity that's also accreting into a significant star cluster. The whole mess glows at magnitude 6.5 and lies at a similar distance to IC 1805, perhaps just a hair closer. The IC duo is challenging for visual observers — the clusters are easy to see in the smallest scopes, but large backyard instruments are required to pull out the low-surface-brightness wisps of hydrogen gas that make up the associated nebulae.



▶ **COSMIC GLOBE** NGC 7635, nicknamed the Bubble Nebula, is characterized by a wide emission nebula with a central cavity excavated by a hot, massive star within. The object lies about 7,900 light-years away and poses a visual challenge for small telescopes.

About 1½° south of the core of the Heart Nebula lie two extraordinary galaxies, dimly visible through the thick blankets of dust associated with the plane of the Milky Way. These nearby objects are so obscured that they remained undiscovered until 1967, when Italian astronomer Paolo Maffei found them in the near infrared. **Maffei 1** and **Maffei 2** are both approximately 11 million light-years away. Very low in surface brightness and significantly reddened, they are best thought of as targets for astro-imagers. Only large backyard scopes have a shot at showing their forms — in this case, an 11th-magnitude lenticular galaxy (Maffei 1) and a 16th-magnitude barred spiral (Maffei 2).

Another notable object is the nearby irregular starburst galaxy **IC 10**, which you'll find 1½° due east of Caph. American amateur astronomer Lewis Swift spotted the object in 1887; it was definitively recognized as a member of our Local Group of galaxies by 1996.

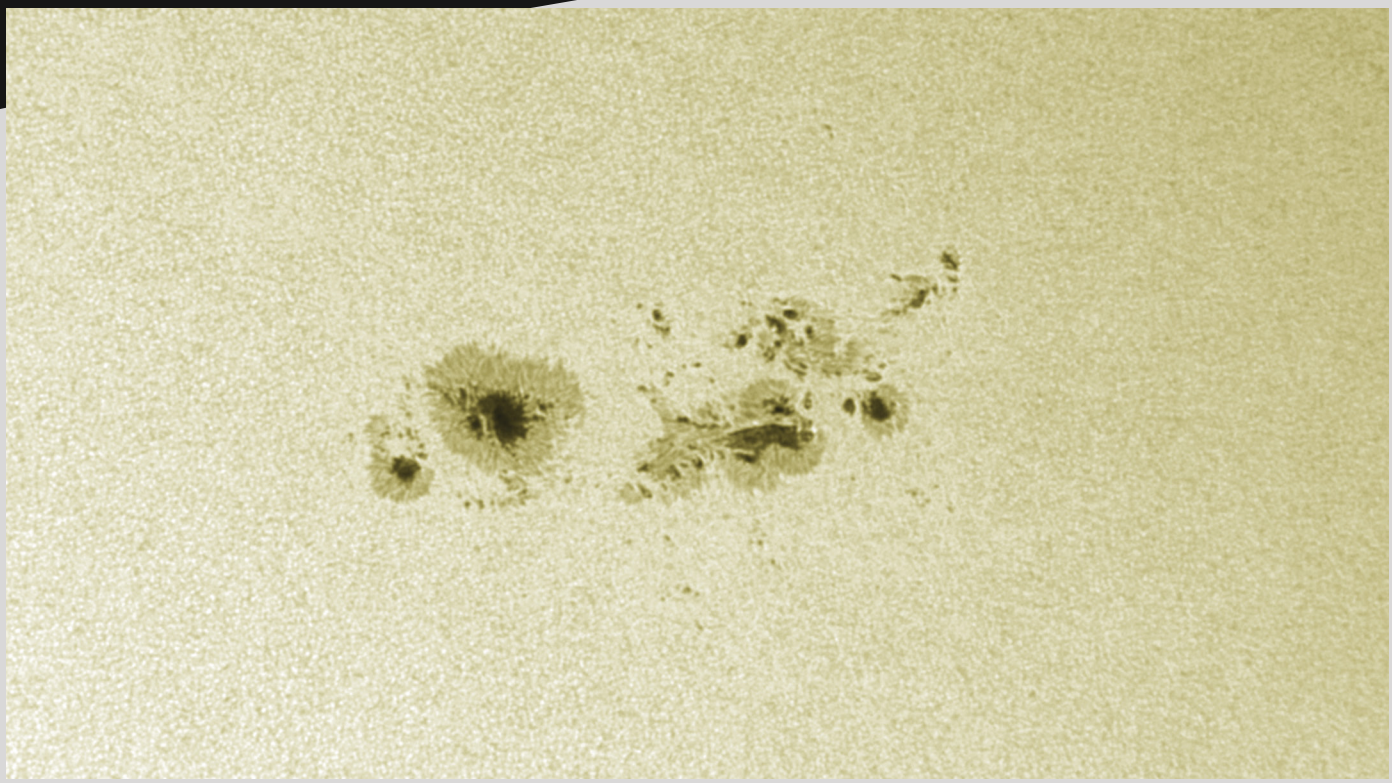
IC 10 lies 2.2 million light-years away and glows with the brightness of a 10.4-magnitude star. Despite its proximity and relatively high surface brightness, the object is somewhat challenging for visual observers as it's heavily obscured by the plane of the Milky Way. Nonetheless, in a 6-inch scope it's visible as a fuzzy patch in a rich star field, and large amateur instruments in the range of 10 inches or more will show its knotty, patchy luminosity when viewed under a dark, steady sky.

■ **DAVID J. EICHER** is editor emeritus of *Astronomy* magazine and author of 26 books on science and history.



▲ **STARBURST GALAXY** A nearby irregular galaxy ensconced in our own Local Group, IC 10 is nonetheless tough as a visual target due to its relatively low surface brightness.

NGC 7635: ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA; IC 10: KPNO / NOIRLAB / NSF / AURA



Sunspots as a Metric

This time-tested method lets you track the solar cycle.

▲ Observing sunspots is a great daytime astronomy activity. Counting and classifying them (like the example of AR 3354 seen above on June 30, 2023) lets you track solar activity.

It's a great time to observe the Sun. About every 11 years, activity on our daytime star reaches its maximum, producing lots of sunspots, prominences, and flares. The 11-year solar cycle is really just an average of a period that varies from as few as 9½ to as many as 14 years, so solar scientists don't really know how long a cycle runs or when it ends until after it happens. But we do know that we're a bit past the peak of the current one.

German amateur astronomer Samuel Heinrich Schwabe discovered the sunspot cycle in 1843. After carefully counting sunspots for some 20 years, he noticed a peak in the number occurred about every decade (see page 22).

Swiss astronomer Johann Rudolf Wolf confirmed Schwabe's finding, and in 1852, he examined historical sunspot records and set the first solar cycle as happening in February 1755. We're now in solar cycle 25, which began around December 2019. Wolf also published a formula for determining the relative sunspot number, which was called the *Wolf number* for more than a century. Scientists now refer to it as the *international sunspot number*. Wolf's formula is:

$$R = k(10g + s)$$

where g is the number of observed sunspot groups, s is the number of individual sunspots, and k is a calibration factor (different for each observer).

If you just want to do daily counts for your own enjoyment, you can eliminate k from the formula. But if you're intending to be a serious solar observer, you'll increase your counting precision by calculating your personal k number. That number is a correction factor used to equalize observations by different people. Sunspot numbers can vary from one observer to another because of the different telescopes being used, the varying local atmospheric conditions, and the physical differences (like vision) among the observers themselves.

To figure out your k number, use this formula:

$$k = r/n$$

The variable r is your calculated Wolf number, and n is the published value for the same date. You'll find the official number of spots for the current date at **tinyurl.com/2uvb87j2**. The report also lists sunspot numbers for the previous 31 days.

A more precise k number is determined by averaging several (up to 10) observing sessions. The numbers you get aren't important, but they should be relatively consistent. If they're all over the place, wait a week or two and try again. But keep observing the Sun during that time. The good news is that if

ALL IMAGES SEAN WALKER / S&T

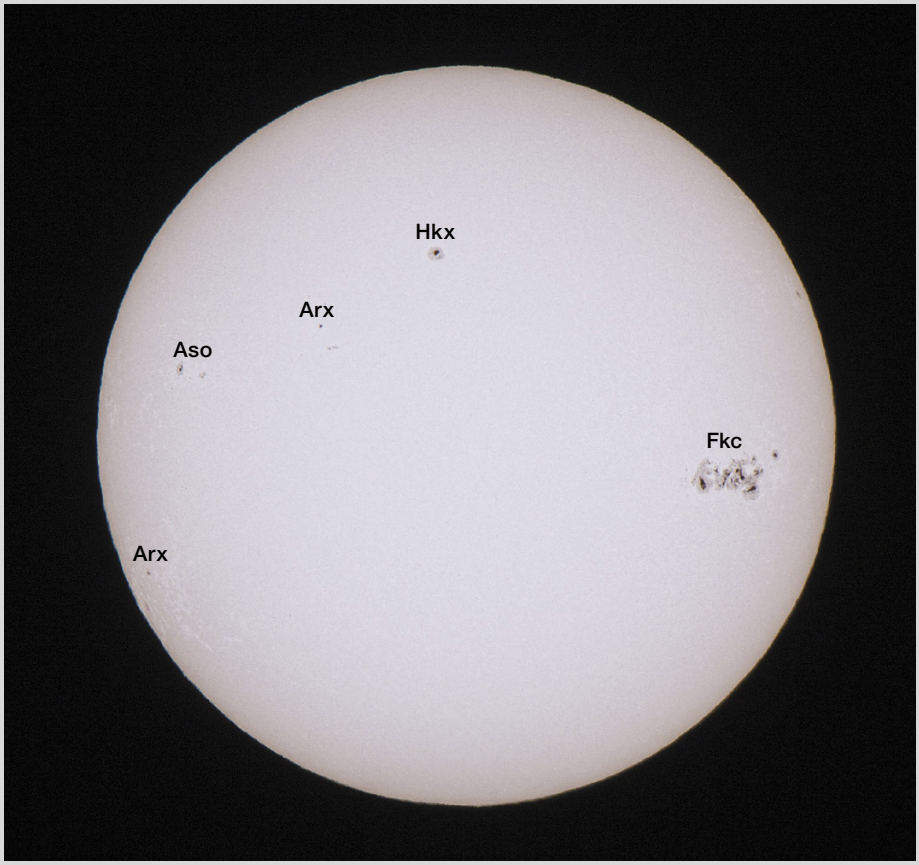
you use the same telescope and observe from the same location, you'll only have to calculate your *k* number once.

Obtaining your own daily sunspot numbers and making them as accurate as you can is lots of fun. But you might want to go even further, because sunspots come in a variety of types. So why not try classifying the spots you see? To do that, use the *McIntosh classification system*. Introduced in 1966, this standardized scheme uses three letters to classify any type of individual sunspot or group.

As you examine sunspots — more specifically, sunspot groups — you'll notice that most have what's known as a *bipolar* structure. This means that you'll see two main spots (or gatherings of spots), one on each end of the group. The dark, inner area of a sunspot is the *umbra* and the outer, lighter part is the *penumbra*.

The first letter of the McIntosh system (uppercase *A* through *H* but with no *G*) describes the overall group structure — its *Z-value*. Give it an *A* if it's an individual spot or group of spots without a visible penumbra or bipolar structure. *B* indicates a group of spots with no penumbra but exhibits bipolar structure. *C* describes a bipolar sunspot group whose main spot has a penumbra. *D* is also a bipolar group with the largest spots having penumbrae, but one of the two main spots only has a simple structure. The length of the group is generally less than 10° of solar longitude, or 1/18 of the Sun's apparent equatorial diameter. An *E* is a large, complex bipolar group with two main spots surrounded by penumbrae and lots of smaller spots spanning at least 10°. Groups assigned an *F* are the largest, spanning at least 15°. And finally, *H* indicates a single spot with a penumbra.

Once you've designated the first letter in a group, move on to the second letter (*x*, *r*, *s*, *h*, or *k*), which describes the penumbra of the largest spot, its *p-value*. You can give it an *x* if there's no penumbra. It gets an *r* if it's incomplete or has irregular boundaries, and the penumbra is brighter than normal. The next type is *s*, I guess because it's symmetrical with a diameter less than 2.5°. Spots with *s*-type penumbrae change slowly. Type *h* are the same as *s*, but with a diameter of more than 2.5°. Finally, type *k* has asymmetrical penumbrae like *r*, but with a diameter of more than 2.5° measured north to south.



▲These sunspot groups seen on May 10, 2024, are labeled using the three-letter McIntosh classification system.

The third and final letter (*x*, *o*, *c*, or *i*) describes the distribution of the spots in the group, its *c-value*. If it's just one spot, it's an *x*. Give it an *o* (open distribution) if the group has two distinct parts but there are no spots between them. Type *c* (compact distribution) also has two parts, but between them are lots of large spots with at least one having a penumbra. When activity in a *c*-type is high, you might observe a huge penumbra around the whole group. Finally, if there are spots without penumbrae between the two parts, give it an *i*, which is an intermediate type between *o* and *c*.

To achieve your most accurate counts, observe between two hours after sunrise and two hours before sunset. View before or after this window and you'll be looking through the thickest part of Earth's atmosphere. Use at least a 4-inch telescope with a white-light solar filter and choose an eyepiece that nearly fills the field of view with the Sun's disk. A shield, hood, or wide-brimmed hat helps to block direct sunlight or glare from the eyepiece and to increase image contrast. Apply sunscreen liberally. Over time, you'll record lots of different classifications. Keep track of them in a logbook and go have some fun in the Sun!

Your observations are valuable! Learn how to contribute your own sunspot counts to the official record with the American Association of Variable Star Observers at aavso.org/solar.

■ **MICHAEL E. BAKICH** observes the sky day and night from his backyard observatory in Tucson, Arizona.



◀ BIG ASTROGRAPH

Observable Space (formerly PlaneWave Instruments) announces a new wide-field astrograph. The DeltaRho 280 (starting at $9,900) is an 11-inch f/2.75 photographic instrument designed to support some of the largest detectors commercially available today. This carbon-fiber OTA houses an ellipsoidal primary mirror with a spherical secondary paired with a field corrector, together producing a 55-mm image circle. The tube measures 467 mm (18.4 inches) long including its focuser and weighs 14.5 kg (32.0 lbs). The DeltaRho 280 includes tip-tilt focal-plane adjustments and a built-in heater to prevent condensation during long imaging sessions. Observable Space also provides collimation software to help users establish optical alignment quickly and accurately.

Observable Space
2228 Cotner Ave., Los Angeles, CA 90064
planewave.com



◀ DEEP-SKY CAMERA

Chinese manufacturer SVBony adds a new model to its growing line of deep-sky cameras. The SC571CC Cooled Color Astronomical Camera ($1,199.99) is designed around the highly sensitive Sony IMX571 backside-illuminated CMOS detector, which has a 6,224 × 4,168 array of 3.76-micron-square pixels measuring 23.4 × 15.7 mm, or 1-inch SQR format. This 26-megapixel sensor has a 16-bit A-to-D conversion, 50,000 electron full-well capacity, and zero-amp-glow circuitry that together produces a clean signal in long exposures. Its dual-stage, thermoelectric cooling produces stable operating temperatures of as much as 35°C below ambient. The camera can download up to 13 full-resolution frames per second, and its onboard 512 MB of DDR3 memory ensures no frames are lost. Each camera comes with a 2-inch nosepiece, a 2-meter (6.6-foot) USB 3.0 cable, a 12V 3amp power supply, and several adapter rings.

SVBony
+86 150 3810 6914; svbony.com



◀ BIG MAK

Sky-Watcher announces a new addition to its SkyMax line of Maksutov-Cassegrain telescopes. The SkyMax 200DX is an 8-inch optical tube assembly with a focal length of 2,000 mm (f/10) designed to deliver pinpoint stars across a 44-mm corrected field. The borosilicate primary mirror is focused by moving along a custom zero-shift four-rod focuser and includes collimation adjustment screws. An active cooling fan on the back of the tube helps the optics reach ambient temperature quickly at the start of the evening. The SkyMax 200DX measures 64.8 centimeters (25.5 inches) long and weighs 12.0 kilograms (26.5 lbs). Each purchase includes a D-style dovetail mounting bar, a metal lens cap, a quick-release finder bracket, a 12-volt power supply for the cooling fan, and a camera extension adapter.

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

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Perpetual lunacy



The extraordinary **C1 Moonphase** from Christopher Ward. A watch that tracks the moon for 128 years – without missing a beat. With an aventurine glass dial infused with copper oxide to represent the night sky. And a 3D 'moon' sculpted from Globolight© – a luminous ceramic – that precisely follows the real moon's journey across the sky. A watch this advanced can cost up to $55,000. But the C1 Moonphase starts from less than $2,900: the very definition of insanity.

Do your research.

Christopher Ward

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Tune In to Cosmic Radio

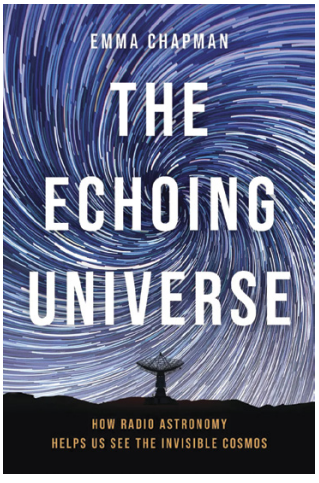
THE ECHOING UNIVERSE: *How Radio Astronomy Helps Us See the Invisible Cosmos*

Emma Chapman
Basic Books, 2026
352 pages, ISBN 978-1-5416-0185-7
US$32, hardcover

"INSTEAD OF STRIVING for high-resolution images comparable to what optical telescopes can give, radio astronomers strip away the glitter and graphics to get to the raw data that describes the whole story," writes Emma Chapman in *The Echoing Universe*. And stripping it all down to the raw data is exactly what Chapman does for the reader in her latest book. She seamlessly avoids the jargon sometimes found in science writing and tells clear, lively stories of the discoveries made with radio telescopes, making the wonders of radio astronomy accessible to all.

Chapman is an astrophysicist based in Nottinghamshire, UK, who focuses on studying the cosmos at radio wavelengths. Having spent most of her career using radio telescopes — starting with her PhD, for which she analyzed data on the earliest stars in the universe — she's well placed to expound on all things radio astronomy.

In *The Echoing Universe*, Chapman describes the universe through the "ears" of radio telescopes. She starts close to home — at our Moon — and takes us on an exploratory jaunt progressively farther out in space and time, all the way back to the Big Bang. Chapman covers the biggest areas of scientific discovery brought to us thanks to radio telescopes — discoveries that even the armchair astronomer might be aware of, including the first known quasars or the recently revealed images of supermassive black holes. She also outlines topics such as planetary science, regaling the reader on how we explored our celestial neighbors before we even had the capability of sending probes to them.



Anybody who has seen the movie *Contact* or (one of my personal favorites) *The Big Dish* will have an image in their minds of colossal parabolic dishes scanning the skies, passively capturing cosmic radio waves to reveal distant pulsars or perhaps even E.T. But what fewer people might be aware of is that radio telescopes can also be used in "active" mode, in which astronomers shoot powerful signals at solar system objects and wait for the echo. Scientists have used such techniques to map asteroids that pass near Earth.

Planetary exploration is the focus of the first third of her book. The second third covers the Milky Way and all it contains, and the last third examines the origin of the universe and the more esoteric subjects of dark matter and dark energy.

Along the way Chapman deftly weaves historical tidbits into the scientific narrative, putting everything into context. No book on radio astronomy would be complete without mention of SETI, the Search for Extraterrestrial Intelligence, and Chapman does a measured dive into the world of listening for "that" signal from outer space, without the hype. The book is worth reading for this chapter alone.

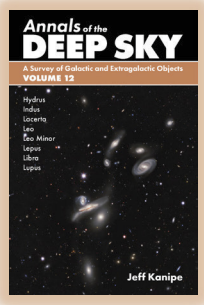
An excellent addition, to my mind, is the appendix listing radio telescopes that one can visit. If you do decide to head out to one of these, heed Chapman's advice and check online for the latest information.

Chapman peppers the book with amusing similes that make the science come alive, such as when she describes the Sun's photosphere where photons "get absorbed and emitted in all kinds of directions, such that it is like trying to see the floor of a jacuzzi when the bubbles are turned on." Each chapter is headed by a quirky, often thought-provoking, quote culled from sources varying from Henry David Thoreau to Douglas Adams. Her sense of humor threads throughout the book, that famous English self-deprecatory spirit shining in many places. For one example, her footnote on Ray Bradbury's story of children on Venus who had "no memory of anything but unbroken clouds and perpetual rain" reads, "Had he lived in England, he would not have had to imagine at all."

But don't be fooled by the levity of Chapman's tone. This is a serious book on a serious topic. At the time of this writing, cuts have been announced to research funding at Jodrell Bank, the UK's premier radio facility that's been operational since 1945. Unless other sources of funding can be secured, all observations will cease in April 2028. Now, with scientific research threatened elsewhere, such as in the United States (see, e.g., *S&T:* Aug. 2028, p. 22), we need adept science communicators more than ever.

■ Editor in Chief **DIANA HANNIKAINEN** was a radio astronomer in her previous life and hopes *everyone* gets a chance to read Chapman's book.

NOW AVAILABLE!



Annals of the DEEP SKY

A Survey of Galactic and Extragalactic Objects | VOLUME 12

by Jeff Kanipe

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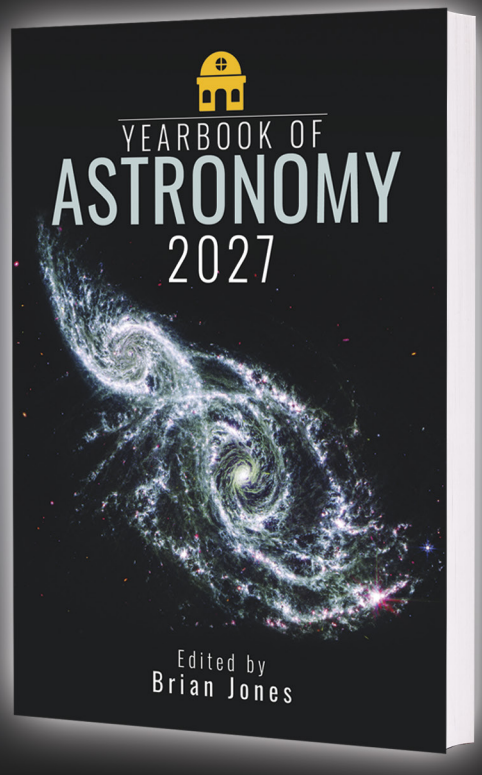
The annual appearance of the *Yearbook of Astronomy* has been eagerly anticipated by astronomers ever since this invaluable book first appeared in 1962. Maintaining its appealing style and presentation, the *Yearbook of Astronomy 2027* contains comprehensive jargon-free monthly sky notes and charts to enable astronomers everywhere to plan their viewing of the year's eclipses, comets, meteor showers and minor planets as well as detailing the phases and so on of the Moon and visibility and locations of the major planets throughout the year. To supplement all this are 25 entertaining and informative articles on a wide range of topics, including Lithium; Gravitational Lensing; The Mythical Vulcan; The Vera Rubin Observatory; The Astronomers' Stars: Across the Spectrum; Mars Attacks! How the Red Planet Affects Earth's Climate; What's the Matter? It's Dark Down Boulby Mine; A History of Observatory Designs: The Modern Era; The Unluckiest Astronomer Who Ever Lived; and The Flight Log of Exoplanet Explorer 9: The First Landing on an Exoplanet.

The *Yearbook of Astronomy* continues to be essential reading for anyone lured and fascinated by the magic of astronomy. An inspiration to amateur and professional astronomers alike, it warrants a place on the bookshelf of all stargazers and watchers of the skies.



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Going Deep in Your Data

Try these processing techniques to bring out more details in your astrophotos.



Astrophotographers often focus on well-known objects in the deep sky — bright nebulae like M42 and the Rho Ophiuchi complex, or nearby galaxies M31 and M33 and prominent star clusters that don't require extremely long exposures to produce an attractive picture. Yet many celestial structures reside on the outskirts of these showpiece targets. Even relatively empty areas of sky often contain faint dust clouds and nebulosity if you expose deep enough. And getting "deep enough" means recording many hours of exposure, where the total integration time can be hundreds of hours devoted to a single target.

Thanks to advances in digital detectors and powerful software to handle the data, you can reveal objects only recently discovered by intrepid amateurs. Who knows? Perhaps *you* can discover some yourself. Here's how I do it.

Acquisition Strategy

Unlike targeting, say, the Trapezium in Orion, imaging weak signal requires a different approach from conventional deep-sky astrophotography. Planning how you record the data plays an important role in bringing out structures that lie at the very limit of the background noise. Photographing extremely faint objects requires accumulating many exposures over many nights, so preparation becomes particularly important.

The primary objective is to optimize the signal-to-noise ratio (SNR) in your final result. With this in mind, it's best

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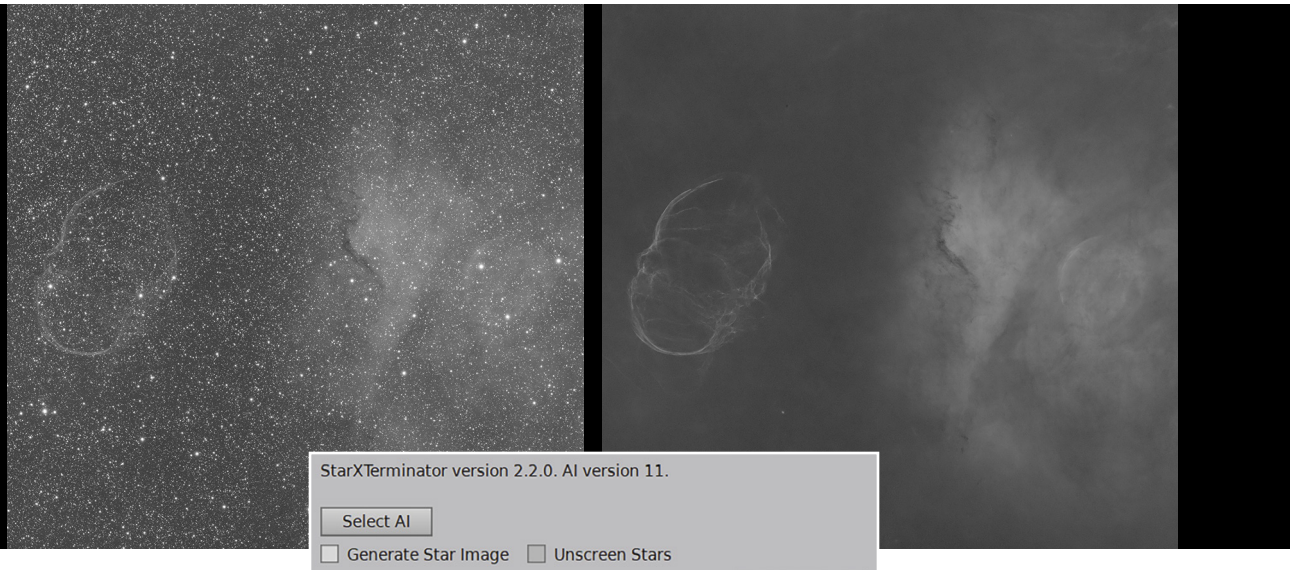
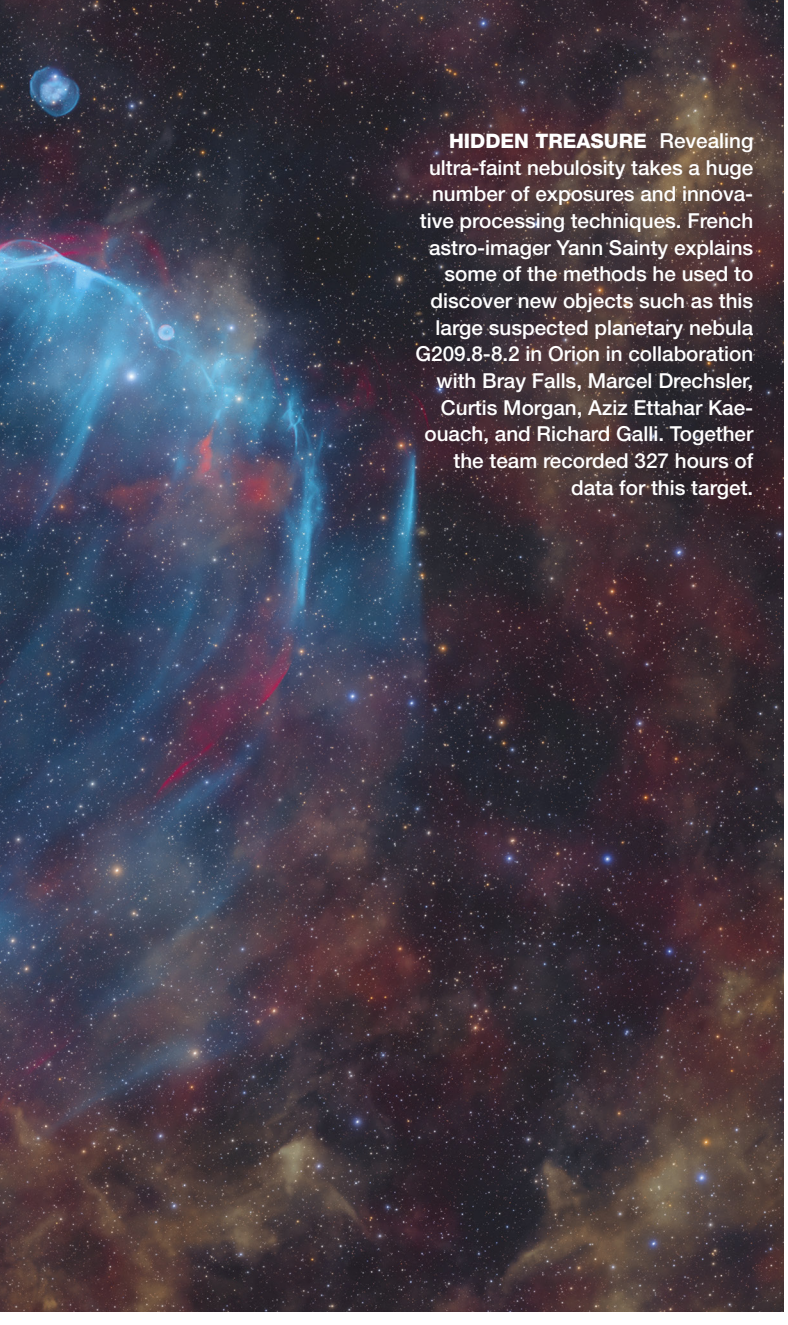


REMOVING STARS To focus attention on the nebulosity, it's best to separate the stars from the image and reintroduce them later in processing. RC Astro's ***StarXterminator*** add-on for *PixInsight* makes quick work of the process while keeping the image in a linear (unstretched) state.



HIDDEN TREASURE Revealing ultra-faint nebulosity takes a huge number of exposures and innovative processing techniques. French astro-imager Yann Sainty explains some of the methods he used to discover new objects such as this large suspected planetary nebula G209.8-8.2 in Orion in collaboration with Bray Falls, Marcel Drechsler, Curtis Morgan, Aziz Ettahar Kaeouach, and Richard Galli. Together the team recorded 327 hours of data for this target.

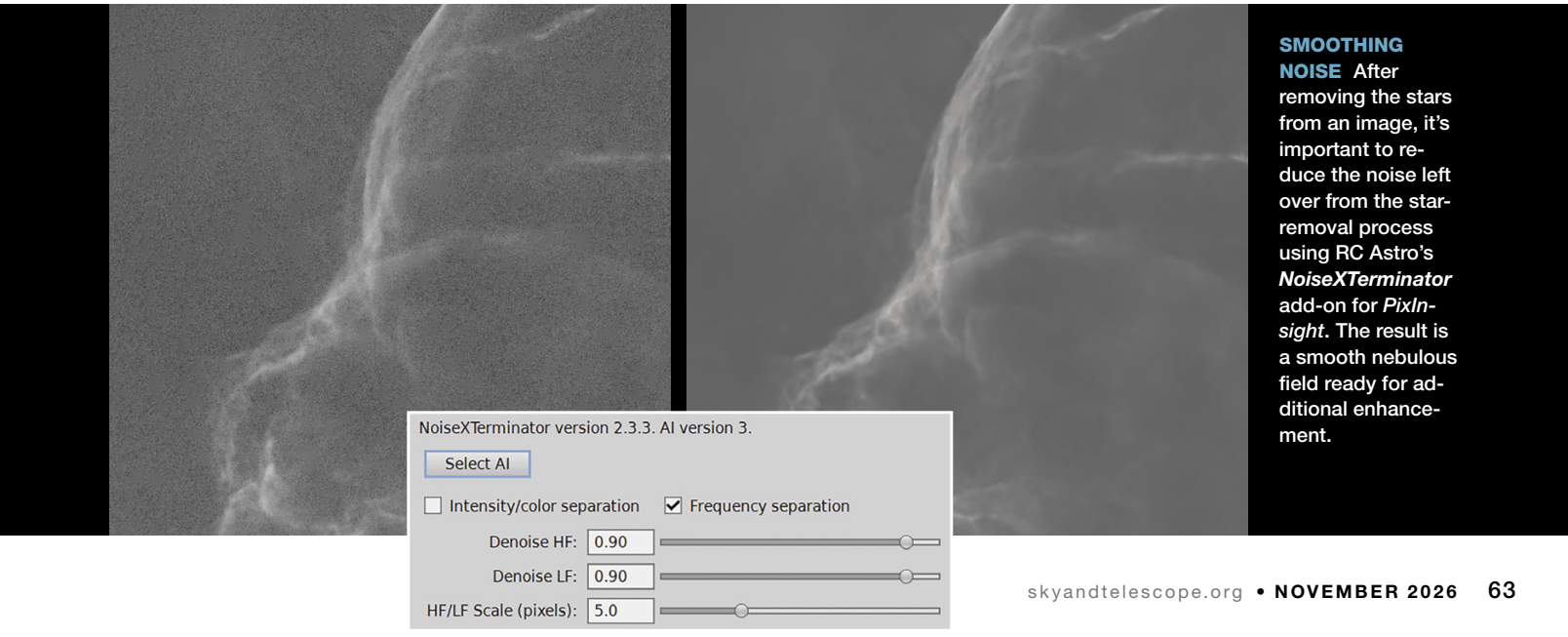
to use the longest possible individual exposures your equipment and sky conditions are capable of achieving. Long subexposures allow the signal to emerge more clearly from sky background and electronic read noise.

Before setting out on a deep-imaging project, make sure your equipment is performing at its best — that means the scope is perfectly collimated, the mount is polar aligned, and the camera's detector is squared with the focal plane so stars are round across the entire frame. You also need to determine how long you can expose an individual frame before reaching your location's *sky-fog limit*. This is the point when exposing longer simply makes the background sky brighter and doesn't add anything beneficial to your final image.

Unless you're imaging from an extremely dark sky, chances are you'll encounter your sky-fog limit before hitting the tracking abilities of your mount and autoguider. Additionally, today's CMOS detectors are much more sensitive than CCDs of the past, so you may be limited to 10 or 15 minutes for each subexposure.

One way to ensure consistent data is to concentrate on imaging through a single filter per night, regardless of whether you're using a color camera or monochrome one. Color cameras paired with multi-passband filters can take excellent narrowband data these days, though I personally prefer monochrome with a full retinue of L, R, G, B, and narrowband (oxygen III, hydrogen-alpha, sulfur II) filters. This way, if the seeing is poor on one night, you can concentrate on longer (redder) wavelengths that are less affected by atmospheric turbulence and focus on shorter (bluer) wavelengths on steadier nights.

The depth of an image ultimately depends on the total integration time. Accumulating many hours of exposure, sometimes dozens, is often necessary to reveal the faintest structures. Many of the nebulae I've helped discover, such as the Atlas Nebula (G209.8-8.2) in Orion or the M31 Arc in Andromeda, required hundreds of hours of exposures accumulated over weeks, often in collaboration with other



SMOOTHING NOISE After removing the stars from an image, it's important to reduce the noise left over from the star-removal process using RC Astro's ***NoiseXTerminator*** add-on for *PixInsight*. The result is a smooth nebulous field ready for additional enhancement.

astro-imagers using similar equipment and approach. The quality of the acquired data directly determines the processing headroom available later. The better the SNR is in the stacked data, the further the processing can be pushed before noise levels become objectionable.

A question most deep-sky imagers ask is: When do you know you've recorded enough data for a particular target? That's hard to answer. My approach is to periodically stack all my frames taken through a single filter after each imaging session and evaluate the SNR visually after applying a strong histogram stretch. If the image doesn't appear "grainy" or noisy, it should be sufficient, and I can move on to another filter. If the result is grainy, more signal is required.

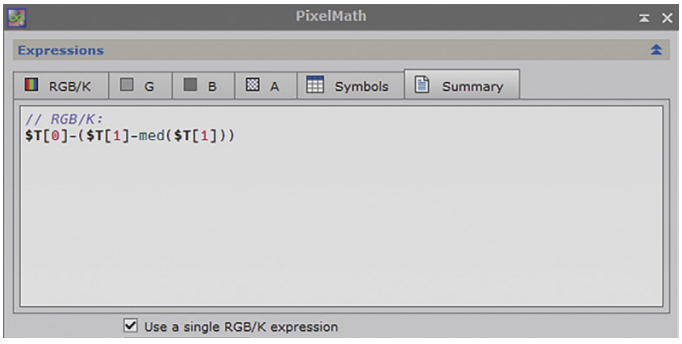
Scraping the Background

Once you're satisfied that you've acquired enough signal through each filter, it's time to see what surprises it may yield. I do much of my data reduction and processing in *PixInsight* (**pixinsight.com**), though other programs such as *Astro Pixel Processor* (**astropixelprocessor.com**) and *Siril* (**siril.org**) can achieve similar results. I also tend to do some final corrections in *Adobe Photoshop* (**adobe.com**).

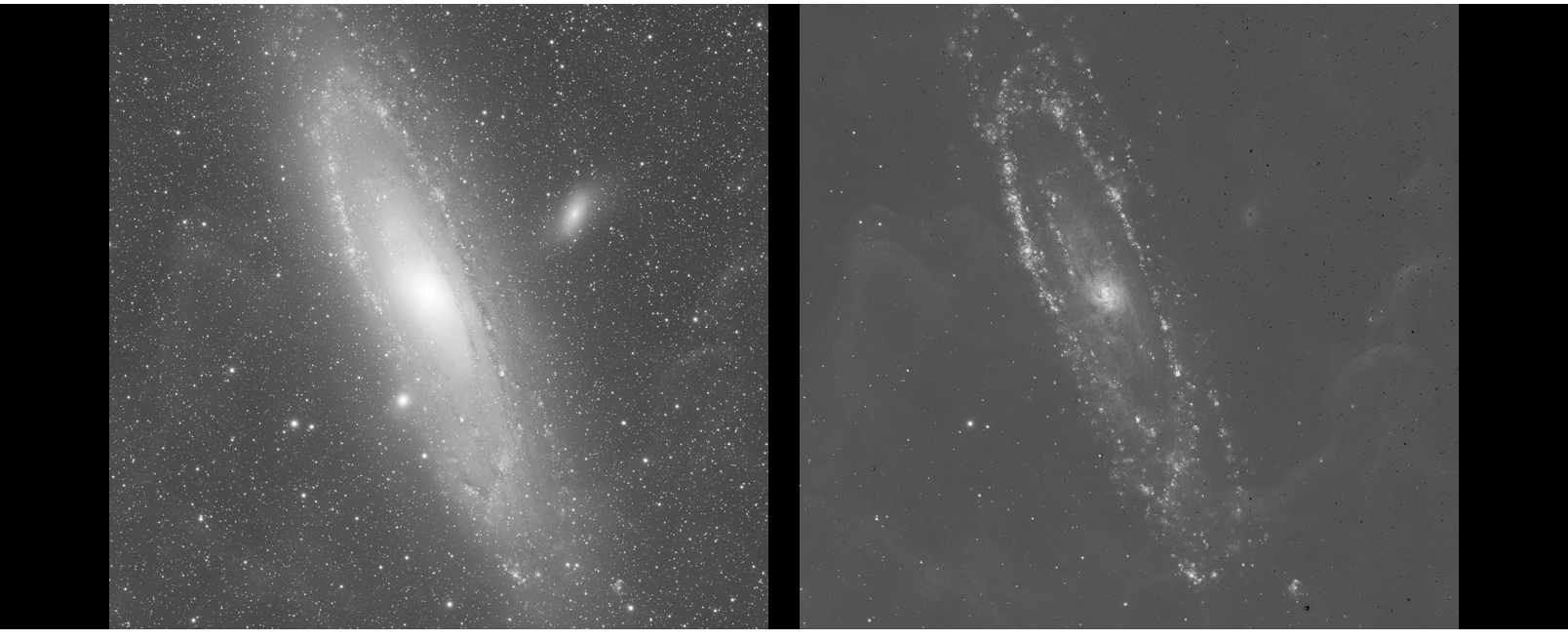
I begin by calibrating all my data in *PixInsight* and then use its ***SubframeSelector*** (***PROCESS > Preprocessing > SubframeSelector***) to reject any subpar exposures. I then align and stack each group of filtered frames using ***PROCESS > ImageRegistration > StarAlignment*** and ***PROCESS > ImageIntegration > ImageIntegration***. After each group is reduced into a master file, I then remove any gradients in the broadband LRGB master frames with ***PROCESS > All Processes > GraXpert***. With all my data reduced into master files, I'll align them all together using the ***StarAlignment*** process.

At this point, to reveal any extremely faint nebulosity, I then need to perform *continuum subtraction* on the narrowband data, which is to mathematically subtract a broadband image (for example, the red-filtered master file) from the hydrogen-alpha (Hα) master image. The narrowband master files contain not only emission nebulosity, but also a component of continuum light originating from dust and other diffuse sources within the field that reduces the visibility of very faint structures I'm after.

My approach to do this is to first remove the stars from each master file using the add-on processes ***StarXterminator*** (**rc-astro.com/software/sxt**) or ***StarNet*** (**starnetastro.com**) and save these starless results as new files (The stars are reintroduced at the end of the workflow). Using these starless images, I'll perform continuum subtraction on each of my narrowband images, subtracting red from both the Hα and S II frames, then subtracting the green



▼▶ **SIGNAL ISOLATION** Continuum subtraction is the final preprocessing step that removes the broadband signal from each of the narrowband channel images. Here, the author uses the ***PixelMath*** process in *PixInsight* to subtract the red-filtered image from the hydrogen-alpha master file to reveal hidden details in the inner regions of M31. Note that you can perform continuum subtraction before or after removing the stars.



from O III. (A detailed description of this technique appears in the January 2026 issue, page 28.)

The result after continuum subtraction is a picture showing only the narrowband nebulae in the targeted field that can then be stretched more effectively, without boosting the sky background or the stars, or other components in the composition. Next, I'll reduce the noise on these starless images. I prefer Croman's *NoiseXterminator* (**rc-astro.com/software/nxt**) add-on for *PixInsight* as it's very effective while preserving fine structures in the data before the images are stretched. It's important to perform this step before any nonlinear stretching or making any adjustments to color, saturation, or vibrance. Applying color adjustments too early may amplify chromatic noise, particularly in the green channel.

Now that all the preprocessing is done, I'll combine the RGB starless master files into a color image. So now I have starless L, RGB, O III, Hα, and S II images. At this point, I'll combine the narrowband data into a color image using one of the various palettes popular within the astrophotography community. For example, I might combine the Hα and O III data using the HOO palette, in which the Hα is designated red and the O III data is assigned as both the blue and green channels. This is done by opening the O III and Hα starless files, then select the ***Process*** > ***ChannelManagement*** > ***ChannelCombination***. In this process window, hit the icon to the right of each R, G, and B channel and select Hα as the red, O III for green, and O III again as blue, and hit OK. In a moment you're presented with your starless image as an HOO narrowband image.

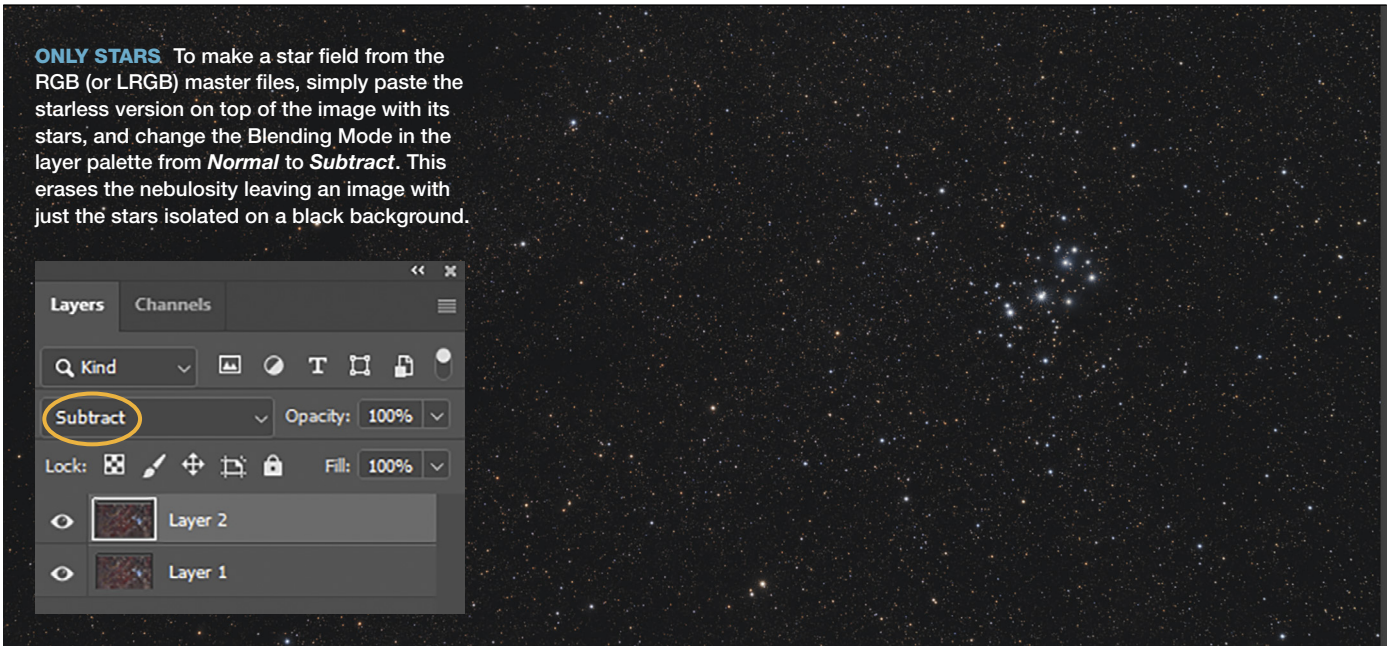
To create a narrowband image in the Hubble palette (named after the Hubble Space Telescope color mapping), simply open the three starless narrowband images and follow the same process, but assign S II as red, Hα as green, and O III as blue. I follow this by balancing the color using the ***BackgroundNeutralization*** process (***PROCESS*** > ***Color Calibration*** > ***BackgroundNeutralization***). I then stretch each of these files using one of *PixInsight*'s ***IntensityTransformations*** processes and export them as 16-bit TIFF files for further processing in *Photoshop*. The program's layer-based workflow and smart objects offer greater flexibility when constructing the final image.

Before we get into reintroducing the stars, let's add the narrowband data into the color data. I typically combine this starless HOO result with the starless RGB image by first opening both in *Photoshop*. I then copy the narrowband image by selecting the image and then typing ***Ctrl + A*** followed by ***Ctrl + C***. Next, I'll click on the RGB image and press ***Ctrl + V*** to paste the starless HOO image onto it. Opening the ***Layers*** window (***Windows*** > ***Layers***) shows the narrowband image titled "Layer 1" above the RGB image that's titled "Background." To blend the two, I change the opacity of the top layer from ***Normal*** to ***Screen*** and instantly, the image is strongly enhanced by the narrowband image. At this point, I'll save this as a layered TIFF file.

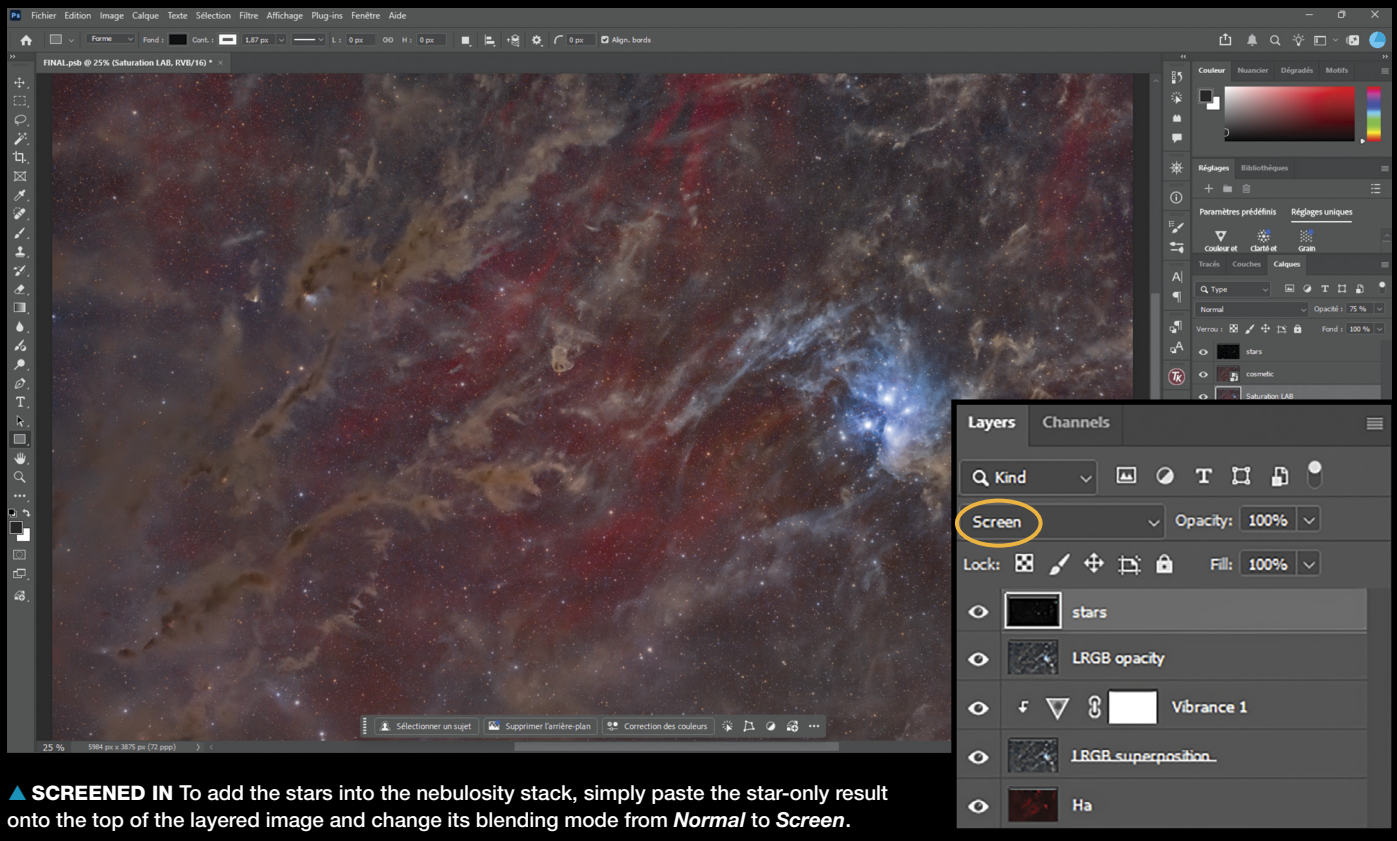
If I've shot L-filtered (luminance) images, I'll first add a starless version to the RGB starless image by changing the color mode of the starless L image from grayscale to RGB, using the pulldown menu ***Image*** > ***Mode*** > ***RGB Color***. I then copy the starless RGB picture and paste it over the L photo and change its blending mode from ***Normal*** to ***Color***. I then may need to increase the saturation and vibrance.

Reintroducing the Stellar Components

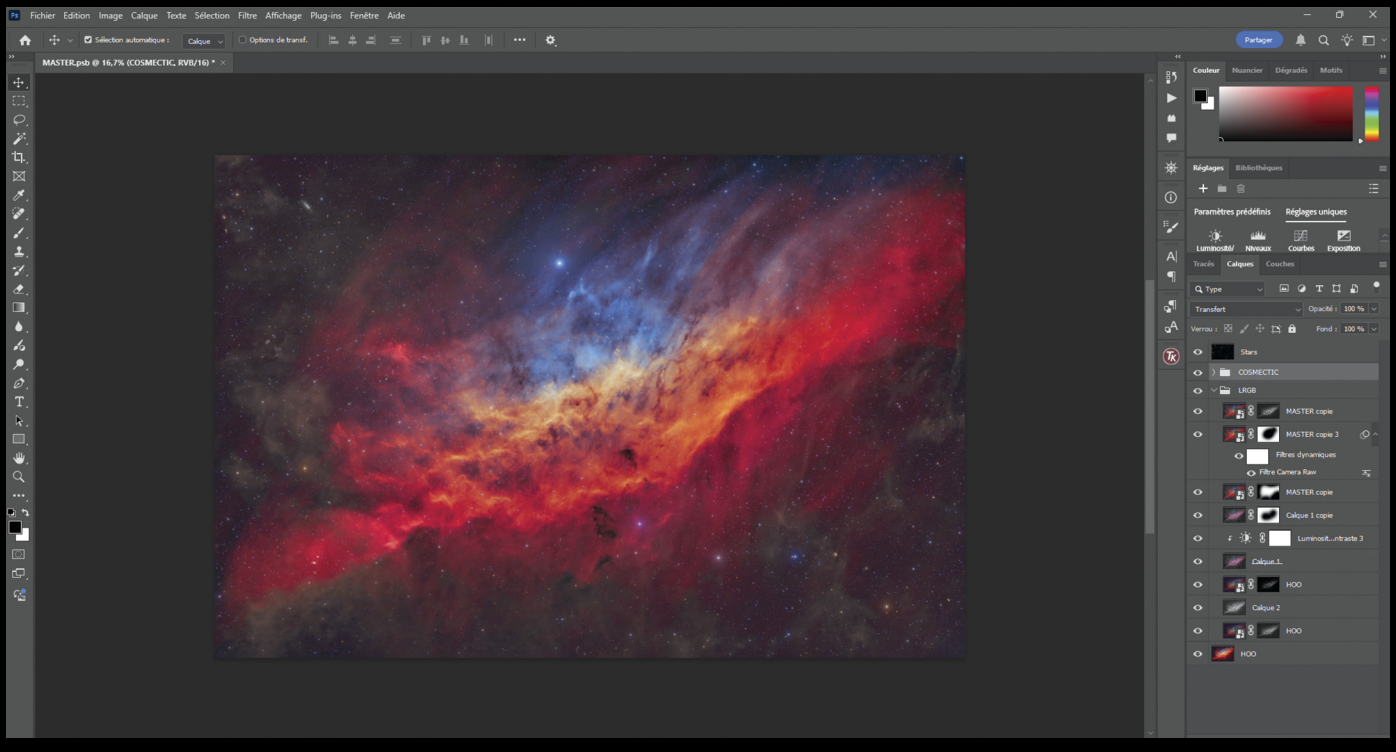
Adding the stars back into the image in *Photoshop* also uses some additional layer techniques. I first generate an image containing only the stars from the RGB data by combining the RGB masters with stars, stretching it in the same man-



ONLY STARS To make a star field from the RGB (or LRGB) master files, simply paste the starless version on top of the image with its stars, and change the Blending Mode in the layer palette from ***Normal*** to ***Subtract***. This erases the nebulosity leaving an image with just the stars isolated on a black background.



▲ **SCREENED IN** To add the stars into the nebulosity stack, simply paste the star-only result onto the top of the layered image and change its blending mode from ***Normal*** to ***Screen***.



▲ **LAYERED ADJUSTMENTS** With all the parts in place, you can enhance each component individually.



DISCOVERIES AWAIT
Using these techniques, the author, along with Xavier Strottner and Marcel Drechsler, discovered a large suspected planetary nebula next to M31, the Andromeda Galaxy, in 2023.

ner as I did the other filtered images, and saving it as a 16-bit TIFF file. I then open this as well as the starless version, copy and paste the starless image onto the version with stars. In the ***Layer*** window, I'll change the top layer (Layer 1) blending mode from ***Normal*** to ***Subtract***, which isolates the stars against a black background (it essentially erases all the nebulosity). The layers are then merged by selecting ***Layer*** > ***Merge Down*** from the pulldown menu. Here I copy this "star only" image and open the starless, layered TIFF file I produced earlier with the broadband color and narrowband color layer and paste it on top. To make the nebulosity appear through the star layer, simply change the star layer's blending mode to ***Screen***, and everything should be blended together seamlessly.

At this point, I'll add an adjustment layer to any of these individual layers to enhance each differently. I hide the star layer by clicking the eye icon to its right to work on the color or narrowband layers. Clicking on the eye icon again reveals the star layer to see how my changes affect the final visual balance. I can then sharpen or enhance the starless layers without adding unsightly artifacts around the stars with this layering technique.

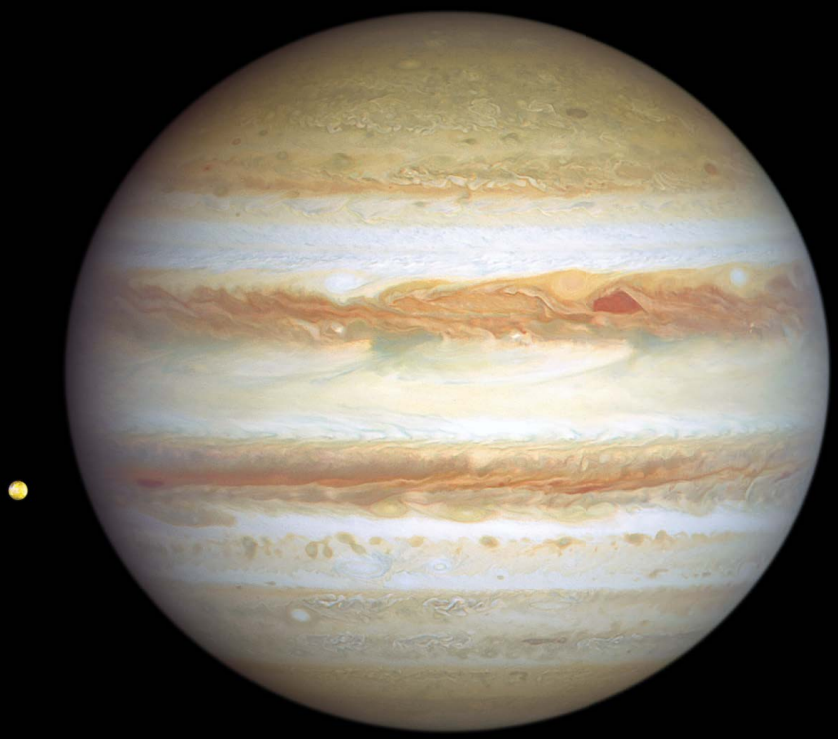
To evaluate my progress, I often zoom in to 100% pixel resolution in addition to viewing the entire frame to ensure that noise is kept at bay and I've preserved the subtle, fine structures. A successful deep-sky astrophoto should remain visually pleasing at a small scale while revealing its richness when explored in detail. Also, taking a step back is equally important. Revisiting an image after a few days with fresh eyes or seeking feedback from fellow astrophotographers often helps me to identify areas that still need additional work.

Final Thoughts

Imaging extremely faint objects requires a different approach from conventional deep-sky astrophotography. The success of such projects depends as much on the quality of the acquired data as on how effectively those data are processed.

Long integration times produce low-noise data, which provide the critical foundation necessary to reveal super-faint structures. Innovative processing techniques such as continuum subtraction help you tease out subtle details that typically remain invisible in shorter exposures. With patience and good technique, you too can reveal structures previously unseen in your own pictures.

YANN SAINTY captures the night sky from the Oukaimeden Observatory in the Atlas Mountains in Morocco.



The 3D Universe

The dome shutter shrieked, metal scraping metal, as I cranked it open to a clear, dark sky. Climbing down from the rickety stepladder, I removed lens covers, started the telescope drive, and rotated the slit to face Jupiter.

It was observing night for the intro astro course, and as one of their teaching assistants, I was on duty. I was always a bit smug about my skill with the ancient electric motor. It was coupled to the dome by what looked like a golf-cart tire with a tread worn smooth by years of use. Like everything in the observatory, it was held together by duct tape and hope.

After I had pointed and centered the 16-inch, I opened the observatory door to admit a few early students. "I've got Jupiter in the telescope — come take a look!"

One by one, they squared up to the eyepiece. "What do you see?" I asked.

"A bright star."

"Why are those tiny stars next to it all in a line?"

"I don't see anything."

The drive wasn't perfect, so I moved in to recenter. And refocus, for good measure. And sneak a look for myself. There were Jupiter's stripes and two of its moons. Hadn't there been three when I first pointed?

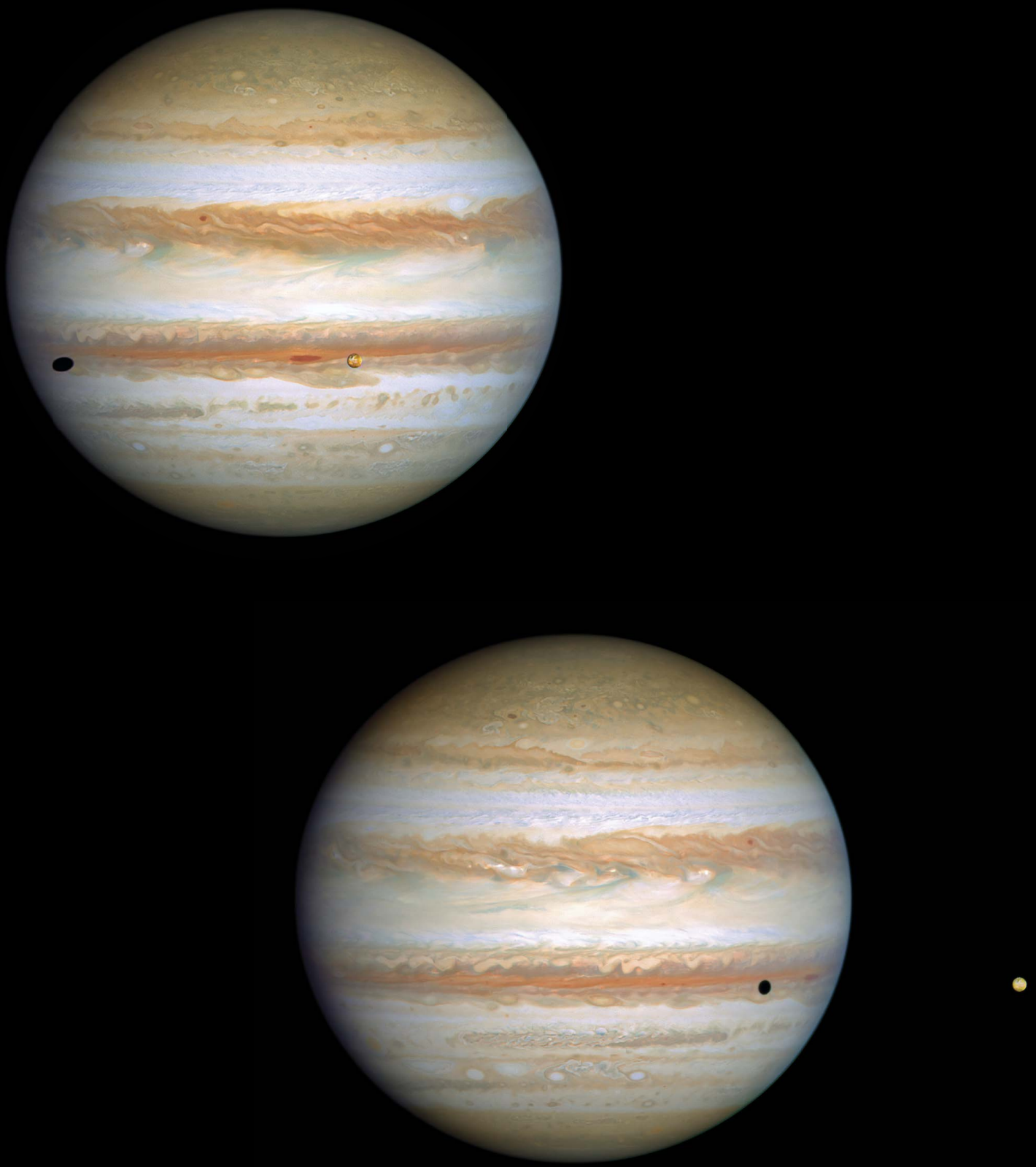
"Hey, everyone, come look again," I said, still glued to the eyepiece. "You know that the four Galilean moons are orbiting the planet, right? Well, one of the moons has disapp—" I stopped mid-lecture. The moon hadn't disappeared. It was at the very edge of Jupiter's limb. And it was casting a shadow on the giant planet.

Suddenly, the field of view seemed to have depth to it. I was standing on Earth, the Sun behind me casting a moon's shadow on Jupiter. I could see the distances and angles that made it happen. I could feel almost physically that I was on a planet — just another planet, like Jupiter — sailing through space in a vast clockwork solar system.

The students were murmuring behind me. "Sorry!" I gave way, shaking my head to bring myself back to solid ground, and the line started moving again.

The resolution of these three Hubble Space Telescope images of Io orbiting and casting its shadow on Jupiter certainly beats that of the university 16-inch. They were taken on January 6, 2024, about 2½ hours apart. In the middle image, Io seems to be floating above the big planet's surface. The shadow it casts tells me that the Sun is over my right shoulder. But I still get the same feeling I did that night: The universe is three-dimensional, and I am part of it.

—MEG THACHER



Photographs by
NASA / ESA / Amy Simon (NASA / GSFC),
Image Processing: Joseph DePasquale (STScI)

Celestron's NexImage 20 Planetary Camera

This high-speed video camera provides both high resolution and a wide field of view.



The Celestron NexImage 20 color planetary camera contains an extremely high-resolution detector and is designed to fit directly into 1¼-inch focusers.

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What We Like

High spatial resolution

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What We Don't Like

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**Prices subject to change*

FOR ROUGHLY a quarter century, "lucky imaging" has been the dominant technique used to record the most detailed images of the major celestial bodies in the solar system. This process uses high-speed video cameras to shoot short clips of the planets, the Moon, or the Sun (with the addition of a solar filter) to capture moments of atmospheric steadiness. These videos are then run through sorting and stacking software that automatically combines the best frames to yield ultra-high-resolution pictures of our celestial neighbors.

Celestron has offered several planetary camera models over the years in partnership with German-based industrial camera maker The Imaging Source. In 2025, Celestron announced its latest collaboration that caught my attention: the NexImage 20, containing a new, 20-megapixel CMOS detector with the smallest photosites (pixels) I've ever seen in a planetary camera. I borrowed one recently to see how well it performs with a selection of my instruments.



◀ *Left:* The detector in the NexImage 20 may appear small, but that 7.4-millimeter-wide chip contains more than 20 million 1.4-micron photosites (typically referred to as pixels) behind its permanently mounted UV/IR-blocking chamber window. *Right:* The rear of the camera body has a single USB-C port that connects the camera to your control computer.

Tiny Photosites

When the NexImage 20 arrived, I marveled at how small it was — its disk-like body measures just 47.6 millimeters (1.87 inches) across and 2.5 mm tall. This is about as large as some of the spacers I use to place a cooled camera at the proper distance from a field flattener for deep-sky imaging. With its included 1¼-inch nosepiece, the entire camera is about the same size as an 8-mm Plössl eyepiece. Within this minuscule housing resides its Onsemi AR2020 back-illuminated CMOS sensor, with 1.4-micron-square pixels in a 5,240 × 3,840-pixel (7.3 × 5.4-mm) array. Besides the nosepiece, which connects to the camera body via a C-thread, a 3-meter (10-foot) heavy-duty USB-A to USB-C cable and user manual are included.

The AR2020 sensor's tiny pixels are of particular note. The size of the pixels in a camera can be thought of as similar to your eyepiece focal length — that is, the smaller number, the higher the magnification it produces. In digital photography, that's known as *pixel scale*, how much sky each pixel sees in arcseconds. As noted in my feature in the October 2026 issue (page 28), you can determine the pixel scale for a telescope and camera combination with this equation:

$$\textit{Pixel scale} = 206.265 \times (P / F)$$

wherein F is your telescope's focal length (in millimeters) and P is your camera's pixel size in microns. So, for example, a camera with 2.76-micron pixels, paired with an 8-inch f/10 Schmidt-Cassegrain telescope having a focal length of 2,032 mm, produces a pixel scale of 0.28 arcsecond per

ALL PHOTOS BY THE AUTHOR

pixel at prime focus. For context, solar system photographers find that the ideal pixel scale when targeting the planets is between 0.1 and 0.3 arcsecond per pixel. With the NexImage 20's unprecedented 1.4-micron-square pixels, that same 8-inch SCT produces a pixel scale of 0.14 arcsecond per pixel, which is within the ideal range for resolving as much detail as you can with an 8-inch aperture.

Not only does this detector have tiny pixels, it also has a lot of them — enough to capture the entire Moon on the chip using an optic with a focal length of about 550 mm. So you'll get a great shot of the Moon that can be "zoomed in" to see even finer details. This makes the camera a particularly good match for small- to mid-sized scopes.

The NexImage 20 is capable of recording up to 8 frames per second (FPS) in its full, 10-bit mode, or 19 FPS in 8-bit mode. Additionally, it can operate as fast as 90 FPS when using an on-chip, region-of-interest (ROI) crop of the sensor.

As a color camera, the NexImage 20 uses microscopic color filters over the individual pixels to produce a color image. In practice, this means the pixels are divided into three interwoven grids — a quarter of the pixels have red filters over them, another quarter have blue filters, and the remaining half have green filters. Processing software separates the image data into the respective colors, then fills in the checkerboard-like gaps in each channel to create the final composite color image, a process known as *interpolation*. This action produces slightly less spatial resolution compared to an image created with a monochrome sensor used with individual color filters. The interpolation algorithms written into current stacking software now make the differences between a monochrome and a color sensor inconsequential, particularly if your interest is to capture natural-color pictures. The camera has a permanently mounted ultraviolet/infrared (UV/IR) blocking window to ensure proper color balance. This also means that the camera can't be used to capture images of, say, Venus in ultraviolet wavelengths or Jupiter through a methane (CH_4) filter.

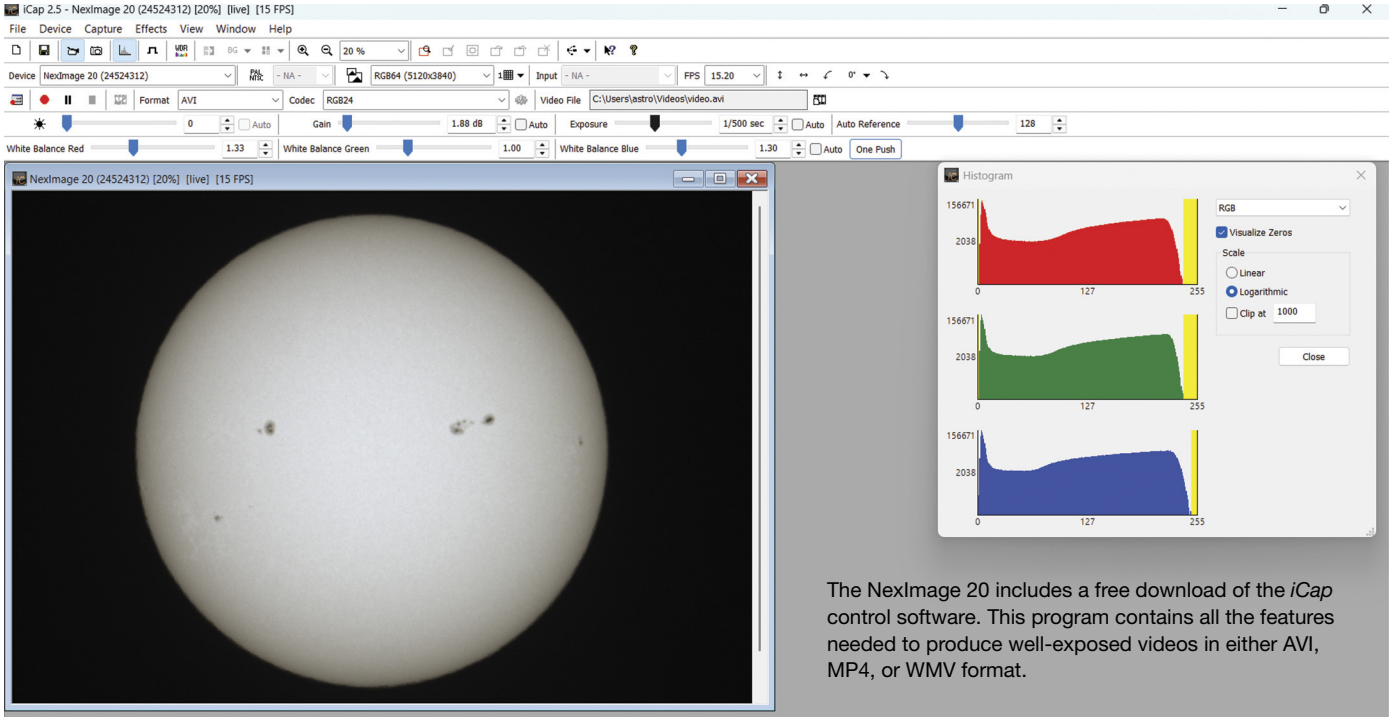


▲ The camera performs quite well when using a region-of-interest (ROI) crop on the detector, which permits frame rates of up to 90 per second. The author captured this image of Jupiter on March 18th through his Celestron C14 telescope with the camera at prime focus.

In Operation

To install the camera on your computer, the included manual instructs users to go to Celestron's website to download the camera driver as well as the *iCap* control software for Windows devices. Although the camera does work with Macs, users will need to use third-party software such as *FireCapture* (**www.firecapture.de**), or *SharpCap* (**www.sharpcap.co.uk**), to control it. You first install the camera driver and then plug the camera in when the installation program instructs it.

I operated the camera with the downloaded *iCap* software, a program I'm familiar with since first encountering The Imaging Source cameras in the late 2000s. It works quite well and has all the functions necessary for set-



The NexImage 20 includes a free download of the *iCap* control software. This program contains all the features needed to produce well-exposed videos in either AVI, MP4, or WMV format.



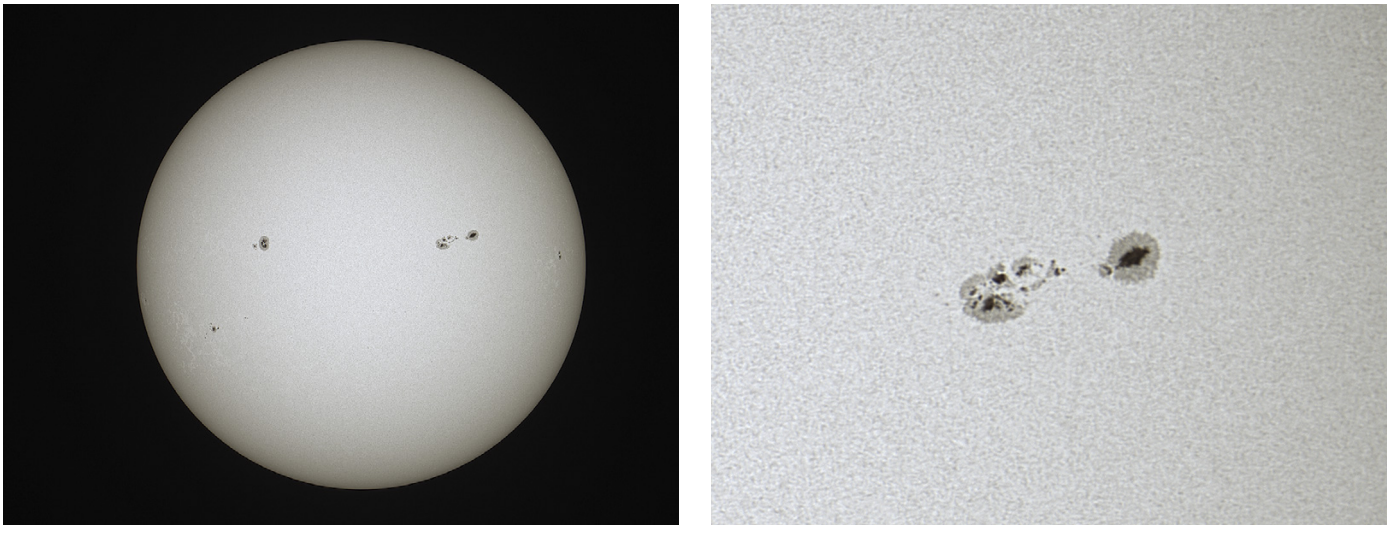
◀ The NexImage 20 excels at recording expansive, high-resolution images of lunar craters. The author shot this image of Clavius Crater and its surroundings through his C14 with the camera binned 2× to best match the average seeing conditions at the time.

ting the shutter speed, gain, and color balance, as well as a handy histogram function that provides an important visual monitor to ensure proper exposure, without over- or underexposing your target. For some of my testing, I controlled the NexImage 20 with the latest version of *FireCapture* freeware, though I sometimes reverted to using *iCap* for certain observations.

The camera was installed without problems, and I was out targeting the Moon on the next clear evening. Using the NexImage 20 is just like any other planetary camera, though when operating the camera with *iCap*, I found it helpful to open two additional toolbars. Using the pulldown menu, select ***View*** > ***Toolbars*** > ***White Balance Bar***. This opens three sliders that allow you to adjust the red, green, and blue channels on-screen to establish a proper color balance. Additionally, open the histogram using ***View*** > ***Toolbars*** > ***Histogram*** to monitor the signal of each individual color channel. With these opened, I unchecked ***Auto*** to the right in the White Balance bar, then increased the ***Exposure*** and ***Gain*** sliders until the image appeared well exposed. You can press the ***One Push*** button, which automatically sets the white balance that sometimes produces a neutral color of the Moon. You can then tweak each white balance slider to fine-tune each channel.

Imaging the Moon with the camera's 20-megapixel-detector produces a very large, high-resolution image. When targeting the Moon during this year's daytime occultation of Venus on June 17th, I recorded the entire ingress of the planet at the prime focus of my 92-mm Astro-Physics f/6.65 Stowaway refractor simply by swapping the eyepiece with the NexImage camera. A single video clip with this setup yielded an image that can be reproduced as a full page in the magazine with ease. Keep in mind that 20 megapixels is very close to the pixel count in many crop-sensor (APS-format) DSLR and mirrorless cameras. You won't need to mosaic the Moon together from multiple videos, though you can make even higher-resolution results with only a slightly longer focal length and then stitching the two halves together.

Imaging the planets was even easier using the camera's ROI crop, which



▲ The small pixels within the NexImage 20, combined with its relatively wide field, make the camera attractive for capturing highly detailed, full-disk images of the Sun. The author recorded this shot on the morning of July 23rd with the camera attached to his Astro-Physics 92-mm Stowaway refractor equipped with a Baader Astro Solar Safety Film filter. At right is a full-resolution crop of the sunspot group AR 4493 from the same video.

limits the readout of the chip to only the area selected. This produced a fairly high frame rate while I was imaging Jupiter last winter.

The camera's AR 2020 back-illuminated sensor is fairly sensitive, and its tiny pixels means that you typically won't need any additional magnification boost using a Barlow lens or other amplification. Yet those tiny pixels can be both a blessing and a curse. As mentioned earlier, the camera is a great match for small- to mid-sized telescopes, achieving the pixel scale necessary to resolve the smallest lunar and planetary features to the limit of your scope. However, those pixels are too small for optics with focal lengths of 2,500 mm or more. Pairing the camera with my Celestron C14's 3,910-mm focal length produces a pixel scale of 0.07 arcsecond per pixel, a size that's *oversampled* in all but absolutely perfect conditions. Oversampling means that the pixels are too small for the telescope's focal length, spreading small-scale features across many pixels, resulting in a picture that's big but fuzzy. Fortunately, the camera can be *binned*, in which groups of pixels work together as a single pixel that's twice as large. This means that the 1.4-micron pixels become 2.8 microns in effective size, resulting in a pixel scale of 0.15 and a better match for the scope's long light path. This binning is inconsequential when shooting the planets, though it has a noticeable cost when using the entire sensor, shrinking the total pixel count from 20 megapixels to 5. I'll note that the binning feature works quite well when using it in *iCap*; attempting to activate binning in *FireCapture* caused the program to freeze.

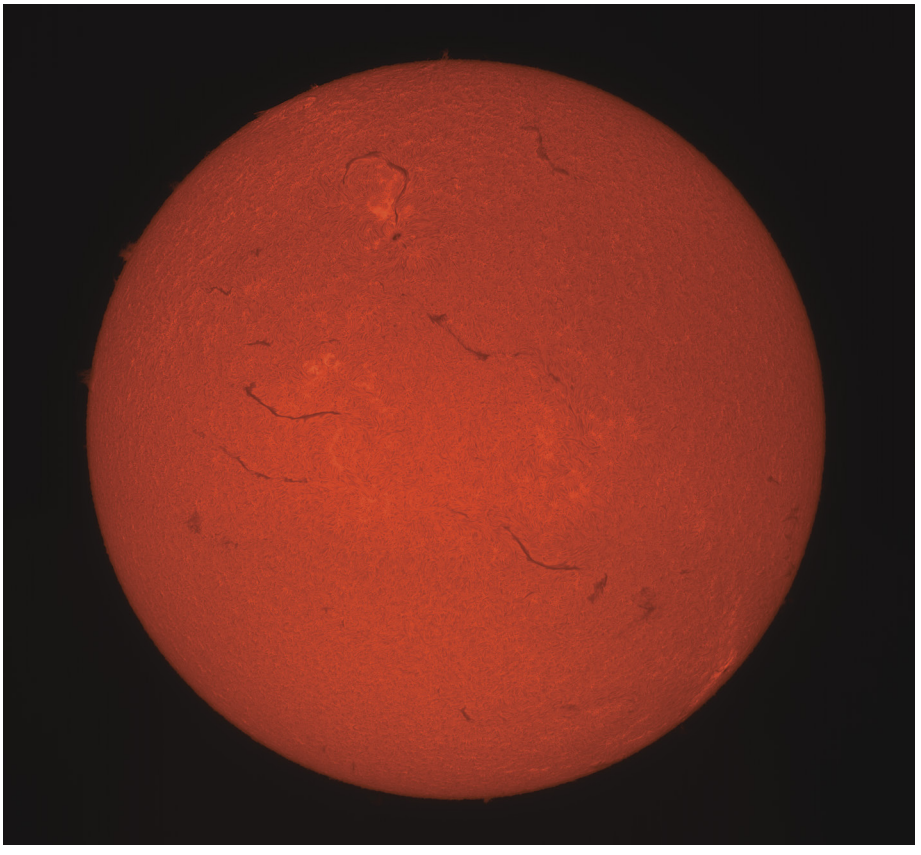
The NexImage 20 can also be used to capture excellent images of the Sun through a safely filtered scope. As the Sun is about the same angular size as the Moon seen from Earth, the camera can fit the entire solar disk on its sensor using focal lengths of up to about 550 mm. Fortunately, the passband of the camera's UV/IR blocking window is wide enough to include the important hydrogen Balmer lines, so the NexImage 20 can be used to record the Sun through scopes equipped with special hydrogen-alpha (Hα) filters. I paired it with both a white-light filter and a Sky-Watcher Heliostar 76mm H-Alpha Solar Telescope (*S&T:* Dec. 2025, p. 68), both producing good results.

The biggest drawback to using the entire sensor of the NexImage 20 is that it produces *big* pictures, and that means big videos that need to be stacked. And I mean *really* big videos. For example, a 1-minute video of the Moon recorded in 8-bit mode yielded an 11-gigabyte file. Copying a dozen of these off my laptop via its USB 3.1 connection onto my more powerful desktop computer to stack the results took more than half an hour. Furthermore, stacking these giant videos takes a very long time — it typically required a couple of hours to stack all my lunar or solar images. If full-frame videos are what you're after, then expect to budget a lot of time (and memory capacity) for post-processing. Fortunately, that isn't the case with videos recorded using the ROI feature.

Conclusion

The NexImage 20 is a good camera for beginners and experienced users alike for imaging the Sun, Moon, and planets in their natural color. Its tiny pixels eliminate the need for the addition of Barlows or other focal extenders to achieve the ideal pixel scale for resolving tiny details in the atmosphere of Jupiter and albedo features on Mars. The camera is particularly attractive for lunar imagers with small scopes, and its binning capability makes it versatile for astrophotographers who use a wide variety of telescopes and focal lengths.

■ Senior Editor **SEAN WALKER** often targets the Sun, Moon, and planets from his Dunkelheit Observatory in Litchfield, New Hampshire.



▲ Although the camera has a permanently mounted UV/IR-blocking-filter as its optical window, its passband includes the 656.28-nanometer Balmer line, enabling the camera to record images of the Sun through a hydrogen-alpha (Hα) filter. This shot is a two-panel mosaic captured by pairing the camera with a Sky-Watcher Heliostar 76mm H-Alpha telescope.

by Jonathan Kissner

The Side-By-Side Problem

A telescope maker doubles up on his scopes for his backyard dome observatory.

EVEN WHEN YOU BUY everything you need, things don't always work out as planned. This is what Milwaukee, Wisconsin, amateur telescope maker Steve Marshall learned when he tried to mount his two telescopes atop his brand-new pier — they wouldn't fit inside his observatory dome under construction.

A longtime chemistry teacher, Steve loves to share the night sky with friends and students alike. He also dabbles in one-shot astrophotography and never travels anywhere without a telescope. "I've always been shy of buying new gear," he remarks.

Steve had been using his existing instruments — a 14-inch Meade RCX400 and a 5-inch Orion refractor — for the last decade or so. His plan has always been to keep observing with his old scopes as much as he could, often with a piggybacked Pentax DSLR or an astro-modified Canon EOS Rebel XSi to shoot wide-field starscapes. "This was a lot of fun in any dark sky," Steve recalls. "I 'discovered' things like the California Nebula that way."

It was only after several things came together that he decided a dome observatory was doable. A gifted TMB 130SS (an incredible refractor) and a lead on an 8-foot-diameter fiberglass dome that a friend couldn't use both arrived around the time that his RCX400 fork mount completely gave out. This gave him a good excuse to pick up a brand-new Celestron C14 EdgeHD. He'd also inherited a house outside Durango,



▲ This view inside Steve Marshall's 8-foot dome shows the Celestron C14 EdgeHD and the TMB 130SS refractor mounted side by side atop an Astro-Physics 1600GTO German equatorial mount. Despite all the equipment, there's enough headroom for multiple observers.



▲ Steve found each scope's center of gravity by setting it up on his dining room table and focusing on distant trees, experimentally checking each balance point to within an eighth of an inch.



▲ Drilling the center bolt hole into the Astro-Physics mounting plate. The plate came with pre-tapped holes for various telescope configurations, except dead center, which is precisely where Steve needed one.

ALL IMAGES ARE COURTESY OF STEVE MARSHALL

Colorado, where the skies are far darker than in Milwaukee. And a treatable cancer diagnosis lit a fire under him.

Steve was committed to mounting his two scopes side by side so he could continue enjoying both visual observing and astrophotography. This meant throwing together a sturdy-enough configuration to make an observatory-grade mount feel appropriate and not overkill. "Commercial side-by-side telescope arrangements come with a disclaimer that some flexing is inevitable, no matter how well balanced, due to the narrow width of the base saddle," he notes. But he wanted the scopes to be co-aligned — the big C14 staying centered on the refractor's view — so "some flexing," however inevitable, was unacceptable.

And Steve also figured the setup could fit inside the dome: "Careful sketches showed that I could squash both scopes close enough to view through a 2-foot-wide shutter, regardless of orientation." So he settled on mounting the pair on a solid, ¾-inch-thick aluminum plate. However, this meant there are no adjustments for center of gravity, so he wanted to nail the scopes' relative positions as accurately as possible the first time.

"Finding each scope's balance point necessitated setting up the scope one at a time on my dining room table, focusing on distant trees on the next mountain ridge, and determining the balance point to within an eighth of an inch," says Steve. He found that the Schmidt-Cassegrain focus (which is achieved by moving the primary mirror) shifts the center of gravity by about half an inch, but using an external Crayford focuser meant this wasn't an issue. The C14's big metal aperture cover, however, moved the balance point almost a whole inch.

The geometry of the setup imposed a problem on the telescope mount, an Astro-Physics 1600GTO German equatorial mount. Although its mounting plate had tapped holes for almost any scope configuration you'd want, Steve needed one dead center: "So, with utmost care, I used the plate's central dimple to drill and tap a central bolt hole." He was relieved to discover his local hardware store had all the bolt types and threads he needed.

While digging to anchor the pier, he hit bedrock early. He looked at the 10-inch-diameter ATS pier he had already bought and the significantly shallow hole, and panicked: "I was thinking of ways to accurately cut down the pier's length — with a handsaw? Drill guide holes? Send it back to the manufacturer?" Steve found a local company that deals mainly with irrigation pipes. "The guy I talked to said to bring it in that morning and they'll have it ready by noon. They were really excited about my telescope project."

It took some "neighborhood help" to pull it all together, and a small shift of Steve's 3-inch finderscope was all that took to get everything balanced perfectly. He had overdrilled three of the four holes for the main refractor, allowing him to fine-tune its aim to match the collimated SCT. Cramped dome quarters required installing a shorter, heavier counterweight shaft; this added 30 pounds (14 kilograms) more, which brought the counterweight total to 108 lbs.

First light came in October 2025, with his brother and his childhood astronomer friend Al visiting for the occasion. After refining the Go To pointing on Vega, the scopes went straight to galaxies and globulars. M31, M33, and M15 were all wonderful, says Steve, but best views of all was Saturn, which was "great in the C14 even with my 50-mm eyepiece, with several moons clearly seen."

Two years of hard work had finally paid off. The side-by-side mount worked, and with the two scopes aligned, Steve loves being able to easily switch from the high-magnification views of the C14 to the rich, wide-field views in the TMB refractor. Steve describes how the finished project feels as the "exquisite pleasure of almost effortless surveying of the deep night sky." Operating the observatory is easy enough that his neighbors and friends are now trained to use it, and his sister-in-law "demanded nightly viewing to see Jupiter's moons move about!"



▲ Steve's friend Rick is seen marking positions on the aluminum plate. This was essential, as placement had to be right the first time. The tight spacing of the two scopes left no room to shift either scope laterally for balance afterward.



▲ The finished saddle plate features two Losmandy-style dovetail mounts for the C14 and TMB refractor. The plate measures 16 by 18 inches and weighs 24 pounds (11 kg). With the two scopes, the total load comes to 126 lbs.

■ Contributing Editor **JONATHAN KISSNER** is sketching plans to move on from tarp-based observatory solutions.



WISPY LINEUP

Patricio Calderari

The young Moon illuminated by earthshine hangs above Venus and the peak of Monte Rosa in the Alps bordering Switzerland and Italy.

DETAILS: *Nikon D850 DLSR with Nikkor 80-to-200-mm f/2.8 zoom lens. Total exposure: 2.5 seconds at 130 mm, f/5.6, ISO 250.*

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▷ DUSTY PATH

Gerald Rhemann and Michael Jäger

This deep image of greenish Comet 10P/Tempel captured the evening of July 9th reveals its faint dust *trail* extending vertically across the frame. This line, not to be mistaken for a dust tail, consists of particles shed by the comet over the course of many orbits around the Sun.

DETAILS: *Astrosysteme Austria ASA 12-inch f/3.6 astrograph with ZWO ASI6200MM Pro camera. Total exposure: 85 minutes through luminance and color filters.*



▽ ABOVE THE VALLEY

Radoslav Zboran

The Summer Milky Way with Scorpius blazing prominently at center right crowns this picturesque scene above the Austrian village of Zillertal.

DETAILS: *Astro-modified Canon EOS 6D DSLR with Sigma 35-mm lens. Total exposure: 10 seconds through a star-glow filter at ISO 3200.*



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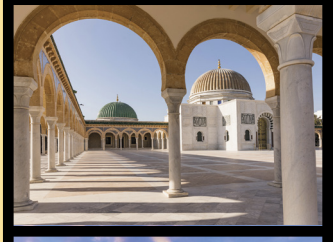







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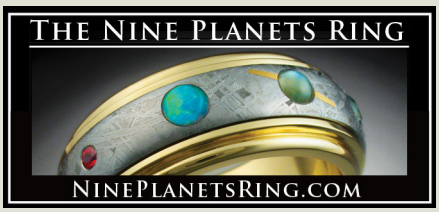

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Here's the info you'll need to "save the date" for some of the top astronomical events in the coming months.

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Everywhere!
https://is.gd/MoonNight

October 1–4
SJAC FALL STAR PARTY
Belleplain State Forest, NJ
sjac.us/events-activities/parties

October 3
ASTROASSEMBLY
North Scituate, RI
tinyurl.com/AstroAssembly

October 3
NOVAC STAR GAZE
C. M. Crockett Park, VA
tinyurl.com/NOVACStarG

October 3–11
PENNYRILE STARGAZE
Dawson Springs, KY
facebook.com/southstarparty

October 4–11
PEACH STATE STAR GAZE
Deerlick Astronomy Village, GA
tinyurl.com/PeachStateSG

October 5–10
ELDORADO STAR PARTY
Eldorado, TX
eldoradostarparty.org

October 6–11
ENCHANTED SKIES STAR PARTY
Magdalena, NM
enchantedskies.org

October 7–11
YORK COUNTY STAR PARTY
Susquehannock State Park, PA
yorkcountystarparty.org

October 8–10
ILLINOIS DARK SKIES STAR PARTY
Chandlerville, IL
sas-sky.org

October 8–11
IOWA STAR PARTY
Coon Rapids, IA
iowastarparty.com

October 9–17
OKIE-TEX STAR PARTY
Kenton, OK
okie-tex.com

October 10–15
DEEP SOUTH STAR GAZE
Norwood, LA
tinyurl.com/DSSG26

October 11–14
MICHIANA STAR PARTY
Tippecanoe, IN
michiana-astro.org

October 16–25
JASPER DARK SKY FESTIVAL
Jasper National Park, AB
jasperdarksky.travel

November 5–11
CHIEFLAND ASTROFEST
Chiefland Astronomy Village, FL
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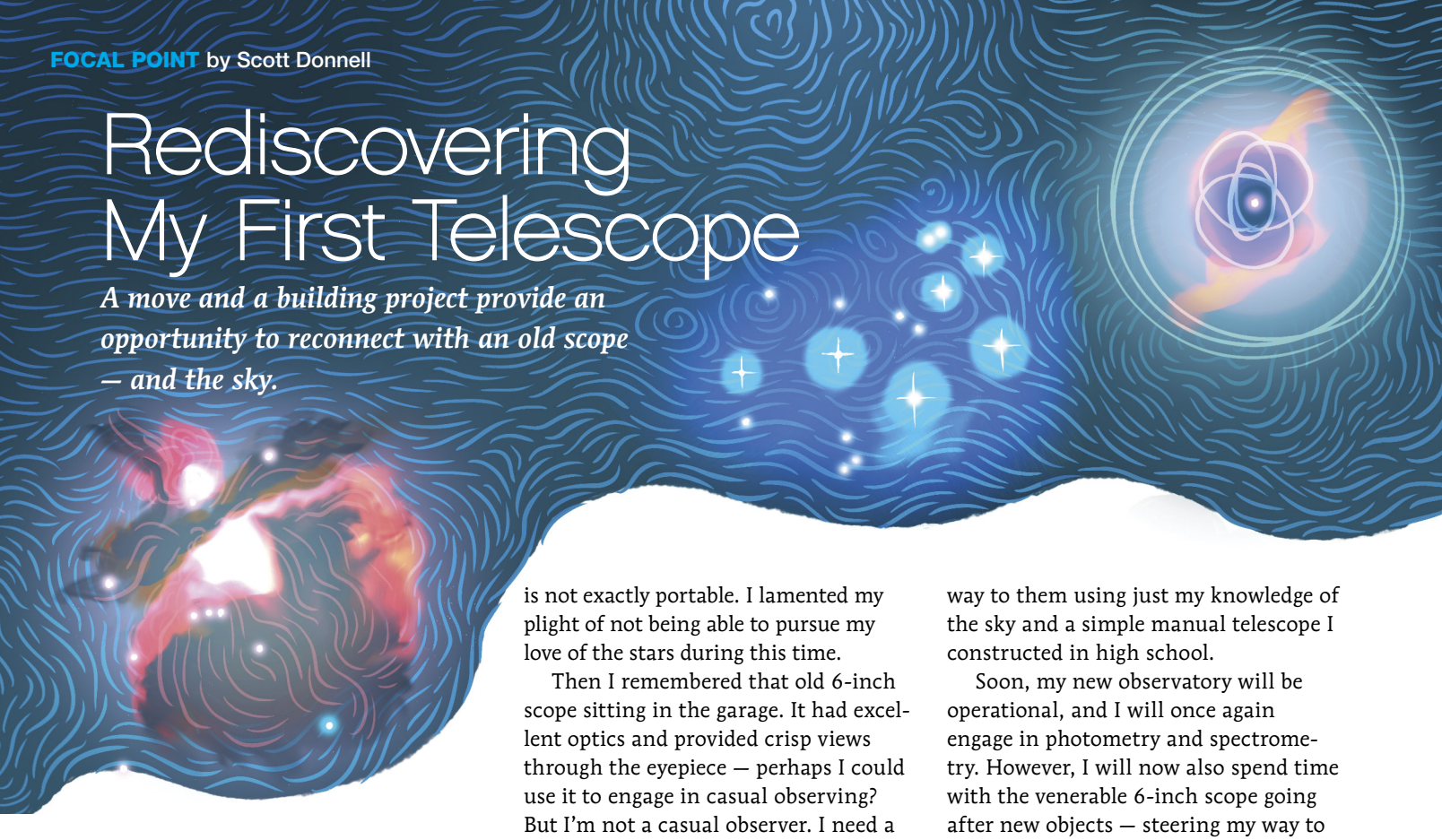
A move and a building project provide an opportunity to reconnect with an old scope — and the sky.



MY ASTRONOMY JOURNEY began when I was in elementary school. In summer and winter, I observed and noted the positions of bright stars and the shapes of the constellations. It wasn't until high school that I obtained my first telescope — a homemade 6-inch f/8 Newtonian set on an Edmund Scientific equatorial mount. I spent many wonderful hours with that scope observing the planets, double stars, star clusters, nebulae, and galaxies.

As I grew older, I progressed to a larger scope, exploring the world of digital imaging — first trying my hand at astrophotography, then delving into photometry of variable stars and, more recently, spectrometry. I hadn't used my old 6-inch scope for years. It sat in the corner of my observatory in quiet repose, a reminder of my first forays into visual observing so many years ago. It was, and still is, a fine instrument, but it's no longer useful to me. Or so I thought.

Having recently moved, I'm currently without an observatory. I've started building a new one, but it takes time and competes with other priorities demanding my attention. My large scope, which I use for photometry and spectrometry, is not exactly portable. I lamented my plight of not being able to pursue my love of the stars during this time.

Then I remembered that old 6-inch scope sitting in the garage. It had excellent optics and provided crisp views through the eyepiece — perhaps I could use it to engage in casual observing? But I'm not a casual observer. I need a purpose to motivate me. I decided my purpose would be to observe all 100 objects in the Astronomical League's Stellar Evolution Observing Program.

Tackling the first objects on this list exposed an unexpected problem: Getting on my knees and craning my neck to peer into the finder so as to aim the scope is something my old bones don't handle well anymore. But, undeterred, I found a solution: a laser pointer mounted in rings and attached to the front end of the scope. I used it to center on a star and nudged the scope in right ascension and declination until I landed on the intended target. This worked so well that I was able to locate and observe all 100 objects in the Stellar Evolution list.

My little scope taught me that even the most modest instruments, without automation or Go To pointing, can be useful in pursuing one's observing goals and further developing the skills needed to recognize star patterns. I've since been working on observing all 100 stars in the AL's Carbon Star Observing Program, and I find great satisfaction not only in the beauty of these aging stars but also in the fact that I navigated my way to them using just my knowledge of the sky and a simple manual telescope I constructed in high school.

Soon, my new observatory will be operational, and I will once again engage in photometry and spectrometry. However, I will now also spend time with the venerable 6-inch scope going after new objects — steering my way to them like an old sailor navigating his way by the distant stars.

■ **SCOTT DONNELL** is a retired space systems engineer and lead of the AAVSO's Spectroscopy Special Interest Group. At the time of writing, his new observatory was almost complete.



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