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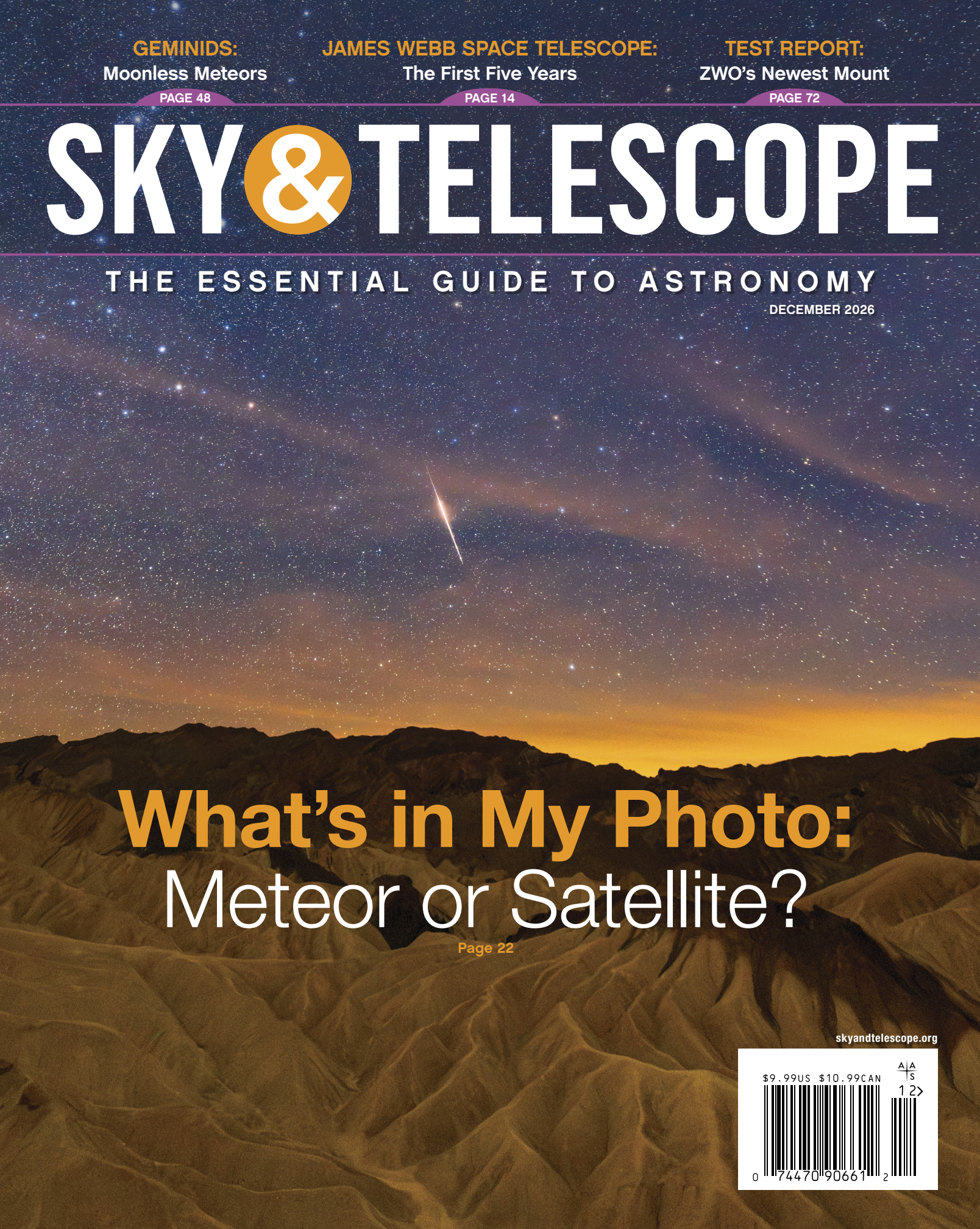
THE ESSENTIAL GUIDE TO ASTRONOMY

DECEMBER 2026



What's in My Photo:
Meteor or Satellite?

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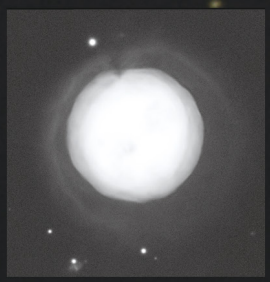
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ON THE COVER



A bright Geminid appears above Death Valley National Park.
PHOTO: BABAK TAFRESHI

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HEART NEBULA BY TONY HALLAS

The Season of Giving

'TIS THE SEASON! Again. The season of holidays, of the solstice, of the (potentially) best meteor shower of the year. Of saying goodbye to an old year and getting ready to welcome the new one. One endearing human trait in many cultures (I find) is how we tend to think of time in whole units. We remember events in one-year increments, when we cast our minds back to what happened last year at this time. Or a decade ago. Or even 85 years ago, as we did last month when we celebrated a *Sky & Telescope* milestone. Stellafane is currently marking several 100-year watershed moments in the founding of what went on to become the country's most celebrated telescope-making convention.

And so, during this season of holidays and reminiscences of the year gone by, we also remember that it's been five years since the launch of one of the most successful space telescopes ever. Science Editor Camille Carlisle has done the heavy lifting for us and has collated the James Webb Space Telescope's most stunning images and penned an excellent narrative that gives them context. Turn to page 14 for a veritable astronomical eye-candy fest.

Like clockwork every mid-December, meteor watchers are treated to a wonderful celestial display when the Geminids pepper the night sky with their blazing streaks. This year is particularly fortuitous, as the waxing crescent Moon will set well before the show starts, paving the way for dark conditions (page 48). Of course, catching falling stars requires clear skies and the willingness to venture forth into arctic temperatures for those at more northerly latitudes.

The Geminids are a photogenic meteor shower, as beautifully showcased on this month's cover by Contributing Photographer Babak Tafreshi. But, as we all know too well, increasingly larger numbers of satellites are crisscrossing the night sky. For visual observers, the distinction between meteor and satellite is straightforward. For imagers, not so much. If you enjoy capturing meteors like Tafreshi and are confused by what you might be seeing in your photo, turn to page 22 for the informative guide by contributing editor and blogger extraordinaire Bob King on how to distinguish between the natural and the artificial in your images.

As the Northern Hemisphere prepares for the darkest time of the year, some people despair at the lack of sunlight; others rejoice. The "others" are likely astronomers — the long, dark nights provide for ample time under the stars to look up, enjoy the views through an eyepiece, and contemplate the magnificence above. If you, like me, are passionate about astronomy, in this season of giving you might consider sharing your enthusiasm with a friend or family member who might not yet have had the opportunity to appreciate the night skies the way you do. Better yet, why don't you get them a gift subscription to this magazine to *really* get them hooked? After all, *S&T* only exists thanks to readers like you.



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SKY&TELESCOPE
The Essential Guide to Astronomy

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Seeing Deeper

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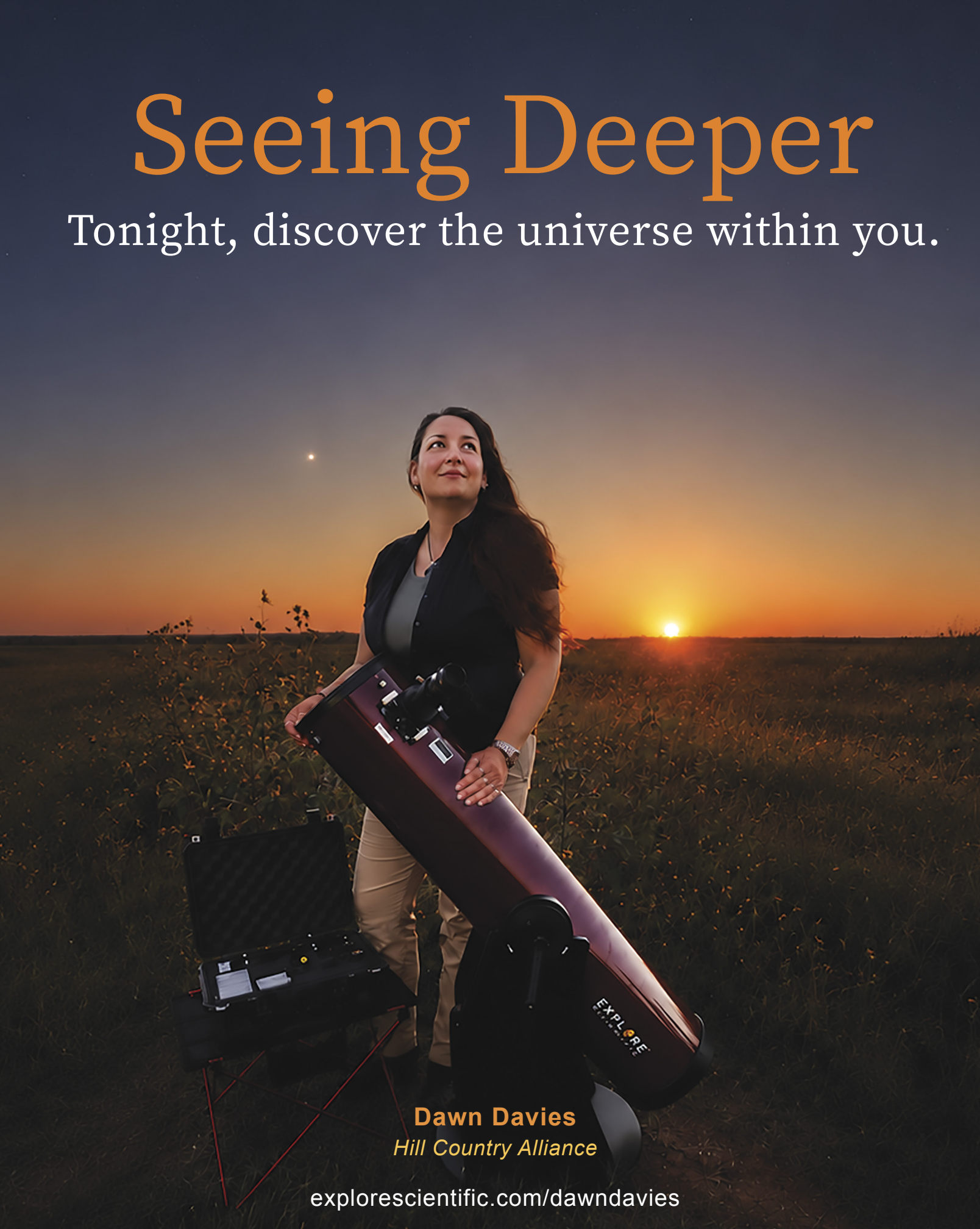

Dawn Davies

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◀▲ This map from 1877 depicts Cambridge, Massachusetts, as the Clarks would have recognized it. Their workshop (above) sat on Henry Street on the northern bank of the Charles River near what is today known as Magazine Beach.

Everyone Has a Favorite

Alvan Clark & Sons — mentioned in Trudy E. Bell's "The Big Role of Small Observatories" (*S&T:* July 2026, p. 60) — built the greatest refracting telescope lenses in human history. I was surprised and a bit disappointed to learn that their original factory and observatory buildings in Cambridge, Massachusetts, are completely gone. Has there ever been any effort to fund a small museum, exhibit, or a plaque commemorating this monumental, little company and its extraordinary contributions to astronomy?

Thanks for your wonderful magazine. I've been a reader for more than 57 years.

George Lauro
Cambridge, Massachusetts

Sean Walker replies: *Since my family was centered around Cambridge and Somerville during the entire 20th century, I've looked into the old location of the Clark workshop. In fact, several of my ancestors worked at the car dealerships as mechanics in the 1930s and '40s just across the river where Boston University now is — they likely passed by the old site and the disintegrating giant pier and optical tube assembly on their way to work.*

A "Historical Marker," as the Cambridge City commission calls them, marked the site in a small grassy area at 300 Sidney Street. Now, technically, I don't believe that was the actual location of the Clark property, as that plaque was diagonally across the intersection, which is now the site of the MIT Furniture Exchange.

Additionally, I've found a photograph taken by Leslie Jones of the giant pier and refractor optical tube assembly that was the test tube for many of their biggest lenses (below). It was still standing on the property in 1935, but by this time, it was more of a signpost than an actual telescope — the ends of the tube had corroded and parts had fallen off, so it looked rather ghostly.

I enjoyed Trudy E. Bell's article on 19th-century telescopes and observatories, but there was an omission in the Alvan Clark & Sons' largest telescopes. The 26-inch Leander J. McCormick refractor at the University of Virginia was also a Clark scope. Although it's a near twin of the 26-inch at the Naval Observatory, corrections were made to its lens design.

The telescope was donated in 1877. But the observatory wasn't completed until 1884. For decades the telescope was used to determine the distance to thousands of stars. The telescope is still in use today, primarily for teaching and public outreach.

John Sokol
Red House, Virginia



▲ This giant pier and optical tube assembly stood on the grounds of the Alvan Clark & Sons workshop for more than 75 years.

In the article "The Big Role of Small Observatories," the second paragraph states "Four of these marvels of glass and steel were erected in the U.S." But Bell omitted the 24-inch Clark refractor installed in 1896 in Flagstaff, Arizona. I was there again in April and saw the most incredible view of Jupiter! As someone who has worked in the field on Kitt Peak and with the University of Arizona, I've looked through many a *big* scope and this was the best Jupiter I have ever seen.

Teresa Bippert-Plymate
Tehachapi, California

In the opening of "The Big Role of Small Observatories," Trudy E. Bell highlights four behemoth U.S. refractors manufactured in the late 19th century by the famed Alvan Clark & Sons of Cambridge, Massachusetts. To this august collection should be added the 24-inch Clark refractor that was installed in 1896 at

MAP AND ZOOM: FRANKLIN VIEW CO. (1850) / WIKIMEDIA COMMONS / CC BY 2.0 (2); TELESCOPE: COURTESY OF THE BOSTON PUBLIC LIBRARY / LESLIE JONES COLLECTION

Lowell Observatory in Flagstaff, Arizona. It was with this telescope that Lowell astronomer Vesto Slipher discovered the systematic redshifts of galaxies (called "spiral nebulae" then) in the early 1910s. Through its great lens Percival Lowell earlier espied his fanciful Martian canals, and the Moon later was mapped at high resolution in the 1960s for NASA in preparation for the Apollo Moon landings. The campus is family-friendly — come visit!

Joseph N. Marcus
Lowell Observatory Advisory Board
St. Louis, Missouri

Trudy Bell says: *The readers are correct that during the same time interval the Clarks were setting records, they also made other large refractors, including those mentioned above. But none of these other large instruments were record-setters for the world's largest telescope at the times they were built. When the 26-inch Leander McCormick telescope was dedicated at the University of Virginia in 1885, it had been preceded 12 years earlier by the 26-inch Clark at the U.S. Naval Observatory (mounted in 1873). The USNO 26-inch also preceded the 24-inch at Lowell Observatory at Flagstaff, Arizona (1896). In fact, by 1896, the 26-inch USNO refractor had been surpassed by the 36-inch Clark refractor at Lick Observatory (1888), and the Yerkes Observatory 40-inch Clark refractor was nearly finished (mounted in 1897).*

Attic Observatory

I also built a private attic observatory in my house — it's not as grand as the one Paul Geithner described in "The Clover Hollow Mountain Observatory" (*S&T:* July 2026, p. 34) — but perhaps it could serve as an inspiration for others. My old house once had an oil furnace, but it was removed. So I modified the narrow oil flue brick chimney into a pier for my Celestron Powerstar C8 and two smaller scopes. We cut a skylight opening around it and expanded the former closet to enclose the equipment.

The whole thing (not counting astro gear) cost little more than $1,000 and served me well for around 20 years.

Roger Kern
Pacific Grove, California

FOR THE RECORD

- "A Mystery Solved?" (*S&T:* Sep. 2026, p. 60) incorrectly states that Asaph Hall discovered the two satellites of Mars, five years before E. E. Barnard started his search for planetary satellites at Lick Observatory in 1892. Deimos and Phobos were discovered in 1877, 15 years before Barnard's observations.
- The globular cluster 47 Tucanae on the cover of the July 2026 issue was mislabeled Messier 15 on page 2.

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

75, 50 & 25 YEARS AGO by Sabrina Garvin

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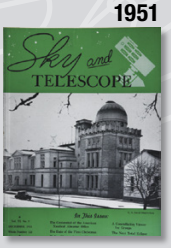
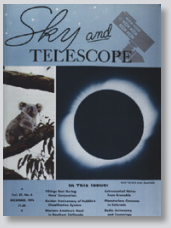


1976



2001



December 1951

Spatial Jurisdiction "In international law it is well established that national states have sovereignty over the atmosphere above their territories, but the law so far has not defined how far the atmosphere shall be considered to extend. . . .

"[Oscar] Schachter [United Nations legal department] suggests that to avoid interference with freedom of space travel the outer boundary of a state's territory be limited to the region known as the air space. He proposes that outer space be governed by rules similar to the international laws of the high seas; each national state would exercise jurisdiction only over its own space craft, persons, and goods. Because of possible grave consequences from military operations by space craft, there is a possibility that war might be outlawed in international space.

December 1976

Antarctic Meteorites "Japanese scientists have reported finding over 1,000 meteorites of various types lying on a few dozen square miles of Antarctic ice, according to Walter Sullivan in the *New York Times* for October 21st. The region is near the Yamato Mountains . . .

"The specimens, which weigh up to 12 pounds, were collected during expeditions in 1969, 1974, and 1975. Remarkably, only one is an iron meteorite. In museum collections generally, irons are about as numerous as stony meteorites, simply because the latter are likely to be passed over as ordinary rocks by casual discoverers.

"However, in the Yamato ice fields, the only 'rocks' are objects that have fallen from the sky. Hence all meteorite types are equally likely to be discovered, and unbiased relative frequencies can be determined. There is also a special opportunity to discover hitherto overlooked types of meteorites."

December 2001

Striking Sparks "Each year since 1986, the [Sonoma County Astronomical Society (SCAS)] has given away club-built 5¾-inch f/7 Dobsonian telescopes to deserving local students through its unique Striking Sparks program . . . More than 160 such scopes are now scanning the skies of this wine country . . .

"Behind every grand scheme is a dreamer. [Robert H.] Ferguson recognized that young people's interest in science was lagging in school, and he wanted to do something about it. . . . So in 1985 he proposed his telescope giveaway plan to the SCAS, which heartily approve it.

"Early in the school year the SCAS sends out letters to all the county's schools, soliciting essays from students on why they deserve to win [one of the 10 handmade telescopes]. A jury of club officers and dignitaries . . . select the finalists, and then invite the winners to the annual Striking Sparks Day awards ceremony."



In this artist's concept, LHS 1140b is shown in the foreground, enveloped in a helium-rich atmosphere. Another rocky planet is seen in the distance, orbiting the same cool red dwarf star.

MELISSA WEISS / CENTER FOR ASTROPHYSICS, HARVARD & SMITHSONIAN

EXOPLANETS

Atmosphere Detected on Rocky World

HELIUM IS ESCAPING from a world 49 light-years away, possibly marking the first detection of an atmosphere on a terrestrial planet.

Collin Cherubim (then at Harvard University) led the team that detected helium leaking from the upper atmosphere of LHS 1140b. The planet is 70% larger than our own and has more than five times Earth's mass. It orbits a dim, red-dwarf star every 25 days, putting it in the star's *habitable zone*, which means liquid water might exist on its surface.

While modeling the evolution of atmospheres around smaller worlds, Cherubim noticed that certain planets initially gathered envelopes of hydrogen and helium. While they eventually lost the lighter hydrogen, they held onto their helium longer.

So Cherubim went looking among known, smaller worlds to see if they exhibited helium signatures. Observing in September 2024 with the Magellan Clay telescope in Chile, Cherubim's team measured the light of LHS 1140b as the planet passed in front of its star. During such *transits*, they could detect the make-up of its uppermost atmosphere. The helium signal appeared loud and clear.

The team estimates that 200 metric tons of helium blow off of LHS 1140b every second, blasted away by the star's high-energy radiation. The helium vapor streams around and *ahead* of the planet in a long tail, perhaps due to interactions between the magnetic fields of the planet and its star. The amount of helium absorption depends on the amount of stellar radiation the planet's receiving, the team found. With its star clocking in at more than 3 billion years old, the researchers conclude LHS 1140b is probably in its last stages of losing its primordial hydrogen and helium.

Charles Cadieux (University of Montreal, Canada), who was not involved in this study, urged caution noting that helium can also be found in stars. "I was very surprised and very excited about this result," Cadieux says. "I think we need more observations in the end to really know what is going on with this habitable-zone planet."

Adding to the complexity are previous James Webb Space Telescope observations of the world, which had ruled out a puffy atmosphere and hinted instead at heavier compounds in the atmosphere, such as carbon dioxide, nitrogen, and water.

It's possible both findings are true: LHS 1140b might have a helium-rich upper atmosphere, while heavier elements are trapped below. Webb's infrared observations may have accessed deeper layers of the atmosphere.

More recently, Webb is in the process of making nine additional observations of LHS 1140b throughout its orbit, which will help shed light on the nature of this world's atmosphere.

■ ARIELLE FROMMER

IN BRIEF

Third Planet for Beta Pictoris

The famous Beta Pictoris system has a third giant planet. Like the other two, the new world is also a gas giant, revealed by the heat leftover from its formation. It's much farther out from the host star and much less massive than both its planetary siblings; Beta Pic b and c are both about nine times Jupiter's mass, while Beta Pic d has the heft of just 2 or 3 Jupiters. Two teams made the same discovery independently, with both results published July 15th in the *Astrophysical Journal Letters*. Both teams discovered the planet serendipitously, one taking spectra of its atmosphere with the James Webb Space Telescope, the other finding it in images from the Very Large Telescope in Chile and other archival observations. Beta Pic d might have carved the inner edge of the debris disk that surrounds Beta Pictoris, clearing away the leftovers of earlier stages of planet formation.

■ MONICA YOUNG

Read more: **skyandtelescope.org/BetaPicd**

Confirmed Companion

Astronomers have used the Very Large Telescope (VLT) in Chile to image Betelgeuse's companion. Previous observations had hinted at a small stellar companion to the giant star at Orion's shoulder (*S&T:* Dec. 2025, p. 9), leading to a prediction detailing when the two stars would be at their widest separation: December 2024. Miguel Montargès (Paris Observatory) and colleagues used SPHERE, an adaptive optics system and coronagraphic facility at the VLT, to image Betelgeuse during this time, resolving its companion just 52 milliarcseconds away. "Honestly, I thought we did not have the sensitivity to detect Betelgeuse B as it was predicted," Montargès says. "Because it is more massive than predicted, we see it!" It

GALAXY

The Milky Way's Arms Might Be Wider Than We Thought

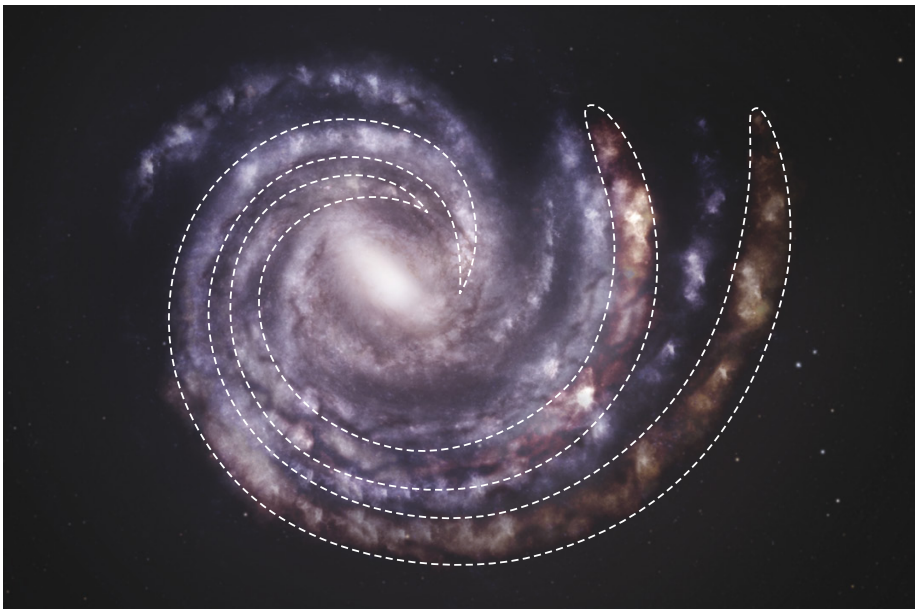
OBSERVATIONS OF POWERFUL cosmic explosions suggest that the outer spiral arms of the Milky Way extend farther away from the center than previously thought.

To map the most distant of the Milky Way's spiral arms, astronomers must rely on indirect methods. Now, the newest of these techniques makes use of *long gamma-ray bursts*, blasts of gamma rays and X-rays from the collapse and subsequent explosion of massive, rapidly rotating stars.

Three gamma-ray bursts, including the brightest burst ever recorded, happened to occur close to the Milky Way's central plane on the sky, called the *galactic equator*. Astronomers thus saw them through the galaxy's disk, which means that their high-energy radiation passed through one or more spiral arms before arriving at Earth.

In the days after the explosions, NASA's Chandra X-ray Observatory and ESA's XMM-Newton space telescope detected numerous X-ray rings expanding around each burst. These are *light echoes,* produced as dust clouds in our galaxy scatter the burst's radiation, sending it our way.

Because light echoes scatter off another surface before heading toward the observer, they take a slightly longer path and arrive later than the burst. By measuring a light echo's size on the sky and the timing of its delayed arrival, astronomers can measure the distance to the massive dust clouds doing the scattering. Many of these clouds lie in the Milky Way's spiral arms.



▲ This artist's impression depicts how observations of X-ray light echoes might have revised our map of the galaxy's outermost spiral arms. New estimates of arm positions are in red and bordered by dashed lines.

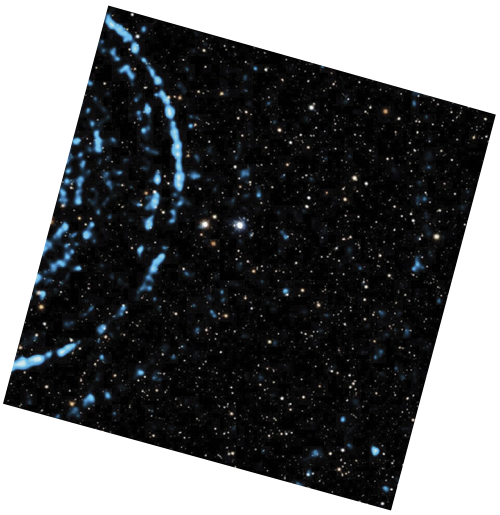
In the June *Astronomy & Astrophysics*, Beatrice Vaia (IUSS Pavia, Italy) and colleagues conclude that our galaxy's Perseus Arm — the one just outside our Local Arm — is where we thought it was. But the Outer Arm beyond it and the Outer Scutum-Centaurus Arm beyond that may both lie up to 10% farther away than earlier studies predicted.

"This could mean that astronomers have to revise estimates of the mass of the galaxy, because that affects how wide the arms stretch," says team member Ilaria Fornasiero (University of Trento, Italy).

With just three sightlines, the results are necessarily preliminary. Similar future observations could improve the arms' distance estimates.

■ GOVERT SCHILLING

MILKY WAY ARMS: NASA / CXC / SAO / M. WEISS; X-RAY LIGHT ECHOES: X-RAY: NASA / CXC / INAF / B. VAIA ET AL.; VISIBLE: PAN-STARRS; IMAGE PROCESSING: NASA / CXC / SAO / N. WOLK & P. EDMONDS



▲ X-ray light echoes surround a gamma-ray burst, whose light has passed through the gas and dust of the Milky Way's disk.

turns out Betelgeuse B has at least twice the mass expected. The team's results, published in the July *Astronomy & Astrophysics*, still need to be confirmed with observations of the smaller star's orbital motion.

■ COLIN STUART

Find more details at **skyandtelescope.org/BetelgeuseB.**

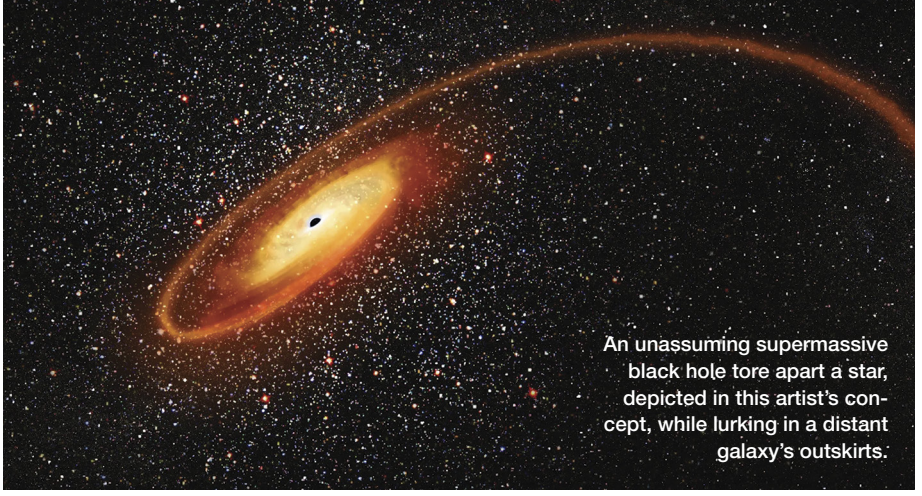
Io Is Smooth and Fluffy

Ash from countless volcanic eruptions have likely built up a porous surface on Jupiter's moon Io, report Shannon Brown (JPL-Caltech) and colleagues in the July *Journal of Geophysical Research Planets.* The researchers' conclusion comes from the Juno spacecraft's six microwave radio antennas, which measured the heat flux coming from the moon. The heat flux indicates that the surface is smooth and has a low *thermal inertia*, meaning it heats and cools quickly. It's therefore either dusty or porous. The radio emission Juno measured from Io is consistent with a surface density 0.7 to 1.1 times the density of water, more akin to snow. The surface may be similar to pumice or *scoria*, a type of rock made by the fall of volcanic ash.

■ EMILY LAKDAWALLA

BLACK HOLES

Supermassive Black Hole Found Wandering



An unassuming supermassive black hole tore apart a star, depicted in this artist's concept, while lurking in a distant galaxy's outskirts.

ASTRONOMERS HAVE long thought supermassive black holes could escape their home galaxies — now they've found one roaming far out in its host's galactic outskirts.

Supermassive black holes normally rest firmly at the centers of galaxies. But theory says that when two galaxies collide, their resident supermassive black holes might not settle down right away, or at all.

An example of this phenomenon came in the form of an unusual *tidal disruption event* (TDE), reported in the August 1st *Astrophysical Journal Letters* by Robert Stein (University of Maryland) and colleagues. TDEs, the sudden release of energy following a black hole's destruction of a passing star, are picked up regularly by the sky-scanning Zwicky Transient Facility (ZTF) in California.

This particular event, TDEabcr, was different. Despite the black hole having the mass of 1 million Suns, it lit up about 30,000 light-years away from the center of its galaxy. Archival images taken before the TDE's detection in November 2025 show no emission at its position or evidence of a second galaxy around it. "You would not have suspected a black hole was hiding there," Stein says.

Stein's team found this TDE using a machine-learning algorithm that specifically looked for such events occurring far from galactic centers. Applying the algorithm to ZTF data starting in August 2025, they found their first event three months later. "It's amazing that we found one so fast," Stein says.

Most likely, the black hole is in a much fainter dwarf galaxy that's merging into the larger one. While in its quiet orbit, the black hole encountered a star and tore it apart, creating the TDE. Another, even more massive black hole rests at the larger galaxy's core.

This black hole is only the first of many, Stein hopes; his group wants to pick up more such off-center TDEs with the Vera C. Rubin Observatory (*S&T:* Nov. 2026, p. 8).

■ JAN HATTENBACH

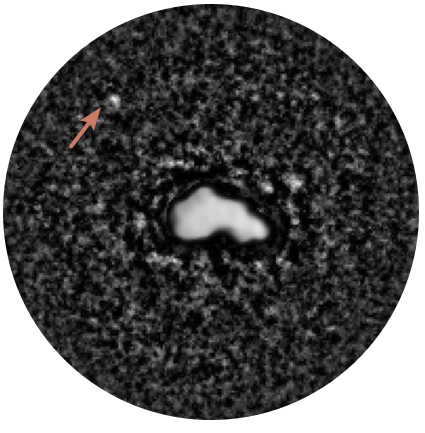
ASTEROIDS

Astronomers Spot Three-Lobed Asteroid with a Moon

ASTEROID 44 NYSA has an unprecedentedly weird shape. A set of images taken with the Very Large Telescope in Chile and the Large Binocular Telescope in Arizona suggest the asteroid is made of three large chunks connected by narrow necks.

As a bonus, the images reveal a companion: a moon orbiting at a distance of about 180 kilometers (110 miles) from Nysa's center of mass. Kate Minker (Lowell Observatory) and her colleagues detail the discoveries in a paper to appear in *Astronomy & Astrophysics*.

Nysa is large, of rare composition, and surprisingly dense. If all the asteroid's mass were reshaped into a sphere, it would be 75 kilometers across — much larger than most of the rubble piles that our spacecraft have visited. Unlike them, this one is a rare E-type asteroid, where "E" stands for *enstatite*, a magnesium-rich silicate mineral found in the interiors of large rocky worlds. But with more than 5 grams per cubic centimeter, Nysa is too dense to be only rock — it has metal, too. Both enstatite and metal have the strength to support Nysa's strange shape against self-gravity.



▶ Adaptive-optics imaging reveals the arched shape of asteroid 44 Nysa, which might consist of three connected lobes. The asteroid's moon, S/2026 (44) 1, is marked with a pink arrow.

Yet the shape's origin is still difficult to explain. The researchers propose two mechanisms, neither of which is entirely satisfactory. One idea is that it's an impact-battered remnant of an earlier body, though it's difficult to imagine how whittling could have formed two narrow necks.

The other idea is that it's a *contact trinary*, three separate bodies whose orbits slowly decayed until they touched. While this story would explain the narrow necks joining larger sections, it's still hard to explain the stability of the arch. Over time, self-gravity should tug the at the two ends, closing the hollow space between them.

The apparent instability suggests Nysa has been disrupted more than once — perhaps another impactor came along and knocked a lobe loose, and they have since reconnected. In that case, the shape may still be evolving.

■ EMILY LAKDAWALLA

TIDAL DISRUPTION: NASA / ESA / D. PLAYER (STSCI); ASTEROID: KATE MINKER ET AL.

AWARDS

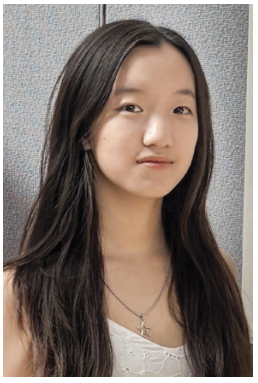
California Teen Wins 2026 National Young Astronomer Award

AS A GIRL on camping trips in California, Elizabeth Zhang felt awe watching the night sky. In high school, she discovered the astronomy club, where she could blend art and science.

"I really started to love it once I actually delved into researching it," says Zhang, 17, a rising senior at The Harker School in San Jose. Her zest led to a search for planets orbiting binary stars, with results that earned her the 2026 National Young Astronomer Award from the Astronomical League.

Zhang accepted the honor on August 15th at the League's annual meeting, in Covington, Kentucky.

Michael Telesco of New Canaan, Connecticut, came in second for his study of a solar-system-like organization around a Sun-like star. Zhang and Telesco received plaques and refractor telescopes from Explore Scientific, an award patron. They also presented their work at the convention.



Third place went to Mohd Iftakhar Tarunno of Upper Darby, Pennsylvania, and Julian Du of Darien, Connecticut. Finalists were Safilin Salma of Upper Darby, Pennsylvania; Michelle Sebastian of Simi Valley, California; and Shravan Calvin Sridhara of San Jose, California.

The National Young Astronomer Award, in its 34th year, honors the nation's brightest high school minds, with some winners having gone on to scientific careers. AL President Chuck Allen, who founded the NYA award, said the competition shows high school students are "cracking" Big Data from the most advanced telescopes.

Zhang's interest in the stars deepened with her school's STEM-intensive curriculum. In the school's astronomy club, she learned from astrophysicist Jian Ge (Shanghai Astronomical Observatory) to code searches of telescope databases. Then she learned of planets that orbit two-star systems, first clearly detected in 2011. Binary stars should eclipse each other predictably, but some don't. Zhang used those "wobbles" to look for planet candidates.

Zhang says she has not decided on a college or coursework, but she's considering astrophysics. She's also finishing illustrations for a book she has written about a girl traveling the universe.

■ ANNE SAKER

THE SUN

Inouye Telescope Sees the Sun Closer Than Ever

SCIENTISTS OBSERVING with the world's largest solar telescope have caught wave-like shapes never seen before on the Sun's visible surface, or *photosphere*. The beautiful structures are key to energy transportation in the Sun's lower atmosphere.

When two fluids flow past each other at different speeds, small disturbances grow quickly into swirling vortices in a process known as the *Kelvin-Helmholtz instability*. The National Science Foundation's 4-meter Daniel K. Inouye Solar Telescope, near the summit of Maui's Haleakalā, has given us a view fine enough to reveal this process occurring on the Sun's visible surface, published August 5th in *Nature*.

Zooming into an active region, David Kuridze (National Solar Observatory) and colleagues watched the motions of hot gas at a wavelength of 416 nanometers (violet light). Like in a pot of boiling water, solar plasma wells up at the center of convection cells known as *granules*. At the surface, the plasma releases radiation and heat into space, cooling and sinking down again at the granule edges.

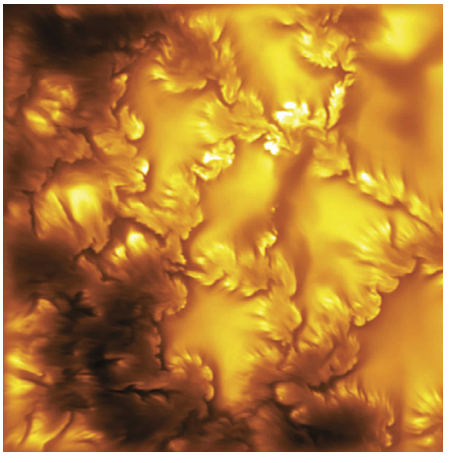
There, where the plasma flows converge, so, too, do the magnetic field lines that the plasma is carrying. As the magnetic field strengthens, it stymies the flow of charged particles. The resulting change in velocity sets up exactly the condition needed for Kelvin-Helmholtz instabilities.

The zoomed-in views of granule edges showed not the blurry, smooth interfaces seen in previous observations, but small swirling vortices. Computer simulations of magnetized plasma boiling into the solar atmosphere confirmed that the swirls have the properties of Kelvin-Helmholtz instabilities.

"The smallest resolved features in these images are around 19 km (12 mi)," Kuridze says. "Tracking their rapid motions over just a few seconds is an extraordinary technological achievement in observational solar physics."

The swirls that the team observed are signs of energy dissipating within the deepest layer of the Sun that we can see directly. Since the energy from pent-up magnetic fields drives most solar activity, such observations may prove key to understanding the complex phenomena — such as flares, coronal mass ejections, and coronal heating — that result.

■ MONICA YOUNG



▶ Wave-shape vortices and stripes within the magnetized plasma of the photosphere are associated with the Kelvin-Helmholtz instability. Watch videos of the plasma's motions here: **skyandtelescope.org/SunKHI.**

ZHANG; ELIZABETH ZHANG; VORTICES ON THE SUN: NSF / NSO / AURA / MPS

Let's Go Clubbing

The celestial Hunter's Club harbors some deep-sky surprises.

FOR WHATEVER REASON, Orion, the Hunter, has four confused deep-sky objects in a narrow ellipse of sky some 3° long and 1° wide near the very tip of Orion's Club, which is represented on star charts by 4.4-magnitude Chi^1 (χ^1) and 4.6-magnitude Chi^2 (χ^2) Orionis. While several sources have sorted the muddle, others have not, so confusion abounds in some amateur circles. Let's look at these troublesome wonders and see how they've been straightened out. Since I can't list all the ways these objects are represented in the vast number of star charts, atlases, and sky apps in existence today, I'll refer solely to the *Sky Atlas 2000.0* as an example.

We'll start with NGC 2174 and NGC 2175, which both lie about 1½° east of Chi^2 Orionis. On the *Sky Atlas*, NGC 2174 is shown as a bright nebula and NGC 2175 as an open cluster. Actually, the latter is an emission nebula. Italian astronomer Giovanni Battista Hodierna possibly discovered it from Palermo before 1654 with a simple Galilean refractor at 20×. German astronomer Carl Christian Bruhns independently found it around 1857, apparently while searching for comets. He described it as "an 8th-magnitude star in nebulosity."

German astronomer Arthur Auwers reported it as the 21st object in his 1862 catalog of new nebulae, and John Herschel included it in his 1864 *General Catalogue of Nebulae and Clusters of Stars* as GC 1366, which later became NGC 2175. So the historical accounts are clear: NGC 2175 is a roughly 40′ by 30′ diffuse nebula centered at right ascension 06^h 09.7^m and declination +20° 29′. It's so large that, under the darkest skies, the object is best seen through binoculars than most telescopes. Today, NGC 2175 is better known as the Monkey Head Nebula and is a popular target for astroimagers. Alas, many modern references still mislabel the nebula as NGC 2174.

What then is NGC 2174? Surprise! It's not an open cluster, but a small knot of nebulosity in the north-northwestern portion of the larger nebula complex. French astronomer Édouard Stephan discovered it in 1877 with the 31-inch reflector at Marseille Observatory, noting it to be, "Extremely faint, between 3 very faint stars." You'll find this 3.5′ by 2.0′ knot at right ascension 06^h 09.4^m and declination +20° 40′.

What of the cluster, then? It may or may not exist. If it does exist, it would be Collinder 84, or Cr 84, as Swedish astronomer Per Collinder listed it as the 84th entry in his 1931 article, "On Structural Properties of Open Galactic Clusters and their Spatial Distribution." But in their book *Star Clusters*, Brent A. Archinal and Steven J. Hynes note that the "reality of the cluster itself is in some doubt."



▲ **MIGHTY WEAPON** This print from a copperplate engraving from the 1661 edition of Johann Bayer's *Uranometria* depicts Orion, the Hunter, wielding his club.

Our next mystery object is NGC 2163, classified as "non-existent" in the 1973 *Revised New General Catalogue of Nonstellar Astronomical Objects*. But it does exist — under a different name: Cederblad 62, or Ced 62, after another Swedish astronomer, Sven Cederblad, who included it in his 1946 catalog. Some sources list or show NGC 2163 and Ced 62 as two different objects, but this isn't the case. NGC 2163 *is* Ced 62, which is how it's shown in the *Sky Atlas*. It's yet another discovery by Stephan with the 31-inch at Marseille in 1873. Like NGC 2174, it's tiny (3′ by 2′); nevertheless, the 11th-magnitude glow is detectable through small telescopes under a dark sky. I've seen it in my 3-inch refractor. In images, the reflection nebula appears as a bluish, bipolar cloud with two symmetrical, funnel-shaped wings extending north–south from the illuminating star. You'll find this little wonder just 1¾° southeast of Chi^2 Orionis at right ascension 06^h 07.8^m and declination +18° 39′.

Our final celestial conundrum is NGC 2195. The *Sky Atlas* identifies it as a small, bright nebula less than 10″ across that lies about 95′ southeast of Ced 62. It has also been listed elsewhere as a lenticular galaxy. But it's neither. NGC 2195 is a double star discovered by German-British astronomer Jacob Gerhard Lohse in 1886 — at right ascension 06^h 14.6^m and declination +17° 38′ — using a 15½-inch reflector in Yorkshire, England. This pair of roughly 13th-magnitude stars about 10″ apart is situated 30″ south of the 10.7-magnitude star TYC 1318-540-1. I've resolved this tight duo with my 3-inch refractor at 300×. For those using larger scopes, an even tighter pair of much dimmer stars lies immediately to the north of NGC 2195. Between it and the 10.7-magnitude star, these pairings create an elongated, nebulous illusion, like a fainter version of M40, the optical double in Ursa Major that tricked Charles Messier!

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

SCIENCE HISTORY IMAGES / ALAMY


OBSERVABLE SPACE
OBSERVABLE.SPACE
SEE // NAVIGATE // COMMUNICATE



PILLARS OF CREATION This composite fuses near- and mid-infrared images to show this dazzling star-forming region. Stars primarily show up at near-infrared wavelengths, including newly formed stars (orange spheres just outside the pillars). Mid-infrared picks up dust. Dust helps gas cool, enabling it to collapse and form stars.

Webb's Greatest Hits

Let's take a jaunt through the now-iconic space telescope's science results thus far.

They say time flies when you're having fun. If so, then professional astronomers are having a fiesta.

Five years ago this month, the James Webb Space Telescope roared off the launchpad. Sometimes dubbed "astronomers' Christmas present," JWST took flight on an Ariane 5 rocket from Europe's spaceport in French Guiana on December 25, 2021. After a month of deep-space travel, it arrived at its destination: L_2, the Lagrangian point 1.5 million kilometers from Earth's nightside. Here, the telescope can gaze at the infrared universe unimpeded by our planet's thermal glow.

Placing JWST beyond the reach of repair seemed foolhardy to some; flashbacks to the Hubble Space Telescope's flawed mirror dogged mission planners' steps. Yet a distant location was part of astronomer Lyman Spitzer, Jr.'s vision when he first proposed a space telescope in 1946. He wrote:

> *To provide for a leisurely orbit and thus for relatively constant conditions, such an observatory should preferably be at some distance away from the Earth, probably as far as telemetering techniques and celestial mechanics might allow.*

Although ignoring this perspective for Hubble proved fortuitous, taking it to heart for Webb was the right move. JWST has dazzled us since science operations began in July 2022, producing a fanfare of fantastic results.

With such bounty, it's easy to forget that the telescope was once seen as an astronomical albatross. Initially greenlighted in 2008 with an estimated launch date of 2014, it suffered multiple delays. Mismanagement and unrealistically low



PILLARS: NASA, ESA, CSA, STSCI, J. DEPASQUALE (STSCI), A. PAGAN (STSCI), A. M. KOEKEMOER (STSCI); SEXTANS A: NASA, ESA, CSA, ELIZABETH TARANTINO (STSCI), MARTHA BOYER (STSCI), JULIA ROMAN-DUVAL (STSCI); IMAGE PROCESSING: ALYSSA PAGAN (STSCI)

▲ **COSMOCHEMISTRY** The dwarf galaxy Sextans A contains small clumps of polycyclic aromatic hydrocarbons (PAHs), large carbon-based molecules that can be a hallmark of star formation. The dwarf is chemically primitive overall, similar to galaxies in the early universe.

funding during development fed a vicious cycle that pushed the price tag from approximately $5 billion to $9 billion. For nearly 20 years, $1 out of every $3 that NASA spent on astrophysics went to the JWST program. And that doesn't include (much smaller) contributions from the European and Canadian space agencies.

Of course, JWST isn't alone in this stumbling; Hubble suffered its own cost overruns, as have other projects. Science takes money and time, neither of which looks good on budget spreadsheets.

And considering what JWST has accomplished so far, you'd be hard-pressed to find an astronomer who'd say the cost wasn't worth it. Boasting 10 times better resolution and 100 times better sensitivity than previous telescopes operating at similar wavelengths, the observatory is giving us an unprecedented look at the infrared sky. Webb is expanding our knowledge on every front, from the solar system to the early universe. Many of these insights come from spectroscopy — in fact, some 75% of JWST's time is spent on spectroscopy, not imaging.

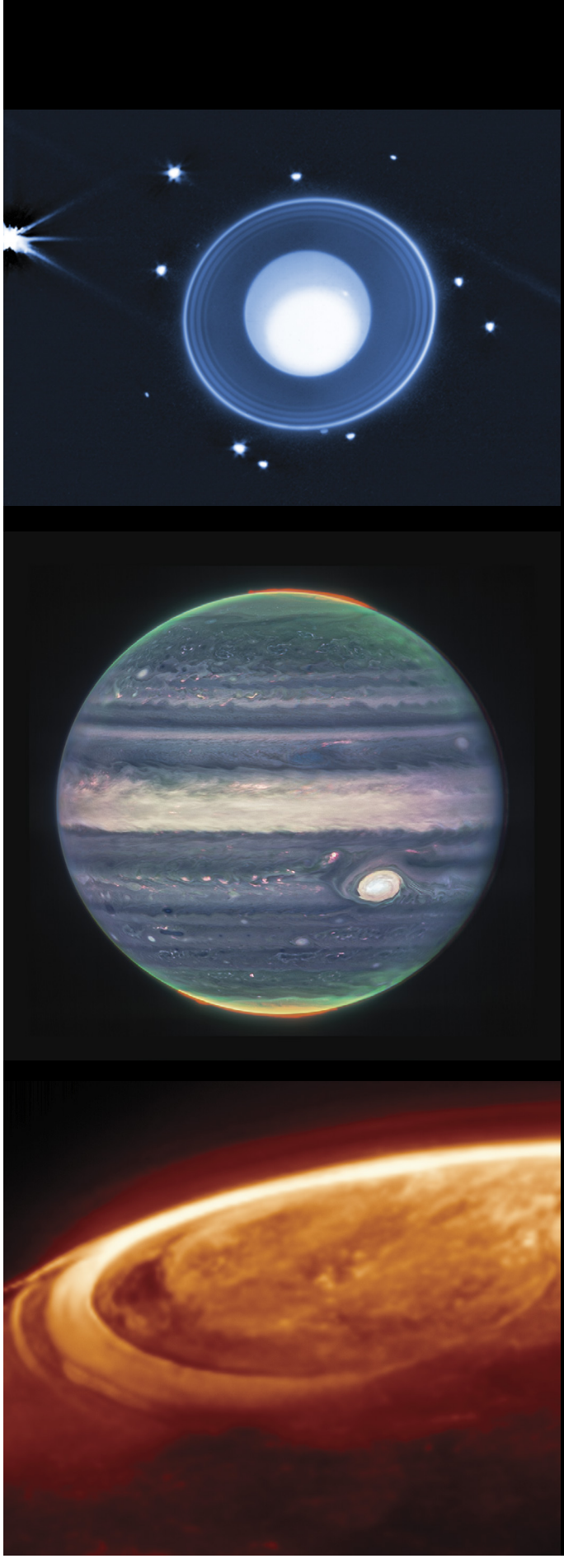
In celebration of JWST's five-year anniversary, let's take a tour of the telescope's greatest science hits thus far. This overview comes thanks in large part to a list compiled for us by project scientist Macarena García Marín (European Space Agency), who works at JWST's science operations center at the Space Telescope Science Institute in Baltimore. I've also sprinkled in others' insights.

The Sun's Entourage

JWST has given us brilliant infrared views of the solar system. We've seen the giant planets hanging like Christmas baubles in the velvety expanse of space. We've had new views of rings and clouds, and we've even discovered a Uranian moon.

The Cassini orbiter previously found geysers spewing from Saturn's moon Enceladus. JWST data show the water vapor stretches some 10,000 km (6,000 miles) in a vast plume that feeds a fat ring around the planet. The rate at which water gushes forth matches what Cassini saw 15 years prior, indicating Enceladus steadily spills water molecules along its orbit.

JWST has also measured carbon dioxide ice on the surface of Jupiter's moon Europa, concentrated in a geologically



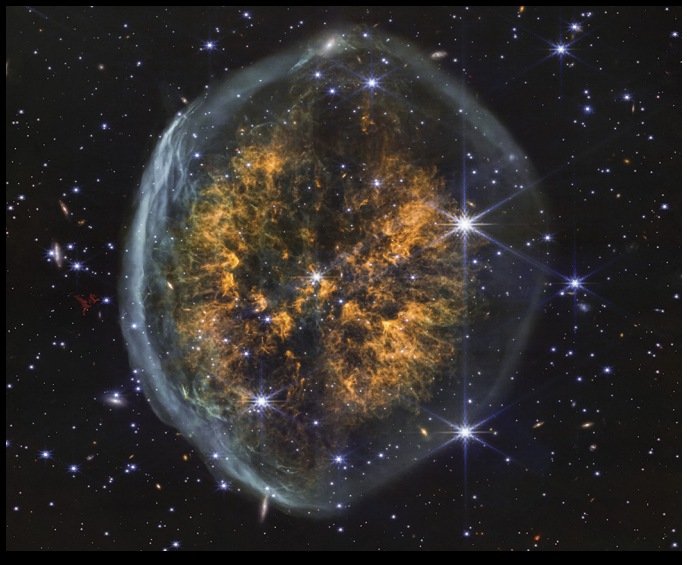
NEW MOON: NASA, ESA, CSA, MARYAME EL MOUTAMID (SWRI), MATTHEW HEDMAN (UNIVERSITY OF IDAHO), IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI); JUPITER FULL: NASA, ESA, JUPITER ERS TEAM, IMAGE PROCESSING BY JUDY SCHMIDT; AURORAL OVAL: ESA / WEBB, NASA, CSA, J. NICHOLS (UNIV. OF LEICESTER), M. ZAMANI (ESA / WEBB)

▶ **NEW MOON** *Top:* This image from JWST's Near-Infrared Camera (NIRCam) shows the newly discovered Uranian moon, S/2025 U1, as a very faint dot at the 10 o'clock position, just outside the rings. Glimmering with it here are 12 of the 28 other known satellites. (Technically, the total shown here is 13, but Cordelia orbits just inside the outermost ring and is invisible due to ring glare.)

▶ **JUPITER** *Middle:* Seen here in near-infrared wavelengths, Jupiter's atmosphere is alight with features. Red marks aurorae, as well as light reflected by lower clouds and upper hazes. Yellows and greens show haze swirling around the northern and southern poles. Blue corresponds to light from deeper clouds, and white to highly reflective clouds.

▶ **SKIES AGLOW** *Bottom:* A closer look at Jupiter's aurorae, catching near-infrared emission from molecular hydrogen ions that are created by the impact of high-energy electrons.





young region of *chaos terrain*, where the satellite's icy shell appears to be fracturing and refreezing. This CO_2 ice is the first strong observational evidence that carbon in Europa's subsurface ocean is weaseling its way to the surface. Nevertheless, there's currently no sign of an Enceladus-like plume: A recent reanalysis of HST data suggests that the water leak planetary scientists thought they saw in 2013 isn't real.

Using JWST, astronomers have determined that the near-Earth asteroid 2024 YR_4 won't hit the Moon when it passes in 2032. Amateurs came to the same conclusion, using archival data from ground-based observatories (*S&T:* July 2026, p. 9). The news was a bummer for those hoping to catch the impact's flash (*S&T:* June 2026, p. 56).

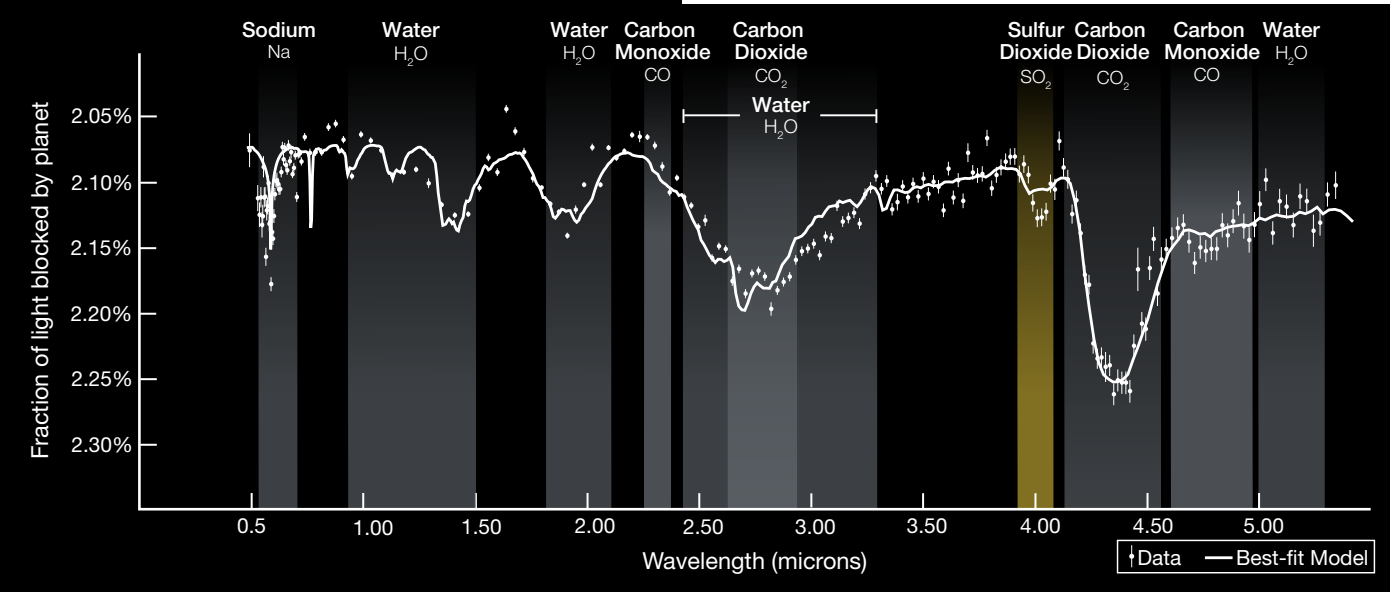
Worlds Around Other Stars

Exoplanets are one of the hottest research topics these days — just check out the session titles at big astro conferences, and you'll see what I mean. Scientists have been waiting for years to turn JWST on their favorite alien worlds, and they're finally reaping the benefits.

Researchers have found an array of molecules in exoplanet atmospheres, including sulfur dioxide in the air of WASP-39b, a gas giant huddled around a Sun-like star some 700 light-years away. Sulfur dioxide can't last long at WASP-39b's temperatures; the fact that we're seeing it means it's actively being replenished. The star's ultraviolet rays must create the

◀ **CRANIUM NEBULA** Created by a dying star's outbursts, this nebula captures different phases of the star's evolution: an outer shell of gas that was blown off first and consists mostly of hydrogen, and an inner cloud with more structure that contains a mix of different gases. The top image is mid-infrared, bottom is near-infrared.

▼ **EXOPLANET CHEMISTRY** This first transmission spectrum from the gas giant WASP-39b, taken when the planet passed in front of its star and the starlight filtered through the atmosphere, unexpectedly revealed the compound sulfur dioxide.



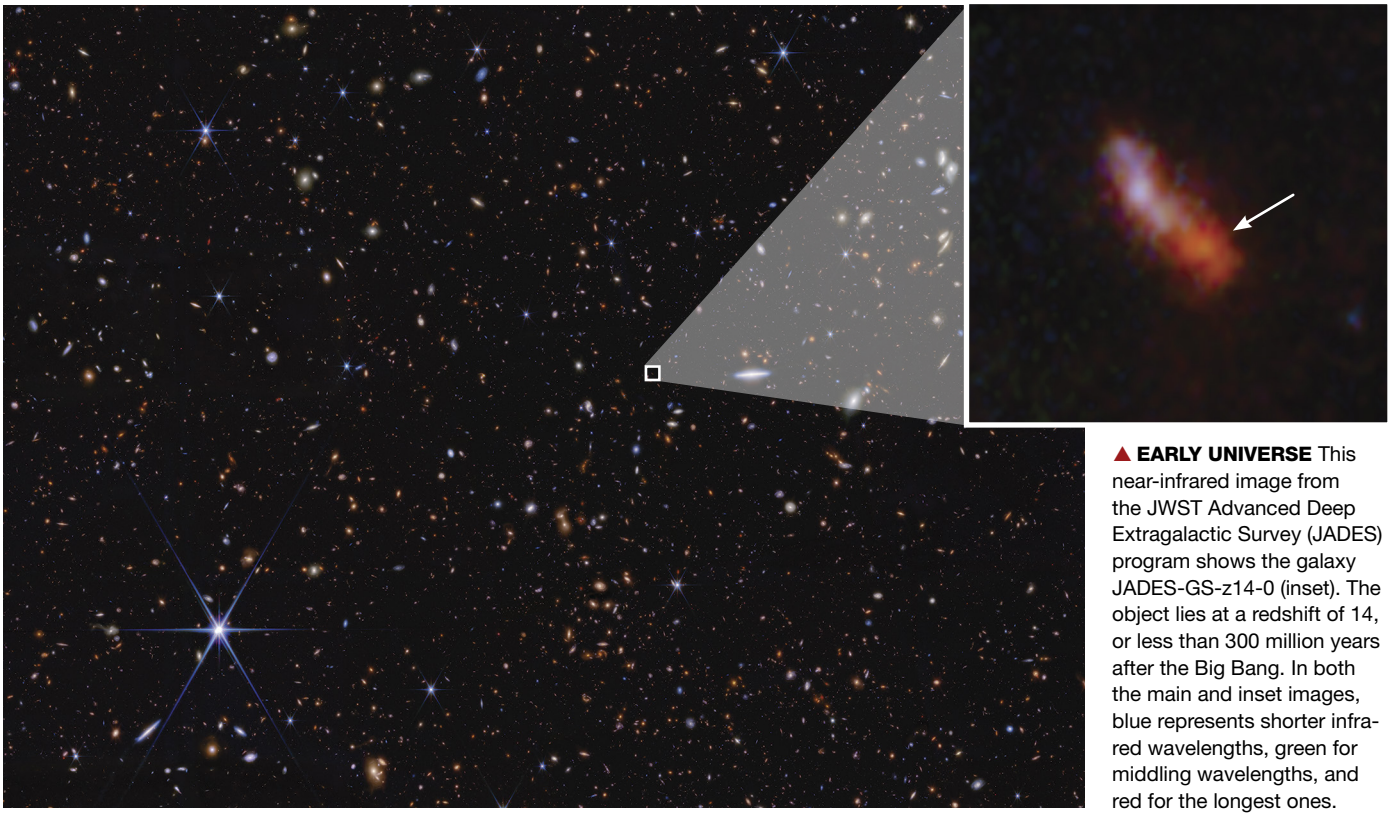
CRANIUM (2): NASA, ESA, CSA, STSCI, IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI); SPECTRUM: NASA, ESA, CSA, JOSEPH OLMSTED (STSCI), ADAPTED BY BEATRIZ INGLESSIS / S&T



▲ **SKELETAL STRUCTURE** This image combines infrared (JWST, top left) and visible and ultraviolet (HST, bottom right) observations of the barred spiral galaxy NGC 1512, observed as part of the Physics at High Angular resolution in Nearby Galaxies (PHANGS) program, which studies all phases of the star-formation cycle. The gas and dust stand out in orange and red in the JWST image, whereas in the HST image the dust is dark because it's absorbing the visible and ultraviolet light HST detects. Knots in the ring in the JWST image mark regions of star formation.



▲ **CLUSTERS EMERGE** This near-infrared image shows a section of one of the spiral arms of M51, where young, dense star clusters are eating their way out of their natal gas. The larger study looked at nearly 9,000 clusters of different ages in four galaxies and determined that the most massive clusters clear away the surrounding gas fastest.



▲ **EARLY UNIVERSE** This near-infrared image from the JWST Advanced Deep Extragalactic Survey (JADES) program shows the galaxy JADES-GS-z14-0 (inset). The object lies at a redshift of 14, or less than 300 million years after the Big Bang. In both the main and inset images, blue represents shorter infrared wavelengths, green for middling wavelengths, and red for the longest ones.

NGC 1512: NASA, ESA, CSA, STScI; PHANGS TEAM, JANICE LEE (STScI), THOMAS WILLIAMS (OXFORD); M51 ARM: ESA / WEBB, NASA & CSA, A. PEDRINI; A. ADAMO (STOCKHOLM UNIVERSITY) AND THE FEAST JWST TEAM; EARLY GALAXY: NASA, ESA, CSA, STScI, BRANT ROBERTSON (UC SANTA CRUZ), BEN JOHNSON (CfA), SANDRO TACCHELLA (CAMBRIDGE), PHILL CARGILE (CfA)

molecule in the planet's atmosphere — proof of active photochemistry on an exoplanet (*S&T:* Dec. 2024, p. 34).

JWST has also looked at the atmospheres of tidally locked planets. These worlds always point the same face at their suns, leaving the other hemisphere in perpetual darkness. Observations reveal that the planets' eternal evenings are hotter and clearer than their cooler, cloudier mornings.

At the other end of the size scale, astronomers are looking at rocky planets around red dwarfs, the pipsqueaks of the stellar family. Red dwarfs are small and faint, making it easier to spot small planets' atmospheres — if the gas is there, that is.

And sometimes, it isn't. Scientists have found atmospheres around the rocky planets 55 Cancri e and TOI-561b; the former might include outgassing from a magma ocean. On the other hand, they've seen not a whiff of gas around the three innermost worlds of the TRAPPIST-1 system. This seven-planet system has enticed astronomers since its discovery a decade ago, but JWST may be torpedoing hopes that its rocky worlds would prove habitable. (The hunt for an atmosphere around the middle planet, e, is as yet inconclusive.)

Looking at the larger collection of observed worlds suggests that Venus-like atmospheres are rare for warmish rocky planets around red dwarfs, Laura Kreidberg (Max Planck Institute for Astronomy, Germany) said earlier this year during a talk at the Harvard & Smithsonian Center for Astrophysics. "And that is already a profound statement," she added. "We could not say anything about which atmospheres are possible prior to the launch of JWST."

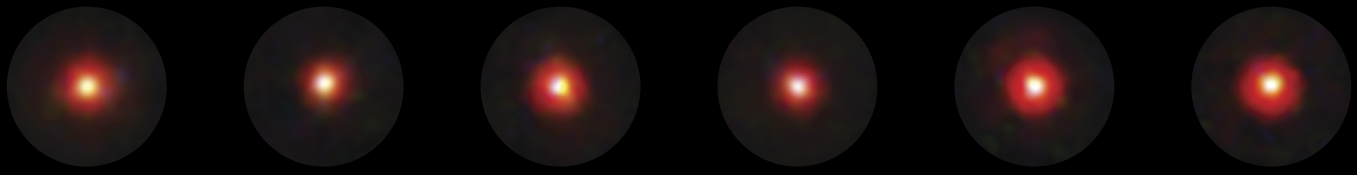
Roll Back the Clock

JWST's chemical reach extends beyond exoplanet atmospheres to material that will form planets and stars. It has turned up key building blocks for *complex organic molecules*, compounds that form the foundation of biochemistry as we know it (*S&T:* Oct. 2026, p. 62).

The infrared eye has also revealed galaxies' skeletal structures, including the dusty filaments that trace spiral arms and the bubbles that stars carve out in surrounding gas. It's found young star clusters eating their way out of their natal cocoons in nearby galaxies and helped astronomers determine that the process takes several million years.

Stars make the heavy elements in the universe, things like iron and calcium. The farther back in time we look, the less time stars have had to churn out these metals. JWST has found fairly pristine gas — and signs of stars forming from that gas — in the universe's first 500 million years. These discoveries include a protogalactic cloud of helium and hydrogen lit up by what might be the first generation of stars (*S&T:* Sept. 2026, p. 11).

Results like these from the early universe have provided some of the most eye-catching science. For example, JWST has spied compact concentrations of young stars within the first several hundred million years, which appear to be nascent globular clusters in small, fledgling galaxies. Such clusters might have played an important role in ionizing the hydrogen fog that filled the universe at the time. This era, called the *epoch of reionization*, is kind of like the end of a cosmic ice age: High-energy photons tore electrons off hydrogen



▲ **LITTLE RED DOTS** Mysterious sources in the early universe, little red dots emerge in large numbers around 600 million years after the Big Bang and undergo a rapid decline about 1 billion years later. They may be an early growth phase of supermassive black holes, during which the beasts are shrouded in cool gas.



▲ **COSMIC LENS** The immense gravity of the galaxy cluster Abell S1063, lying 4.5 billion light-years from Earth, bends and magnifies light from far more distant galaxies (orange shapes), making it possible for astronomers to see the lensed objects as they were a few hundred million years after the Big Bang. This deep image combines some 120 hours of observing time.

atoms, transforming the cosmic landscape and making the universe transparent — a transparency that enables us to look more than 13 billion years across cosmic time.

Reaching far into this past, observations by both JWST and the Atacama Large Millimeter/submillimeter Array (ALMA) indicate that galaxies in the early universe evolved faster than we expected. Astronomers have found well-developed disk galaxies as well as ones that seem to be in their golden years, both within the universe's first billion years or so. Whereas once we had only a rudimentary picture of this period, we're now scooping up galaxies beyond a redshift of 10, or some 500 million years after the Big Bang.

Myriad Little Mysteries

No roundup of JWST results would be complete without my favorite thing: black holes.

The telescope has given us a new look at galaxies' dark hearts, revealing the environments surrounding supermassive black holes and how these objects expel and feed on gas.

Before JWST, astronomers weren't finding "enough" black holes scarfing down gas in early galaxies' cores, said Jenny Greene (Princeton) at a recent conference. Now, there might be too many colossi too quickly, with some appearing to be "too big" for their galaxies. If true, this discovery causes uncomfortable complications for our understanding of how these objects beefed up over time. But astronomers disagree as to whether we're overestimating the objects' masses — if we are, then this problem goes away, she said.

One of the most exciting JWST discoveries has been *little red dots* (*S&T:* May 2024, p. 20). These compact, rosy sources are abundant within the universe's first billion years or so, then dwindle. They blaze with the light of an entire galaxy yet are less than 100 light-years wide, comparable to the size of a single star cluster.

To many researchers, the easiest way to explain so much light in so tight a space is with a fat, madly feeding black hole. But the full details of the dots' spectra haven't matched any scenario, and astronomers don't agree on what little red dots actually are. Ideas range from black holes shrouded in gas (the leading contender) to intense starbursts.

"This has been one of the most exhilarating times in my career, because it's the only time when we have found a phenomenon that we have not seen before, for which we do not actually have an explanation yet," Greene said. "And that has truly been fun."

■ Science Editor **CAMILLE M. CARLISLE** now struggles to pick between simultaneous JWST results sessions at conferences.

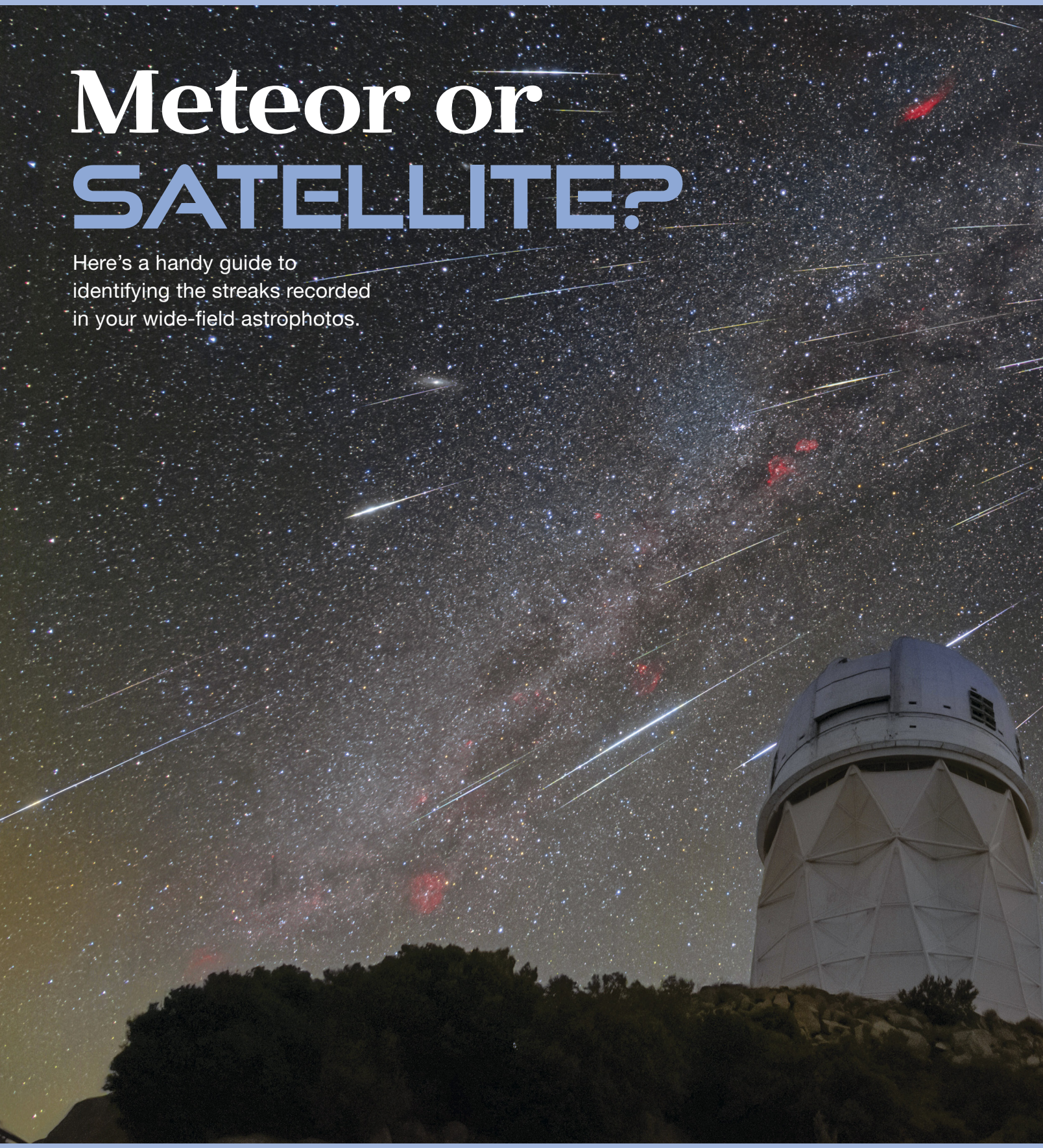


RED DOTS: NASA, ESA, CSA, STSCI, DALE KOCEVSKI (COLBY COLLEGE); S1063: ESA / WEBB, NASA & CSA, H. ATEK; M. ZAMANI (ESA / WEBB); NGC 602: ESA / WEBB, NASA & CSA, P. ZEIDLER, E. SABBI, A. NOTA, M. ZAMANI (ESA / WEBB)

▲ **STAR FACTORY** The young star cluster NGC 602 lies in the outskirts of the Small Magellanic Cloud, a galaxy some 200,000 light-years from Earth, in an environment that's more chemically primitive than what we find in the solar neighborhood. Astronomers used JWST to detect within this cluster the first brown dwarf candidates found outside the Milky Way.

Meteor or SATELLITE?

Here's a handy guide to identifying the streaks recorded in your wide-field astrophotos.





SHOWERING SPLENDOR
Dozens of Geminid meteors streak across the sky above the 4-meter telescope at Kitt Peak National Observatory in 2025. While all of these trails are easily identifiable as shooting stars, today's sky full of artificial satellites makes it difficult to tell the difference.

KPNO / NOIRLAB / NSF / AURA / R. SPARKS

Digital cameras and smartphones have fully democratized night-sky photography. What used to require specialized knowledge and processing techniques, not to mention expensive gear, is now simplified (and partly automated) to the point that anyone can do it. The resulting torrent of astrophotos appearing on social media in recent years demonstrates that legions of newcomers are finding great enjoyment and satisfaction in making images of the stars. More power to us!

But as with any subject that moves from specialists to the general public, misinformation sometimes goes along for the ride. As ever more night-sky images pop up on social media, I often encounter artificial satellites or orbital debris misidentified as meteors or even comets. Is it any wonder? So many satellites crisscross my own pictures — notably when I'm photographing meteor showers and aurorae — that I'm sometimes scratching my head trying to tell one from the other. Like it or not, the proliferation of Earth-orbiting satellites in recent years has compelled us all to contend with this increasing celestial mechanization.

If you're scanning the sky with your own eyes, it's generally easy to tell the difference between meteors and their mimics. Satellites, space stations, and other orbiting debris move much more slowly, with many visible for a minute or longer. That's enough time to alert a companion to look up and see it for themselves. With rare exceptions, such as earthgrazing meteors that lazily skim the upper atmosphere, most meteor trails are swift and last less than a second. By the time you've alerted your neighbor, the thrilling sight is long gone.

But it's a different story with a camera. Leave the shutter open for, say, 10 or 30 seconds, and you're likely to capture a trail from at least one low-Earth-orbiting satellite, if not more. Trail lengths in that time range generally vary from about 1° to 15° depending on the observer's line-of-sight distance to the satellite. Most meteors leave shorter trails, typically 5° or less, but it's not unusual to see at least a few cover 10° to 20° of sky. Either way, their span generally overlaps those etched by satellites.

When photographing a rich meteor shower like this month's Geminids, it's pretty much guaranteed that you'll have a mix of both in your images, with the satellites far outnumbering the meteors. And to the untrained eye they're sometimes hard to tell apart. Both leave straight tracks and share other similarities. Let's look at a few ways to distinguish cosmic rocks from their mechanical imitators.

Profile and Shape

When sifting through meteor shower images, the first thing I pay attention to is the trail's shape. Satellite trails often begin and end abruptly as they enter and exit Earth's shadow and display consistent width from start to finish. They look like straight lines drawn with a ruler and snipped at the ends with scissors.

A meteor trail exhibits a different profile — faint at first

as the *meteoroid,* a particle of space rock usually about the size of a grain of sand, first encounters the atmosphere, then becoming much brighter as its kinetic energy is rapidly converted to heat via ram pressure (air compression). The heat vaporizes the particle, the atoms of which collide with and ionize the surrounding air molecules to create a bright, brief streak of light that quickly fades. A meteor's faint-bright-faint profile resembles a toothpick with sharp ends and a thick middle that sets it apart from typical flat-ended satellite trails. Ah, were it so easy! *Flaring* satellites make even better meteor mimics.

Satellite flare events occur when the angle between a satellite, observer, and the Sun results in a brilliant reflection from a shiny surface like a solar panel array or antenna. In our everyday lives we witness similar glints from metal and glass surfaces as we move about our environment. Most satellite flares brighten, climax, and fade, similar to a meteor but much slower, lasting for several seconds or more. Meteor bursts are momentary, spanning a fraction of a second. Again, if seen by eye there's no question about identity.

Fortunately, flaring satellites tend to continue along their paths after a briefly brightening and remain visible for a time. Your photo will show the satellite's regular trail resuming after the burst and you can confirm it's a flaring satellite by examining the trail's squared-off beginning or end. Most meteors flare at or near the end of their run and then terminate.

Color vs. Monochrome

Satellites shine by reflected sunlight and often appear white to the eye and in photos. There are exceptions. The International Space Station (ISS) glows pale yellow from the amber-colored Kapton film used in solar panels and as insulation for the spacecraft. There are roughly a handful of satellites, including several in China's Qianfan constellation, that exhibit a distinctly ruddy hue. The next time the ISS makes a series of passes across your local sky, check NASA's app (**nasa.gov/spot-the-station**) or Heavens Above (**heavens-above.com**) for "partial" passes. These occur when the ISS is eclipsed by Earth's shadow. With a pair of binoculars, you can watch it change color from yellow to red while the astronauts onboard experience an orbital sunset. Newer Starlink satellites shine with a blue tint because they're coated with a special dielectric mirror film that reduces their brightness so as to be less bothersome to astronomers.

With meteors, all but the very faint ones show color in time-exposure photographs, and their color profiles are quite different from the occasional vibrant satellite. A satellite's hue is mostly consistent throughout its trail length. A blue Starlink leaves a blue streak. Meteors, on the other hand, not only exhibit a different set of hues — typically green, pink, orange, and red — but the color often varies across the trail's length as different chemical elements vaporize and emit light.



NEEDLE IN A HAYSTACK Can you find the real meteor? It's the colorful streak in the center ending in a terminal burst. The rest are flaring Starlink satellites clustered low in the eastern sky a couple of hours before dawn. During the exposure, the two brightest satellites gradually flared to around magnitude –1.5 and then faded. Others were caught brightening (upper left) or fading (lower left).

BOB KING





The most common sequence I've seen in meteors is a green-to-pink transition. Excitation of atmospheric oxygen when the object first enters the atmosphere is often responsible for the green color, which changes to pink/red as it slows down. Magnesium and nickel, both of which are common materials in meteorites, can also tint a meteor green. Speed varies the colors, too, with red more commonly seen in slower-moving meteors.

Among the most colorful objects festooning your long exposures will be airplanes. They're equipped with navigation lights – green on the right wingtip, red on the left, and white on the tail. These lights remain on constantly. Red anti-collision lights mounted on the top and bottom of the fuselage flash multiple times a minute. Bright, white strobes on the wingtips

◀ **ORBITING OUTPOST** *Top:* The International Space Station (ISS) is the brightest and most familiar satellite. Its track displays squared-off ends, and, in this example, uniform brightness. Time exposures that record a longer path will often show variations in the trail's brightness due to the spacecraft's changing distance and Sun angle with respect to the observer. The ISS also exhibits occasional flares, when sunlight reflects at just the right angle off its solar arrays.

◀ **GLINT, NOT BURST** *Bottom:* When the Sun-satellite-observer geometry is just right, some satellites produce bright flares. Since most flares last seconds compared to a meteor's fleeting bright phase, it's easy to tell the two apart with your eye. In photos, they tend to appear monochromatic, which reveals their artificial nature.



TAPERED ENDS Satellite trails like this example (left) etch a bright, linear trail with a crisp start and finish. A Perseid meteor (right) displays a reddish color and a spindle shape with sharp, pointy ends.

BOB KING (3)

provide additional aircraft visibility. Redundant, repeating, and colorful airplane lights are easy to identify. Sometimes their Morse-code-like trails add interest to night-sky pictures.

Continuity Across Multiple Frames

When photographing meteor showers, the best strategy is to take hundreds of consecutive images with a DSLR or mirrorless camera and a fast lens in the hope of catching as many meteors as possible. Or maybe even just one good one. While scanning each frame for streaks with telltale faint-bright-faint profiles or those that end in a bright terminal burst, you're sure to find copycats. Weed them out by looking for color and squared-off ends as previously discussed. Also, double-check to see if the trail appears on multiple frames. If so, you can completely ignore it. Meteors rarely last longer than a second (the average is 0.4 second), so capturing the same one in two frames almost never happens.

I frequently capture bright-headed pseudo-meteors in longer, sequential time exposures. In the first frame, the satellite trail is uniformly bright, but by the start of the next exposure it begins to fade. In that second frame, the impostor will appear to have a bright, meteor-like head at the start of the exposure, followed by a fainter trail. When you flip back and forth between the two frames it's immediately obvious you're looking at the same satellite captured in back-to-back images.

When photographing a meteor shower, there's an additional way of weeding out the satellites from genuine meteors. Random, or *sporadic*, meteors appear anywhere in the sky, but the paths of shower members always trace back to the *radiant*. This is the point in the sky where shooting stars in a known shower appear to come from (as in the beautiful example shown on pages 22–23). While radiant-tracing is helpful in distinguishing between the two kinds of meteors, you can use this criterion as yet another way to filter out look-alikes.

A Night at the Races

Starlink satellites frequently flare one after another low in the western sky (approximately 10° to 15° high) for a couple of hours after the end of dusk and again in the eastern sky in the wee hours of the morning, following similar paths like cars on a racetrack. These objects are dim to begin with but quickly brighten, sometimes rivaling Jupiter and Venus before fading away.

While Starlinks often exhibit the faint-bright-faint profile of meteors, their lack of color, long duration, and clustering behavior expose them as artificial. Newcomers to astrophotography who happen to stumble across them may think a meteor shower is underway. Either that or an alien invasion. I'm not kidding. A concerned skywatcher once called me, convinced these UFOs (a.k.a. Starlinks) he watched night after night in the northwestern sky were up to no good. There's no question they look eerie. Seeing them slowly flare and fade is mesmerizing, like watching helicopters with searchlights nose around a crime scene.

Tumbling Satellites

Remember the tool bag that slipped away from ISS astronauts during a November 2023 spacewalk? That small, suitcase-sized object circled the Earth as a surprisingly bright, tiny satellite until it reentered the atmosphere four months later. Through binoculars it looked like a slowly flashing 6th-magnitude star as it tumbled along in its orbit.

Defunct satellites, spent rocket boosters, payload hardware, and even paint flecks flash as they tumble uncontrol-



▲ **MONOCHROMATIC TELL** While most satellites appear white to both the eye and camera, some Starlink satellites shine blue (seen at left). There are also a few that glow orange and red, such as the unidentified one at right from April 19, 2026. It alternately brightened and faded from view in four sequential images.

BOB KING (2)

lably around the Earth. A glint occurs when a flat surface catches the Sun just so and reflects it back to the observer's eyes or their camera's lens. Some satellites produce steady, rhythmic flashes, while others pulse at irregular intervals.

Larger meteoroids occasionally tumble as they enter the atmosphere, causing their light to vary or flicker during descent. When a space rock penetrates more deeply into the atmosphere, rapidly increasing air pressure may lead to explosive fragmentation and brilliant, firecracker-like flares. Most of these occur as terminal bursts at the end of the meteoroid's bright flight. Satellite flashes, on the other hand, tend to recur at regular intervals along the entire visible path. If in doubt, apply additional criteria such as tapered ends, color profile, and continuity on subsequent frames to distinguish between them.

Look It Up

If you think you've captured a satellite you can use online resources in order to determine its identity. As long as you know the area in the sky it passed through, the direction of its movement, and the approximate time when you took the photo, go to the Heavens Above website. The site should recognize your correct location automatically but if it doesn't, select it by clicking the link in the top-right corner. Then under the Satellites listing, click the "Daily predictions for brighter satellites" link. Choose the date of your observation, and set the minimum brightness to 5.0 to pull up the maximum number of targets. Scan the pass times for one that fits your observation, and then click on the name of the satellite you suspect you saw for a star map showing its track.

Applying each of these different criteria, you'll be able to tell a meteor from a satellite in most of your photos. Occasionally a trail resists my best efforts, especially when I'm shooting sky phenomena like aurorae and conjunctions by taking single frames minutes apart. But I soldier on. You may discover that being a meteor detective has its small joys. If you like solving these photographic puzzles, I've got good news. Tens of thousands more satellites will be launched in the next decade, guaranteeing tons of maddening fun!



▲ **MULTICOLORED TRAIL** A bright Geminid meteor from 2021 displays pink and green colors and a spindle-shaped trail, typical of many meteors. Meteors can also exhibit irregular fluctuations in light along their paths, as well as bright terminal flares.

■ Contributing Editor **BOB KING** enjoys observing and photographing night-sky events from the dark skies of Minnesota and identifying the trails frequently recorded in his pictures.





▲ **SEQUENTIAL REVELATIONS** Two consecutive 25-second time exposures confirm that this trail belongs to a single satellite. In the second frame at right, the satellite continues along the same path but this time resembles a meteor, with a brighter "burst" and fainter tail. The fact that both trails are truncated and colorless further helps to identify it as artificial.

SEAN WALKER (3)



Mapping the Invisible

An unseen force shapes the universe at many different scales.

Magnetic fields are everywhere. Earth's field deflects the solar wind. The Sun's field helps propel that wind and also launches billion-ton clouds of plasma into the solar system. Across the galaxy, diffuse fields weave through molecular clouds, star-forming regions, and the hot gas halo the Milky Way sits in.

Magnetism extends far beyond this, too. In galaxy clusters, where hot, X-ray-emitting plasma permeates the space between the galaxies, fields stretch across millions of light-years, threading the plasma the way veins run through a body. Even the filaments connecting galaxy clusters appear to carry fields that are coherent across tens of millions of light-years.

None of this is decorative. Magnetic fields regulate gas flows, channel energy between wildly different size scales, and resist compression in ways that have no analog in ordinary fluid dynamics.

"If you think about fluid dynamics, about stirring a coffee, about a waterfall," says Sergio Martin-Alvarez (Stanford University), "you would never imagine that there's any effect whatsoever that is like a rubber band, effectively pushing against the direction of the motion." That magnetic tension is present everywhere in the universe, at every scale, all the time. It smooths out the flow of plasma. It resists the disruption of spiral arms. It slows the collapse of gas clouds

▲ **MAGNETIC SKY** This composite image shows magnetic fields (red and blue) along our line of sight across the sky, detected by their effect on light from distant galaxies as it traveled to the Australian Square Kilometre Array Pathfinder radio telescope in Australia, a precursor instrument to the Square Kilometre Array. Red marks where the fields point toward us, blue away. The Milky Way's magnetic field dominates the sky. Maps like this one reveal that our galaxy's field mostly spirals clockwise (the same direction as the arms) except for in the Sagittarius Arm, where for reasons unknown the field points counterclockwise.

CSIRO / ALEC THOMSON ET AL. / ALEX CHERNEY / SAM MOORFIELD

that would otherwise cave in far too quickly.

Astronomers have known about cosmic magnetic fields since the late 1940s, when John Hall and William Hiltner both noticed that starlight was polarized in a pattern that made no sense unless interstellar space was threaded with an ordered field. That's more than 70 years of awareness. But knowing a field is there is not the same thing as actually measuring it.

"Magnetic fields in the interstellar medium are kind of like dark energy in cosmology," says Qizhou Zhang (Center for Astrophysics, Harvard & Smithsonian). "You don't see it, you don't feel it. It's difficult to observe, but you see the effect."

That comparison cuts deeper than it might appear. Cosmologists spent decades assuming the *cosmological constant* (dark energy's simplest form) was zero, until distant supernovae revealed cosmic acceleration in the late 1990s (*S&T:* Feb. 2024, p. 26). Magnetic fields are further along — we know they're real, we know they matter — but how much they matter, at what scales, and where they originally came from remain genuinely open questions.

Every field we see today might have been built from scratch, forged by dying stars and feeding black holes over 13 billion years. Or all those discrete fields might share a common origin, a seedling that sprouted everything else (*S&T:* Sept. 2021, p. 22). We don't know if the universe was born with a magnetic field — even the cosmic microwave background, our sharpest all-sky view of the early universe, only loosely constrains how strong such a field might have been. It is, as Martin-Alvarez puts it, "one of the properties of the cosmological model that we don't talk about." Given what we're starting to learn, that silence is hard to justify.

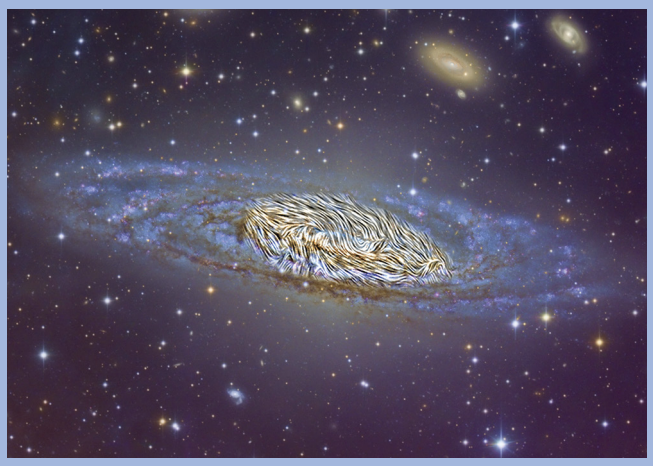
The Art of the Indirect

A magnetic field is a region of force generated by moving electric charges — which in space usually means churning plasma or streaming particles. A field pushes, pulls, and twists anything else charged that moves through it. You can't see it directly. But ignore it at your peril.

The most direct route to measuring a field's strength is by utilizing the *Zeeman effect*. When a light source lies within a magnetic field, the field splits the light's spectral lines into multiple components, slightly separated in wavelength. Measure the splitting, determine the field strength. In principle, it's easy-peasy.

In practice, it's brutal. In the dense molecular clouds where stars form, for example, the magnetic splitting is typically narrower than the intrinsic width of the spectral line itself, Zhang says. Even with the Atacama Large Millimeter/submillimeter Array (ALMA), which is the most sensitive telescope ever built for those wavelengths and excellent at studying these regions, confirmed Zeeman detections in star-forming gas remain rare.

Because direct Zeeman measurements are so difficult to make, the community has learned to work around them. The key realization is that magnetic fields don't just push



▲ **NGC 7331** Using the Stratospheric Observatory for Infrared Astronomy (SOFIA), astronomers detected magnetic fields in several galaxies, three of which appear here. The results show that magnetic fields are always present in galaxies' cold, dense interstellar medium.



▲ **MESSIER 77** SOFIA's observations show that magnetic fields appear to trace the spiral arms in M77's inner regions. The arms likely mark density waves in the spiral disk. The underlying image combines X-ray and visible-light observations.



▲ **MESSIER 82** The magnetic fields in this starburst galaxy follow the outflowing "wind" (red) generated by the intense star formation in the galaxy's heart. Gray is visible starlight, red is hydrogen gas, and yellow is the infrared glow of stars and dust.

NGC 7331: VICENT PERIS, CC BY-SA 2.0 / E. LOPEZ-RODRIGUEZ; M77: NASA / SOFIA, NASA / JPL-CALTECH / ROMA TRE UNIV.; M82: NASA / SOFIA / E. LOPEZ-RODRIGUEZ, NASA / SPITZER / J. MOUSTAKAS ET AL.

on charged matter — they also affect light that's passing through them. These effects carry information about the fields themselves.

Polarized radio waves twist as they pass through magnetized plasma, for example. The rotation angle of this *Faraday effect* encodes field strength along the line of sight. By mapping the rotation across many background radio sources, astronomers can reconstruct large-scale field structure.

Magnetic fields also affect light sources themselves. Elongated dust grains in the interstellar medium rotate perpendicular to the ambient field, which slightly polarizes the glow the grains emit due to their own warmth. Read the polarization angle of this dust emission, read the field geometry.

Neither method directly tells us how strong a field is; both carry assumptions. Such assumptions can lead to overestimating the field strength by factors of a few.

These methods aren't new: Interstellar dust polarization was first detected in the late 1940s, and Faraday-rotation mapping of cosmic fields followed in the 1960s. What has changed is better hardware and scale. Zhang himself turned down a magnetic fields project as a graduate student in the 1990s because the instrumentation simply wasn't ready.

"At that point, it was very, very difficult to observe," he says. "There was very little we could do just because of limited sensitivity."

He came back to the problem a decade later, when the Submillimeter Array (SMA) in Hawai'i gave him the tools to map polarized dust emission across star-forming regions at useful resolution. ALMA followed the SMA, and before its retirement in 2022, the Stratospheric Observatory for Infrared Astronomy (SOFIA) mapped dust polarization across dozens of molecular clouds through large, dedicated programs (*S&T:* Apr. 2023, p. 12).



With enough measurements, astronomers can do statistics. With statistics, patterns emerge that were invisible when each observation stood alone. The field can now ask not just "Does this cloud have a field?" but "How does the field across an entire population of clouds relate to their mass, turbulence, and star-forming activity?"

The Fight Over Star Formation

The universe is surprisingly bad at making stars. Galaxies hold vast reservoirs of gas but convert only a tiny fraction of it into new suns every year — far less than raw physics would predict. Something is hitting the brakes. The question is what. For decades, two camps have disagreed on the answer.

In one corner: Magnetic fields dominate. Strong fields in star-forming clouds freeze gas in place, allowing only a slow trickle of material across field lines through a process called *ambipolar diffusion* — ions locked to the field gradually separate from neutral gas, allowing the neutrals to drift inward under gravity. In this scenario, stars form slowly and reluctantly, regulated by magnetism.

In the other corner: Turbulence dominates. Supersonic gas motions set the pace, magnetic fields are secondary, and the sheer violence of stirred-up gas motions slows the star-formation rate.

Zhang says that back in the 1990s, the debate deadlocked between two nearly irreconcilable camps. Simulators on one side claimed they could reproduce observations without magnetic fields at all. The magnetically regulated camp said turbulence alone was insufficient. Both sides had data. Neither had enough.

And neither camp has won completely. In fact, both are probably right, depending on where you look.

At the cloud scale — tens of light-years across — surveys now show that magnetic fields carry more energy than the turbulent motions of the gas. That means if the field vanished, the Milky Way's molecular clouds would collapse far faster than they do. "If the clouds don't have magnetic fields to play some kind of role, we should be seeing galaxies like the Milky Way forming a lot more stars than we actually observe," Zhang says. In other words, we're seeing magnetism hitting the brakes.

Go smaller, into the collapsing, dense cores where individual stars are born, and gravity takes over. Above a certain gas density, astronomers see the relationship between field orientation and density structure shift, indicating that magnetic pressure is no longer preventing collapse. The field can still slow things down even then, but it isn't running the show anymore.

◀ **SWIRLING** Streamlines superimposed on an image of the starburst ring in the inner regions of the barred spiral galaxy NGC 1097 show the magnetic fields' orientation on the plane of the sky. Gas streams follow the field, feeding the central black hole.

NASA, THE SOFIA SCIENCE TEAM, E. LOPEZ-RODRIGUEZ ET AL., ESO / PRIETO ET AL.

On the other hand, turbulence has had its victories, too. At the smallest scales, inside the dense, chaotic clumps where the most massive stars form, turbulence may win outright. A study published this year found that, on those scales, the elongated shapes of collapsing gas clumps tend to line up parallel to the local magnetic field. A magnetically dominated collapse would push them perpendicular, with gas piling up against field lines it can't cross. Parallel alignment means turbulence is in charge and dragging the field around, instead of the reverse.

Thus, magnetism's role in star formation is a spectrum. The field dominates at cloud scales, weakens as gravity takes over in dense cores, and may be overwhelmed entirely at the smallest scales. The decades-long argument was asking a question that has different answers depending on where you point the telescope.

The Same Rules, Everywhere

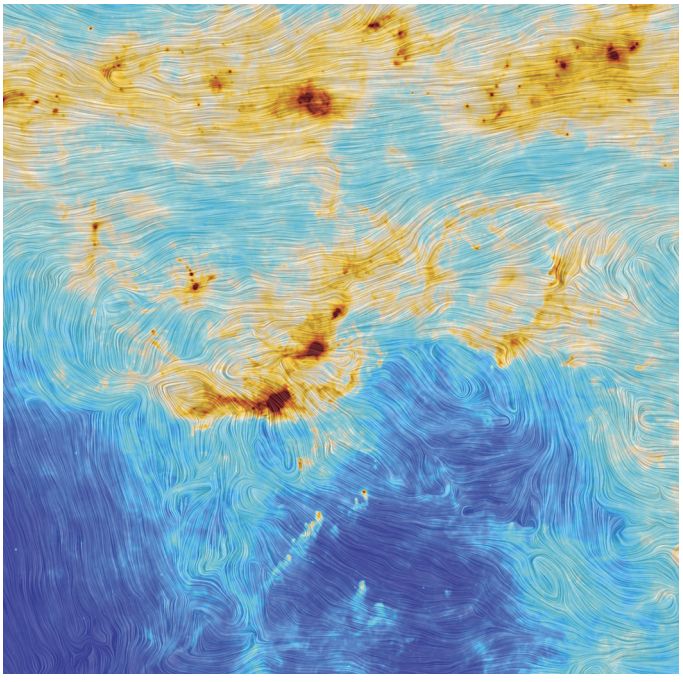
Zoom out from the molecular cloud, and the magnetic field's relationship with star formation flips. Inside a cloud, the field resists collapse — it's a brake. But once stars form and begin dying as supernovae, those explosions amplify the field. The more supernovae, the stronger the field. On the scale of whole galaxies, magnetism stops being a regulator of starbirth and starts being a product of it.

New cosmological simulations from the *Azahar* suite — detailed computer simulations of how galaxies grow, die, and magnetize — find a near-universal relationship between magnetic-field strength and star-formation rate. Across 19 simulated galaxies spanning four orders of magnitude in starbirth activity, from dwarf-mass disks sluggishly forming stars to vigorously star-forming spirals, field strength is proportional to the star-formation rate.

Here's why. Massive stars live fast and die as supernovae. Those blasts churn the surrounding gas. This violent turbulence, it turns out, amplifies whatever weak magnetic field is already present — the churning motions wrap and stretch field lines the way a generator converts motion into electricity. More star formation means more supernovae, more turbulence, and a stronger field.

If enough stars are forming, the field grows until its energy comes into rough balance with the energy of each of the gas's other major reservoirs (such as turbulent motions and heat), a state called *equipartition*. Below a star-formation rate of about one Sun per year (the Milky Way's rate), the field stays in the background, unimportant. But once it becomes strong enough, the field starts pushing back — resisting compression, stabilizing the disk, and influencing the very star formation that built it. It goes from passenger to copilot.

Active galactic nuclei (AGN), the gas-guzzling supermassive black holes at galactic centers, also affect fields on large scales. As they feed, the black holes launch enormous jets of magnetized plasma into the space between galaxies, seeding intergalactic space with fields that amplify as cosmic structures continue to form.



ESA AND THE PLANCK COLLABORATION

▲ **STARBIRTH** The image shows part of the Orion Molecular Cloud complex, as seen via dust emission. The color scale visualizes the dust emission intensity (yellow and red are denser clouds, with larger amounts of dust and gas). The texture indicates the magnetic field's orientation on the plane of the sky. The most prominent red clump lower left of center is the Orion Nebula, M42. While the magnetic field appears neat and organized along the galactic plane at the top of the image, it turns turbulent near the star-forming clouds.

Go out farther into the intergalactic voids, and the field thins but doesn't vanish. A charged particle traveling for thousands of light-years through empty space encounters almost nothing, except a magnetic field so weak it barely registers. But despite its weakness, this field is still enough to slowly deflect the particle's path over cosmic distances. "At those scales," Martin-Alvarez says, "suddenly the field becomes quite important, because it's truly the only thing out there."

Supernovae magnetize molecular clouds. Field lines are locked into the plasma, so gas leaving the galactic disk carries those fields into the halo. AGN jets carry them farther still, into the cosmic web. Each process hands the baton to the next. "Magnetic fields are one of the perfect definitions of an emergent phenomenon," Martin-Alvarez says, "where very small scales really can affect very large ones."

Which brings the story to the question that chain doesn't answer: What was there before the AGN, before the stars, before any of it?

The Hunt for the First Field

The *Lyman-alpha forest* is one of the few tools capable of reaching back far enough to address this question. As light from distant quasars travels across billions of light-years, it passes through clouds of neutral hydrogen, each of which absorbs a specific wavelength of light at 121.6 nanometers,

For a community that has measured the age of the universe to better than ¼%, not knowing whether the universe was born magnetized is, frankly, discomfiting.

called Lyman-α. Cosmic expansion stretches the wavelength of each absorption feature, shifting it redward by an amount dependent on the distance traveled to Earth from the cloud. The resulting thicket of absorption lines encodes the properties of the intergalactic medium between us and the light source — including, potentially, the faint fingerprint of a primordial magnetic field.

If a primordial field existed, it would have left subtle marks on the Lyman-α forest. A magnetic field pushes on charged particles, and the early cosmic soup was full of them. That push would have nudged the gas into slightly denser concentrations than if the field weren't there — a faint statistical excess that would survive and grow, showing up billions of years later as slightly more structure in the forest absorption data than the standard model predicts. The effect is small. Finding it requires enormous statistical leverage.

A recent analysis built that leverage by measuring the Lyman-α absorption in the spectra of 15 distant quasars, each residing at a time when the universe was less than 2 billion years old. The researchers compared those absorption patterns against more than 234,000 simulated versions of the intergalactic medium — each built with different assumptions about gas temperature, how the universe ionized over time, and the strength of any primordial magnetic field.

Initially, the data showed a hint of a field. The absorption patterns had slightly more structure than the standard model predicts — consistent with a primordial field of roughly 0.2 nanogauss, or about one-trillionth the strength of a fridge magnet. The standard model, with no primordial field at all, was ruled out with better than 99% confidence.

Then, the team tried a more conservative approach. They added extra adjustments for measurement noise — one adjustment for each of the three time slices they made of the data. They drew those adjustments from the data rather than from theory. As a result, the hint they thought they'd found became a firm upper limit instead: Any primordial intergalactic field must be weaker than 0.3 nanogauss, at 99.7% confidence.

In other words, the detection dissolved.

Yet the upper limit is the tightest bound yet on primordial intergalactic magnetic fields — an order of magnitude better than constraints based on the cosmic microwave background alone. That's not nothing. But the broader situation is less comfortable. For a community that has measured the age of the universe to better than one-quarter percent, not knowing whether the universe was born magnetized is, frankly, discomfiting.

It gets worse. Observations of *blazars*, AGN with jets aimed at Earth, can theoretically help astronomers probe the magnetic field between galaxies. Gamma rays emitted by those jets should collide with ambient starlight, converting into pairs of electrons and positrons. Those pairs then interact with other photons to produce a second wave of lower-energy gamma rays.

A magnetic field would deflect the particle pairs, and as a result the secondary gamma-ray glow would spread into a faint halo around the blazar. But astronomers disagree about whether observations favor strong fields or vanishingly small ones. "They are truly incompatible," Martin-Alvarez says.

His assessment of the community's response? "Nobody seems to care too much, because it is hard to answer and it is clear that we don't really understand the observations." That absence of understanding means we don't know whether the magnetic field that fills the vast spaces between galaxies is strong or effectively absent.

What Comes Next

The Square Kilometre Array (SKA), under construction across South Africa and Australia, will transform Faraday rotation surveys. Current catalogs contain thousands of polarized light sources that astronomers can use to map out magnetic fields. SKA will push that number into the millions, providing the statistical power to map large-scale field structures, from cosmic filaments to individual galaxy halos, with a precision that current data sets can't touch.

Combined with the Next-Generation Very Large Array, which will detect the faint radio glow that electrons emit as they spiral through magnetic fields inside nearby galaxies, the two instruments together will provide an end-to-end picture of magnetic fields from galaxy interiors out to the diffuse intergalactic medium. Mapping the large-scale field distribution will also help settle the contradictory conclusions from blazar observations.

The 21-centimeter radio signal from neutral hydrogen offers another route. Astronomers are already chasing it from the ground, where bright foregrounds make the measurement punishing. The SKA and proposed experiments on the radio-quiet farside of the Moon aim to reach into the universe's first billion years, when the first stars began ionizing the intergalactic gas. Primordial magnetic fields would have left their mark on the gas temperature and structure during exactly that period.

For Zhang, the most-wanted result is direct Zeeman measurements of the field strengths in molecular cloud cores, rather than indirect estimates. "Being able to measure the field strengths directly, I think that is still a frontier that I'm hopeful we can address," he says. Even a handful of well-characterized direct measurements across a range of environments would anchor every calibration in the field. Astronomers may also be able to map field geometry in external galaxies using the slight polarization that certain spectral lines — like those from carbon monoxide — develop when a magnetic field is present, giving them information about places where dust polarization is too faint to detect.



▲ **CLUSTER CAULDRON** Using a new technique that relies not on polarization but on intensity variations, astronomers have mapped magnetic fields in several galaxy clusters, including El Gordo, shown here. The bow pattern in the lower left is a shock front, where the two clusters that have collided to create El Gordo meet. The merger has also stirred up magnetic turbulence. The background image comes from the James Webb Space Telescope, and the blue glow is X-ray emission detected by the Chandra X-ray Observatory.

Martin-Alvarez's plans are computational: Create high-resolution cosmological simulations that track how AGN jets distribute fields through the intergalactic medium over billions of years. Such simulations could produce the first models capable of addressing the blazar contradiction directly.

Zhang, looking back over 30 years of a field that barely existed when he was a graduate student, sees both lines of research converging. "You see suddenly the blossom of this field that is really brought on by those new telescopes with new capabilities," he says. "Numerical simulations with more powerful computers also play a big role."

The questions being asked now — what the primordial field was, how turbulence and magnetism divide the labor in stellar nurseries, how AGN thread their fields through the cosmic web, what the blazar observations actually mean — sit at the intersection of plasma physics, galaxy evolution, and cosmology's deepest open problems. Magnetic fields have been the universe's silent infrastructure for billions of years. We're finally building the instruments to read the blueprint.

■ **PAUL M. SUTTER** (Johns Hopkins University) is a cosmologist, NASA advisor, author, host, and U.S. Cultural Ambassador.

FURTHER READING: Learn more about magnetic fields in J. B. Zirker's *The Magnetic Universe: The Elusive Traces of an Invisible Force*, published by Johns Hopkins University Press in 2009.

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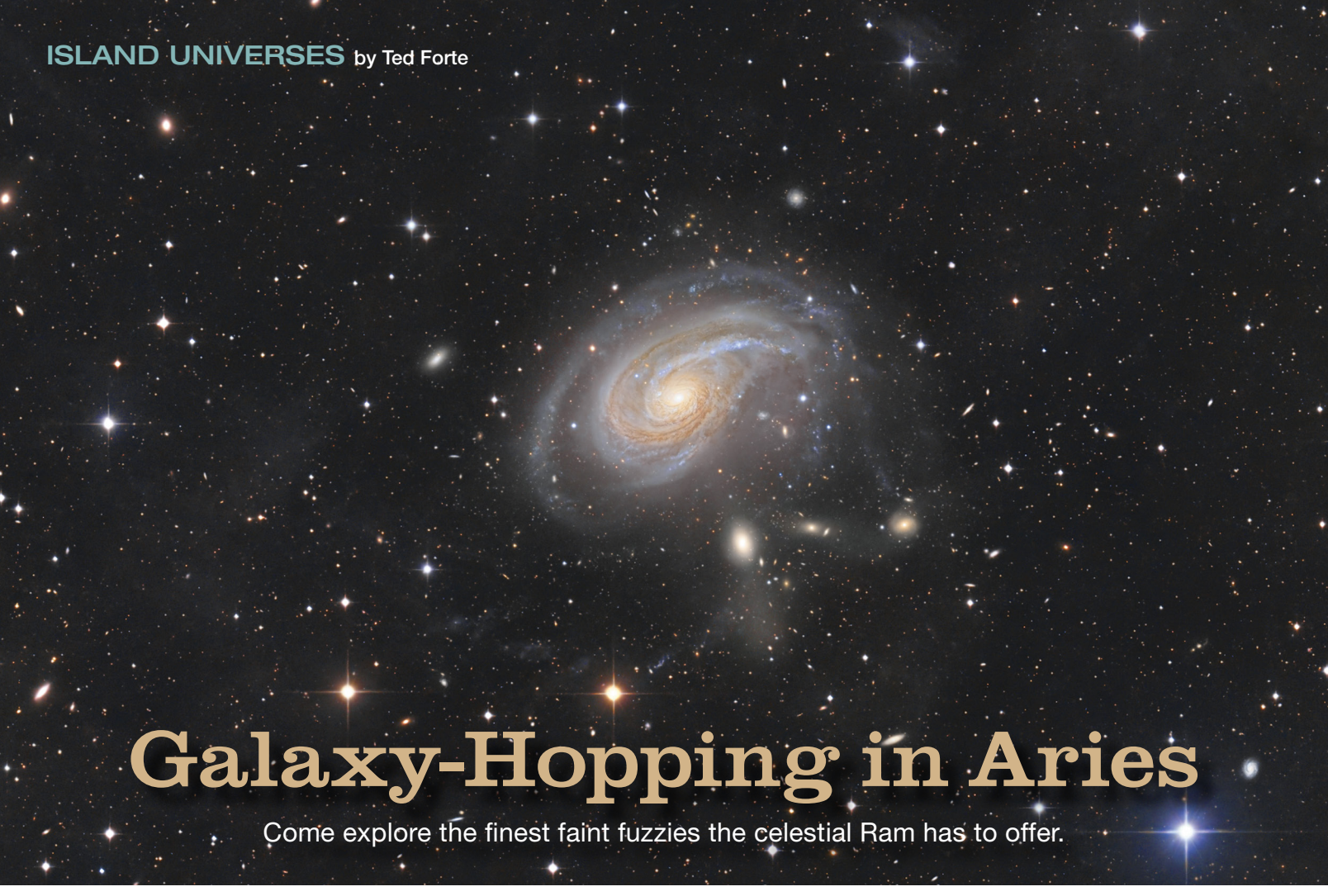


Galaxy-Hopping in Aries

Come explore the finest faint fuzzies the celestial Ram has to offer.

Since Babylonian times, the three (or four) brightest stars of Aries have been depicted as a ram. For a mid-sized Northern Hemisphere constellation covering just 1.1% of the sky, it's quite rich in extragalactic targets. There are more than 10,000 cataloged galaxies within its borders, including 73 listed in John Louis Emil Dreyer's famous 1888 *New General Catalogue of Nebulae and Clusters of Stars* (NGC) and 58 in his subsequent *Index Catalogue* (IC).

To provide an interesting sample of Aries's celestial treasures, for this tour I've selected objects that are well within reach of a 10-inch telescope. I made most of the observations described here with my 18-inch Dobsonian reflector under suburban (Bortle 4) skies. Unless otherwise noted, I used my favorite galaxy eyepiece, a 12-mm Type 4 Nagler that, when combined with a coma corrector, yields 197× with a 25′ field of view.

Now let's get started.

The Checkmark at 1 Arietis

An article by Contributing Editor Ken Hewitt-White in the December 2001 issue (page 113) first alerted me to a group of seven galaxies near Aries's border with Pisces, close to the 6th-magnitude double star 1 Arietis that forms a checkmark-shaped asterism. Or should I say *galacterism*? William Herschel discovered five of the galaxies, all bright enough to be accessible in moderate-sized backyard telescopes, and they provide a perfect starting point for our jaunt across the Ram.

Herschel examined the area twice using his 12- and 18.7-inch speculum-mirror reflectors. On September 15, 1784, he discovered the objects that would later be designated **NGC 697**, **NGC 678**, and **NGC 680**. He observed them again and added two more galaxies, **NGC 691** and **NGC 695**, on November 13, 1786.

NGC 697 dominates the group, which appears to be physically related and includes at least six of the checkmark members and several smaller satellite galaxies. They lie roughly 100 million light-years from Earth. Membership is presumed based on their proximity in space, similar radial velocities, and isolation from other galactic clusters and groups. To find NGC 697, hop 16.7′ east-northeast of 1 Arietis. This large, 12th-magnitude barred spiral appears elongated east-southeast to west-northwest and displays a relatively bright core and fainter outer halo.

▲ **PECULIAR SPIRAL** NGC 772, also known as Arp 78, lies approximately 100 million light-years away. Its strangely lopsided, overdeveloped northern spiral arm earned the galaxy its nickname, the Fiddlehead Galaxy. The extra-prominent arm was created by tidal interactions with its southern neighbor, the dwarf elliptical NGC 770 (the bright galaxy at the 5 o'clock position). Unless noted, north is up in all images.

JOSEF PÖPSEL / STEFAN BINNEWIES / FRANK SACKENHEIM

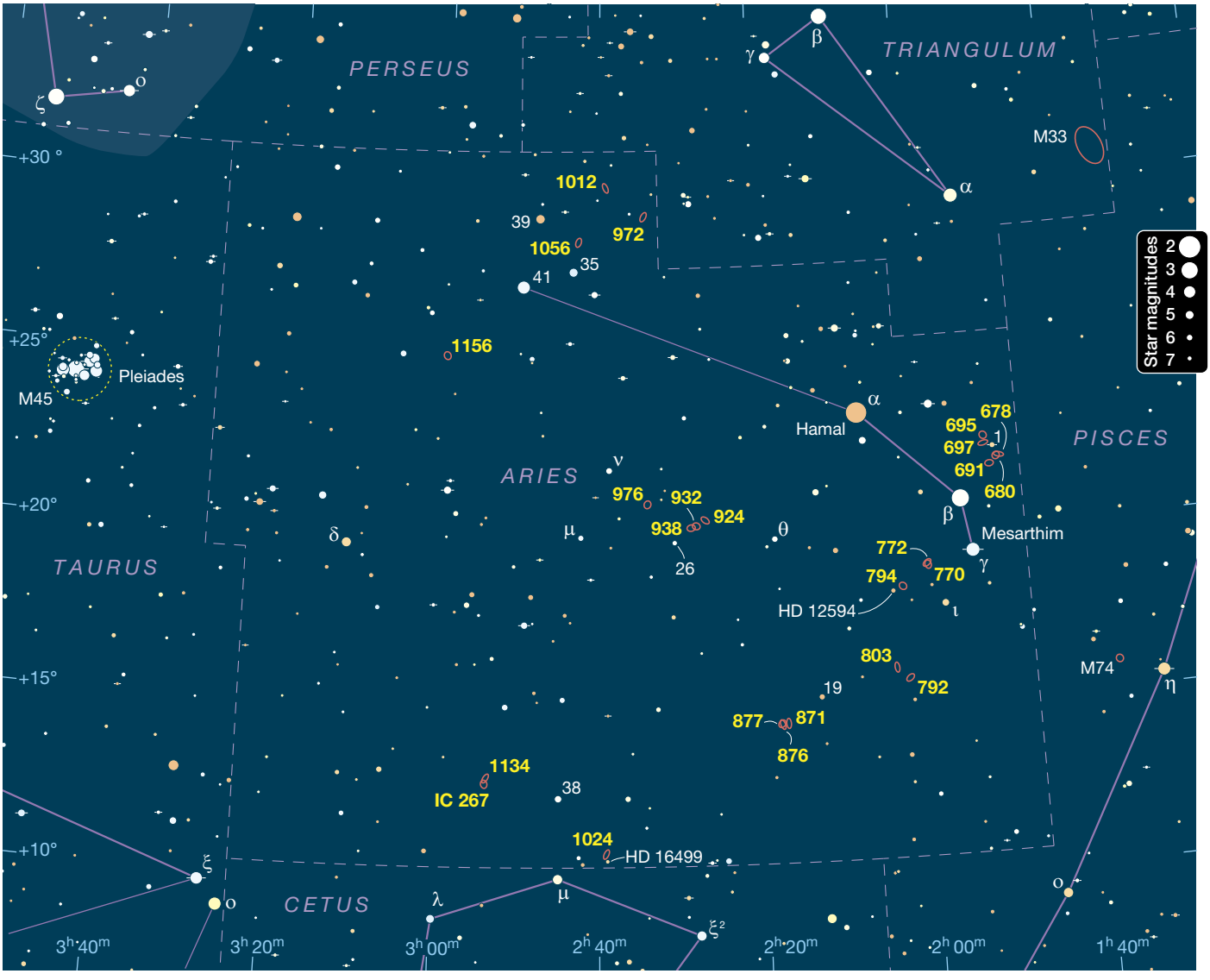
NGC 695, a small, round, 13th-magnitude lenticular of fairly high surface brightness, lies 13.5′ north of NGC 697. Described by Herschel as a "stellar nebula," the object is just a bit more than 40″ in diameter. German astronomer Wolfgang Steinicke, a well-known authority on William Herschel, expressed surprise that he could have perceived such small, diffuse objects. It's a testament to Herschel's incredible skill as an observer.

NGC 680 and NGC 678 are a gravitationally interacting pair, about 19′ south-southwest of 1 Arietis. Just 5.4′ apart, they fit comfortably in the field of a medium-power eyepiece. NGC 680, the only elliptical in the checkmark group, is mostly round, moderately bright at magnitude 11.9, and has an extended, faint halo. NGC 678 is a 12.2-magnitude edge-on that's quite elongated, almost east-west. In my 30-inch Dobsonian at 300×, the galaxy's faint extensions showed up particularly well; they were less obvious in my 18-inch.

Let's jump 18′ southeast from NGC 680 to NGC 691. This 11th-magnitude, face-on spiral appeared nearly round and showed no arm structure, even in my 30-inch at 390×. It exhibited a bright, circular inner core and a faint outer halo.

Cascading from the Ram's Eyes

The lovely double star Gamma (γ) Arietis, or Mesarthim — with its 5th-magnitude components separated by 7.3″ — represents the Ram's Eyes. It's our jumping-off point for a long cascade of relatively bright galaxies trailing off to the southeast. Our first stop, 1.4° east-southeast of Mesarthim, is the 10.3-magnitude spiral **NGC 772** and its nearby, smaller companion, 12.9-magnitude **NGC 770**. I saw NGC 772 as having an intensely bright core and an irregular halo that displayed a strong hint of a spiral arm to its north. Nicknamed the Fiddlehead Galaxy owing to its peculiar shape, NGC 772 is also known as Arp 78. In 1970, American



▲ **EXPLORE THE CELESTIAL RAM** Use this and the other accompanying finder charts to aid you in your celestial navigation. You can refer to the text for additional star-hopping instructions. The charts have north up and east to the left, and the stars are plotted down to magnitude 7.

astronomer Halton Arp found that the spiral is connected to a number of its smaller, nearby companions by luminous filaments. Beyond its disturbed appearance, there was no sign of that wispiness in the eyepiece. Herschel found NGC 772 on November 29, 1785, and reported: "In the most resolvable part a faint red colour perceivable." In his extensive historical observing notes, Contributing Editor Steve Gottlieb points out how unusual it was for Herschel to detect color in a galaxy. I didn't see any red hue in my observation.

Lying 3′ to the south-southwest, NGC 770 is an elliptical that appears much smaller than its northern neighbor and mostly round. Irish astronomer R. J. Mitchell, an assistant to William Parsons, the Third Earl of Rosse, discovered this galaxy on November 3, 1855. German astronomer Heinrich Louis d'Arrest independently found the object six years later, and it was inadvertently listed twice in the 1864 *General Catalogue of Nebulae and Clusters of Stars* compiled by William Herschel's son, John. The two entries were later combined in the *New General Catalogue* list.

From NGC 770, jump 1° southeast to **NGC 794**. William Herschel discovered this 13th-magnitude early-type galaxy on October 15, 1784. John Herschel also noted it nearly 44 years later. Prolific American comet hunter Lewis Swift independently found the object on October 20, 1889, but his description so differed from that of the Herschels that Dreyer thought it might be new and cataloged it as IC 191 in his first *Index Catalogue*. Astronomy historian Harold Corwin speculates that Swift probably saw the object on a particularly good night, and that the Herschels' speculum mirrors might have degraded by the time of their observations, accounting for the disparate descriptions. In my 18-inch, NGC 794 appeared as a rather faint oval with a slightly brighter core.

NGC 803 lies 2.4° south of NGC 794 and about 77 million light-years away. This 12.6-magnitude spiral is elongated nearly north-south, and in my 30-inch Dob at 390×, I detected a hint of arm structure in its faint outer halo. In my 18-inch, it appeared more evenly illuminated with only a very slightly brighter core, and there's an 11.5-magnitude star just 1′ west of it. William Herschel discovered NGC 803 on October 15, 1784, and described it as: "eF [extremely faint], vS [very small], irregularly round, just following a pB [pretty bright] star." My eyepiece impression better matches the description of John Herschel, who viewed the object about 47 years later and described it as: "vF [very faint]; not vS; gradually little brighter middle; . . ." Such subtle differences in the object's description by these great visual astronomers is indicative of the subjective nature of observing by eye, and it's what makes the history of their discoveries so rich and interesting.

A bit farther southwest, 29′ from NGC 803, is the 13.1-magnitude lenticular **NGC 792**, which appears faint and a little elongated with a bright core. A pair of 11th-magnitude stars to the northeast point to the galaxy, while a line of three 12th- and 13th-magnitude stars sits about 3′ to the southwest. John Herschel discovered NGC 792 on September 7, 1828, but missed a smaller companion, NGC 786, just 13′ to the west-southwest.

From NGC 792, we'll jump a full 4° east-southeast to three galaxies that fit in a single, medium-power field of view. They comprise a gas-rich, interacting galaxy group that's dominated by **NGC 877**, a 12th-magnitude barred spiral. You can first locate 5.7-magnitude 19 Arietis about 2½° east of NGC 792; our target is an easy, 1.4° star-hop to the southeast from there. NGC 877 appears as a large, bright oval with an even brighter core. In my 30-inch at 390× and using averted vision, I detected a faint trace of spiral structure. **NGC 876** lies just 2′ southwest of NGC 877. It's a small, 15th-magnitude intermediate spiral angled almost edge-on, with a bright center and very faint extensions. The 14th-magnitude barred spiral **NGC 871** is situated 11.8′ west of NGC 876. It appears as a faint streak elongated north-south that's quite uniform in brightness. William Herschel discovered NGC 877 and 871 on the same sweep on October 14, 1784; Mitchell spotted NGC 876 on November 22, 1854, while observing at Birr Castle with Lord Rosse's 72-inch Leviathan.

▼ **GALACTIC DUO** This view shows the contrasting appearance of the edge-on galaxy NGC 678 and its face-on neighbor, NGC 680, just 5.4′ to its east-southeast. They're members of the checkmark-shaped asterism near the 6th-magnitude star 1 Arietis. The small spiral at left is IC 1730.

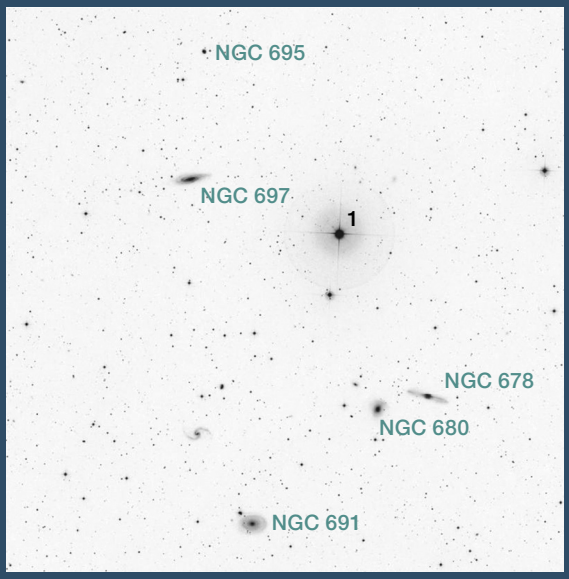


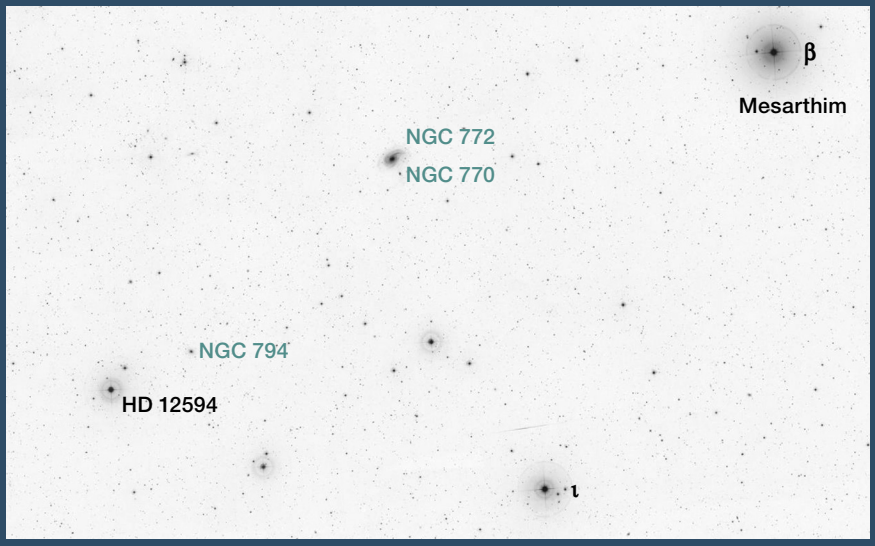
ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA

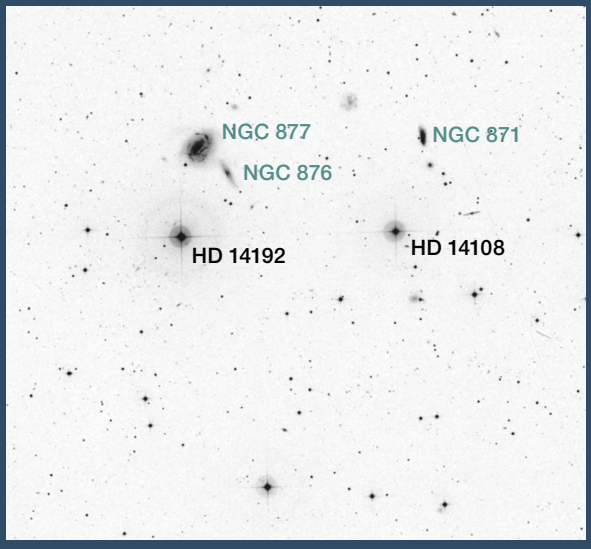
At the Ram's Tail

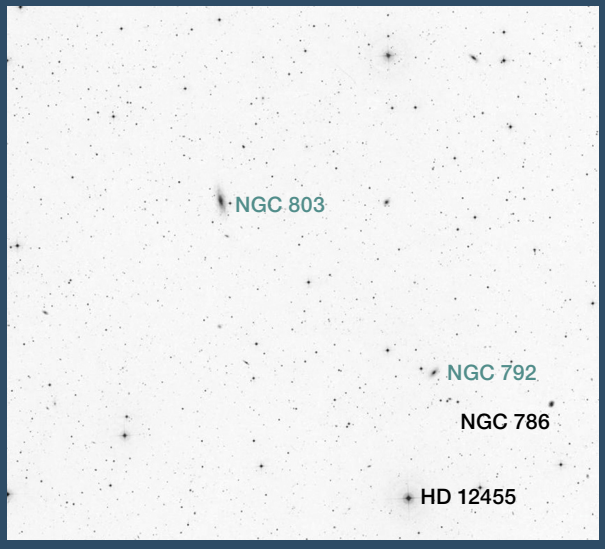
The triple star 41 Arietis, also known as Bharani, typically depicts the tail of the Ram. We'll use this 3.6-magnitude luminary as a springboard for exploring several galaxies that populate the northern reaches of the constellation. Shift 1½° west-northwest to 4.7-magnitude 35 Arietis and then 53′ north to **NGC 1056**. William Herschel discovered this 12.4-magnitude spiral located about 105 million light-years away on October 26, 1786. In my 18-inch, it appeared slightly elongated and relatively faint, but with a much brighter core.

WESTERN ARIES You'll find these graceful groupings of galaxies in the western half of the constellation, especially in the vicinity of 6th-magnitude 1 Arietis, 2.7-magnitude Beta (β) Arietis, and 5.7-magnitude 19 Arietis. The scarcity of bright, nearby guide stars for star-hopping can be a challenge, so use these finders from the Digitized Sky Survey to help you home in on your targets.









DSS FINDER CHARTS THROUGHOUT THE ARTICLE:
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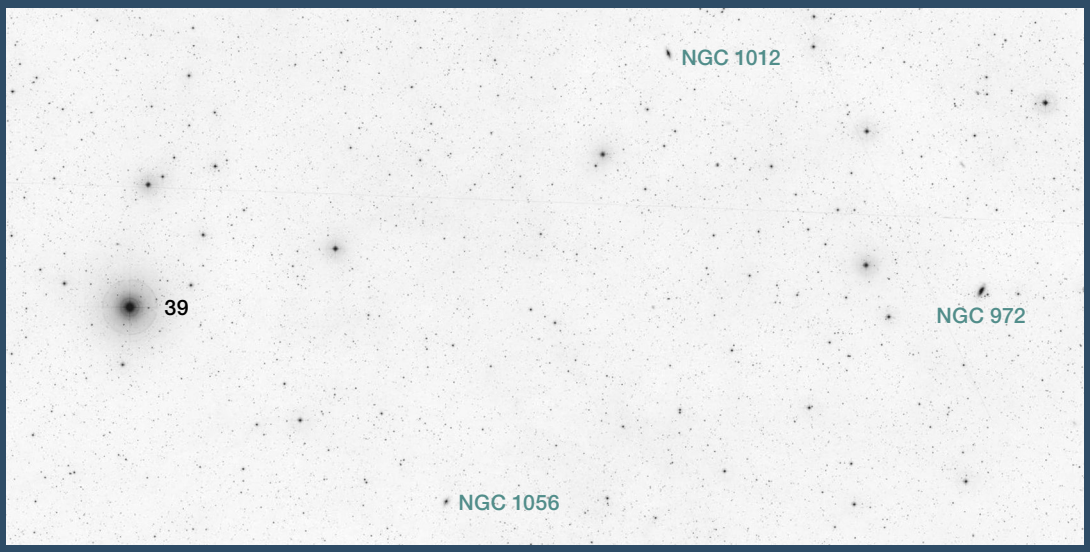
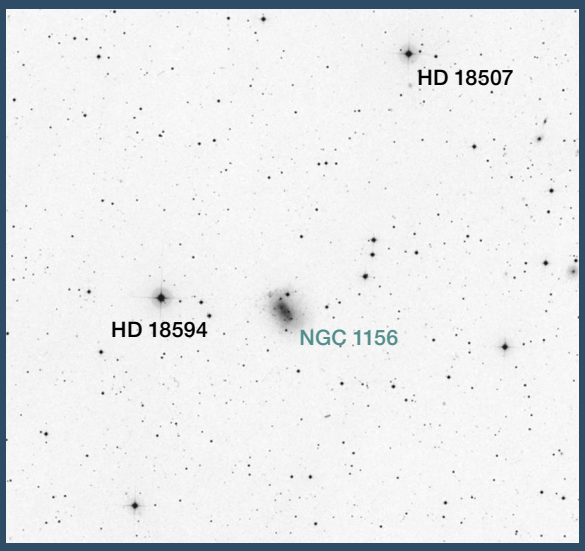




NORTH-CENTRAL ARIES This region of the constellation offers an eclectic collection of galaxy types that are accessible with most backyard telescopes. You should be able to spot the NGC (and IC) galaxies with relative ease, provided you have fairly dark skies and an aperture of at least 10 inches.



Hopping 1.8° north-northwest from NGC 1056, we arrive at **NGC 1012**, a 12th-magnitude lenticular that William Herschel swept up on September 11, 1784. To me, it appeared as a faint oblong, mottled-looking and with a brighter center. A 13th-magnitude star lies just east of the core.

Herschel picked up our next target, **NGC 972**, on the same night as NGC 1012. This 11th-magnitude elongated, blotchy spiral is angled north-northwest to south-southeast and has a bright core. It makes a striking appearance with a string of three 10th- to 15th-magnitude stars that arc along its southwestern quadrant. NGC 972 is located 1.4° southwest of NGC 1012. The two galaxies are at roughly similar distances from us — about 52.8 million light-years for NGC 1012 and about 59.8 million light-years for NGC 972.

We'll return to 41 Arietis to star-hop to **NGC 1156**, situated 2.9° southeast of the star. Nearly midway between the two is an obvious arc of three stars of 8th to 10th magnitudes that will help guide you along the way. There's also an 8.5-magnitude star, HD 18594, just 6.5′ east of the galaxy. NGC 1156 is an 11.7-magnitude dwarf irregular and, at a distance of approximately 23 million light-years, is the closest of all the galaxies on our Aries tour. In my 18-inch, it appeared somewhat rectangular and very mottled, with several faint stars involved.

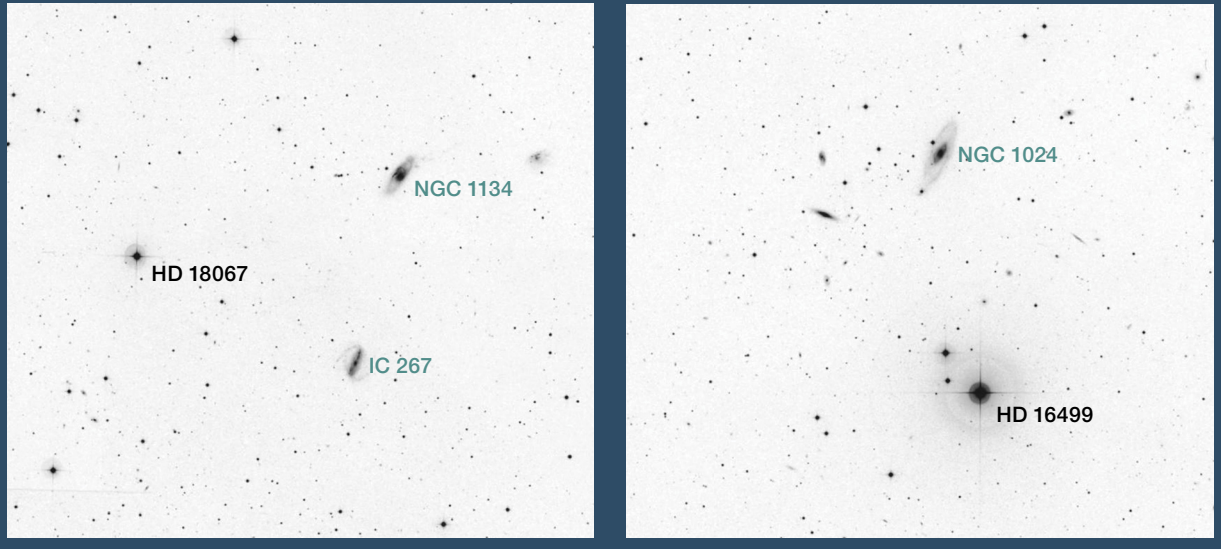


▲ **MAJESTIC SPIRAL** The whirlpool-like winding spiral arms of NGC 976, around 166 million light-years away, fill the frame of this portrait captured by the Hubble Space Telescope. While your backyard telescope won't reveal this level of detail, the high-resolution image gives you an idea of the galaxy's intricate spiral structure. In 1999, NGC 976 played host to a supernova explosion designated SN 1999dq. North is to the upper right.

A Few Final Favorites

Situated almost midway between 5.5-magnitude Nu (ν) Arietis and 6.1-magnitude 26 Arietis, **NGC 976** is a 12th-magnitude, nearly face-on spiral about 166 million light-years away. German astronomer Wilhelm Tempel discovered the object in 1876 with an 11-inch refractor at Arcetri Observatory in Italy. In my 18-inch, it appeared moderately faint, nearly round, and had a bright, round core. The Hubble Space Telescope's image of NGC 976 above shows the galaxy's beautiful, tightly wound spiral structure.

An interesting trio of galaxies lies 2.3° east-northeast of the 5.6-magnitude star Theta (θ) Arietis and about 50′ north-



SOUTHERN ARIES The southern border with Cetus, the Sea Monster, harbors a pleasing sprinkling of faint fuzzies. You may want to bring out your larger telescopes the next clear night to snag the smaller, dimmer targets highlighted in this article.

NGC 976: ESA / HUBBLE & NASA, D. JONES, A. RIESS ET AL.

west of 26 Arietis. The brightest of the triplet at magnitude 12.4, the spiral **NGC 932** has a bit of ambiguity concerning its proper designation. William Herschel first spotted it on November 29, 1785, but many sources incorrectly identify this object as NGC 930. On October 26, 1872, English astronomer Ralph Copeland reported a second object adjacent to Herschel's find. Copeland's object has subsequently been lost but lives on in the conflated designations. Corwin declares that Dryer clearly meant for Herschel's discovery to be NGC 932 and that should be the only designation for the galaxy even though some references, such as the *Uppsala General Catalogue of Galaxies* and the *Catalogue of Galaxies and of Clusters of Galaxies*, equate the two numbers as duplicate. Corwin explains that this is inaccurate, as Copeland specifically described his find as separate from Herschel's. In my 18-inch, NGC 932 appeared round and moderately bright with a considerably glowing, very round core.

Realm of Galaxies in Aries

Object	Mag	Size	RA	Dec.
NGC 697	12.0	4.5′ × 1.5′	01^h 51.3^m	+22° 21′
NGC 678	12.2	4.5′ × 0.8′	01^h 49.4^m	+22° 00′
NGC 680	11.9	1.9′ × 1.6′	01^h 49.8^m	+21° 58′
NGC 691	11.4	3.5′ × 2.6′	01^h 50.7^m	+21° 46′
NGC 695	12.8	0.8′ × 0.7′	01^h 51.2^m	+22° 35′
NGC 772	10.3	7.2′ × 4.3′	01^h 59.3^m	+19° 00′
NGC 770	12.9	1.2′ × 0.9′	01^h 59.2^m	+18° 57′
NGC 794	12.7	1.3′ × 1.1′	02^h 02.5^m	+18° 22′
NGC 803	12.6	3.0′ × 1.3′	02^h 03.8^m	+16° 02′
NGC 792	13.1	1.7′ × 1.0′	02^h 02.3^m	+15° 43′
NGC 877	11.9	2.4′ × 1.8′	02^h 18.0^m	+14° 33′
NGC 876	14.7	2.1′ × 0.4′	02^h 17.9^m	+14° 31′
NGC 871	13.6	1.2′ × 0.5′	02^h 17.2^m	+14° 33′
NGC 1056	12.4	2.3 × 1.1′	02^h 42.8^m	+28° 34′
NGC 1012	12.0	2.5′ × 1.1′	02^h 39.2^m	+30° 09′
NGC 972	11.4	3.3′ × 1.7′	02^h 34.2^m	+29° 19′
NGC 1156	11.7	3.5′ × 2.5′	02^h 59.7^m	+25° 14′
NGC 976	12.4	1.5′ × 1.2′	02^h 34.0^m	+20° 59′
NGC 932	12.4	1.9′ × 1.6′	02^h 27.9^m	+20° 20′
NGC 924	12.7	2.3′ × 1.3′	02^h 26.8^m	+20° 30′
NGC 938	12.4	1.6′ × 1.2′	02^h 28.6^m	+20° 17′
NGC 1134	12.1	2.5′ × 0.9′	02^h 53.7^m	+13° 01′
IC 267	13.0	2.0′ × 1.6′	02^h 53.8^m	+12° 51′
NGC 1024	12.1	3.9′ × 1.4′	02^h 39.2^m	+10° 51′

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.

Herschel discovered the 12.7-magnitude lenticular **NGC 924** on the same sweep as NGC 932. It lies 19′ to NGC 932's west-northwest and is elongated northeast-southwest, and appears only moderately bright with a prominent core. D'Arrest detected **NGC 938** on December 30, 1863, with an 11-inch refractor. This 12.4-magnitude elliptical is fairly small and round with a concentrated core. Find it 9′ east-southeast of NGC 932. An eyepiece with a 40′ field of view will show all three galaxies together. I used a 20-mm Nagler and a Paracorr with my 18-inch (giving 118× and a 42′ field) to take in the entire group.

Heading southeast, we encounter **NGC 1134**, an interesting spiral with a bright, irregular-looking core within a fainter outer halo. Also known as Arp 200, it appeared elongated north-northwest to south-southeast. Arp categorized the object as one of his "galaxies with material ejected from nuclei" and noted NGC 1134's "splash appearance," which he attributed to a faint companion 7′ south of the core. Use the 5.2-magnitude star 38 Arietis to star-hop 2.2° east-northeast to 12th-magnitude NGC 1134.

Just 10′ south-southeast of NGC 1134 is **IC 267**, an edge-on barred spiral of magnitude 13.0. Using my 30-inch Dob at 187×, I found it an easy object to observe with direct vision, appearing very elongated with a bright core. William Herschel discovered NGC 1134 on October 16, 1784, while Swift found IC 267 on November 8, 1877.

Our last stop, **NGC 1024**, lies close to the southern border with Cetus, the Sea Monster. The 12.1-magnitude object is located 1.6° west-northwest of 4.3-magnitude Mu (μ) Ceti and 13′ north of 6.7-magnitude HD 16499 in Aries. In my 18-inch, NGC 1024 appeared elongated north-northeast to south-southwest and had a relatively bright core. There's a 15th-magnitude star along its northeastern edge. Discovered by William Herschel on September 18, 1786, NGC 1024 lies some 152 million light-years distant.

Reliving the Thrill of Discovery

To me, one of the most inspiring aspects of deep-sky observing is the discovery history of the faint fuzzies that populate our star maps. I often feel a visceral connection to those celestial pioneers whose eyes were the first to gaze upon these wondrous objects. Retracing the steps of the Herschels and the other great visual observers of the past provides a sort of communion with these early sky explorers. It helps us appreciate what they accomplished. I hope this tour lent you a similar sense of connection and awe.

■ Contributing Editor **TED FORTE** enjoys hunting galaxies from his home in southeastern Arizona. He can be reached at **tedforte511@gmail.com**.

FURTHER READING: For more background infomation regarding the discovery histories, observing notes, and positions of the NGC and IC objects showcased in this article, see Steve Gottlieb's comprehensive website at **deepskygottlieb.com** and Harold Corwin's at **haroldcorwin.net/ngcic**.

SKY AT A GLANCE
December 2026



1 DAWN: Kick the month off by facing south-southeast just before sunrise to catch the marvelous sight of a string of celestial bodies gracefully arrayed above the horizon. Starting low in the east-southeast you should spot Mercury. As you move upper right, you'll encounter Venus, Spica, the waning crescent Moon, Mars, Regulus, and closing out the line high in the south-southwest, Jupiter. Turn to page 46 for more on this and other events listed here.

4 DAWN: Look to the southeast before the Sun rises to see Spica, Virgo's brightest light, and the waning lunar crescent some 3¼° apart. Venus blazes lower left of the pair.

12 DAWN: High in the south Jupiter is positioned around 3¼° upper right of Regulus, while Mars smolders 6° left of the pair. Keep an eye on this arrangement the next couple of mornings.

13–14 ALL NIGHT: The Geminid meteor shower reaches maximum. The waxing crescent Moon sets in the early evening and won't interfere with viewing. Turn to page 48 for further details.

16 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:00 p.m. PST (see page 50).

19 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:50 p.m. EST (7:50 p.m. PST).

21 THE LONGEST NIGHT OF THE YEAR in the Northern Hemisphere. Winter begins at the solstice at 3:50 p.m. EST (12:50 p.m. PST).

21 DUSK: High in the east, the waxing gibbous Moon is lower left of the Pleiades, and will cover cluster stars for far northeastern North America. Binoculars will help to enjoy this scene.

22 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:39 p.m. EST.

25 DAWN: Above the western horizon the Moon, one day past full, gleams in Gemini with Pollux around 4½° upper right.

27 DAWN: Look toward the west-southwest to see the waning gibbous Moon with Jupiter some 3° upper left. Regulus shines another 3½° left of the planet, while Mars oversees this scene from farther upper left.
—DIANA HANNIKAINEN

▲ The Sun, shortly after the winter solstice, shines from a mere 8° altitude as seen from the shore of Laajalampi Lake in southern Finland. MARKUS HOTAKAINEN

Lunar Almanac
Northern Hemisphere Sky Chart



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

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

LAST QUARTER
December 1
06:09 UT

NEW MOON
December 9
00:52 UT

FIRST QUARTER
December 17
05:43 UT

FULL MOON
December 24
01:28 UT

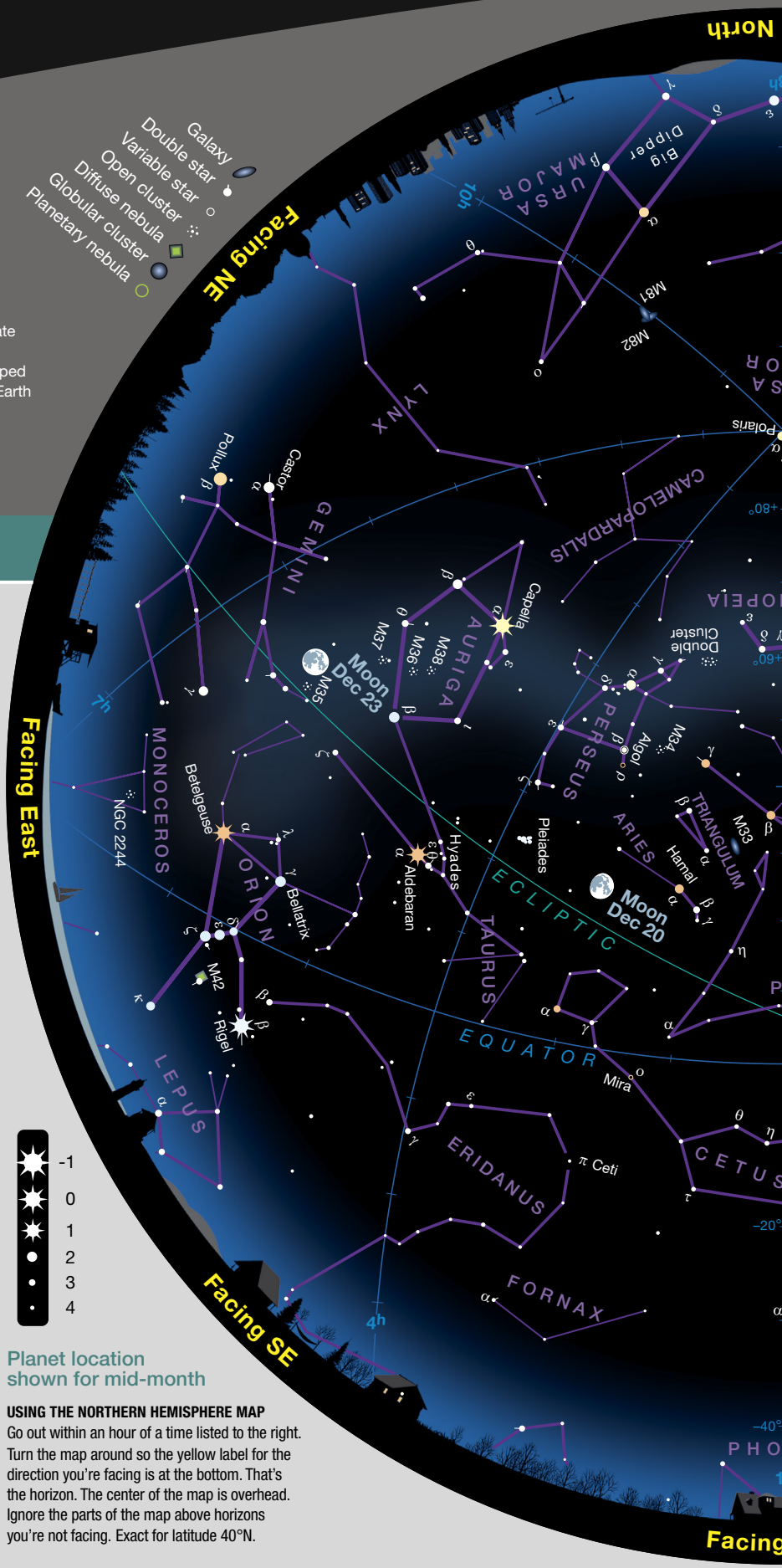
LAST QUARTER
December 30
18:59 UT

DISTANCES

Apogee	December 11, 7^h UT
406,419 km	Diameter 29′ 40″
Perigee	December 24, 9^h UT
356,651 km	Diameter 33′ 30″

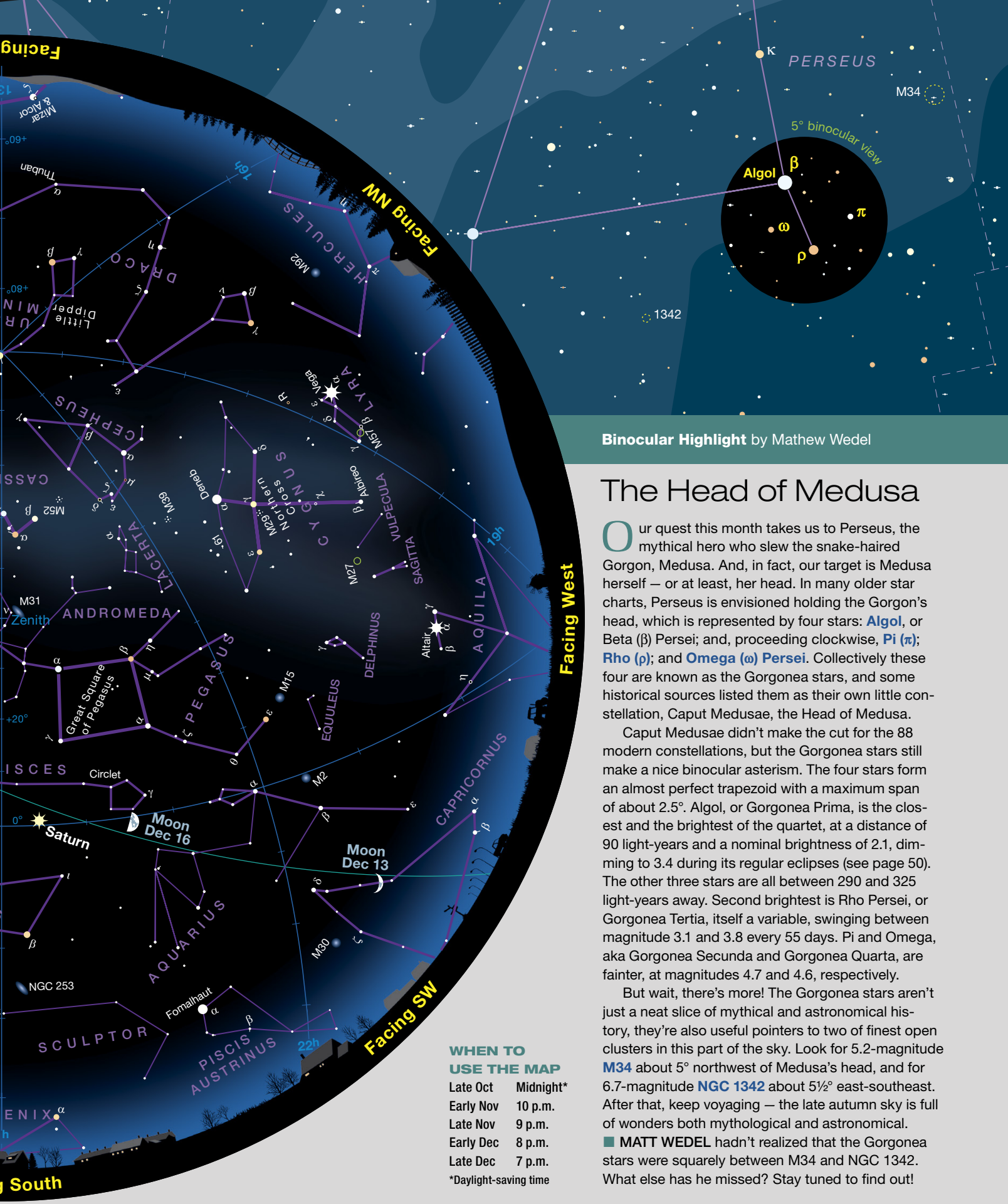
FAVORABLE LIBRATIONS

• Bailly Crater	December 23
• Moretus Crater	December 24
• Helmholtz Crater	December 25
• Adams Crater	December 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

The Head of Medusa

Our quest this month takes us to Perseus, the mythical hero who slew the snake-haired Gorgon, Medusa. And, in fact, our target is Medusa herself — or at least, her head. In many older star charts, Perseus is envisioned holding the Gorgon's head, which is represented by four stars: **Algol**, or Beta (β) Persei; and, proceeding clockwise, **Pi (π)**; **Rho (ρ)**; and **Omega (ω) Persei**. Collectively these four are known as the Gorgonea stars, and some historical sources listed them as their own little constellation, Caput Medusae, the Head of Medusa.

Caput Medusae didn't make the cut for the 88 modern constellations, but the Gorgonea stars still make a nice binocular asterism. The four stars form an almost perfect trapezoid with a maximum span of about 2.5°. Algol, or Gorgonea Prima, is the closest and the brightest of the quartet, at a distance of 90 light-years and a nominal brightness of 2.1, dimming to 3.4 during its regular eclipses (see page 50). The other three stars are all between 290 and 325 light-years away. Second brightest is Rho Persei, or Gorgonea Tertia, itself a variable, swinging between magnitude 3.1 and 3.8 every 55 days. Pi and Omega, aka Gorgonea Secunda and Gorgonea Quarta, are fainter, at magnitudes 4.7 and 4.6, respectively.

But wait, there's more! The Gorgonea stars aren't just a neat slice of mythical and astronomical history, they're also useful pointers to two of finest open clusters in this part of the sky. Look for 5.2-magnitude **M34** about 5° northwest of Medusa's head, and for 6.7-magnitude **NGC 1342** about 5½° east-southeast. After that, keep voyaging — the late autumn sky is full of wonders both mythological and astronomical.

■ **MATT WEDEL** hadn't realized that the Gorgonea stars were squarely between M34 and NGC 1342. What else has he missed? Stay tuned to find out!

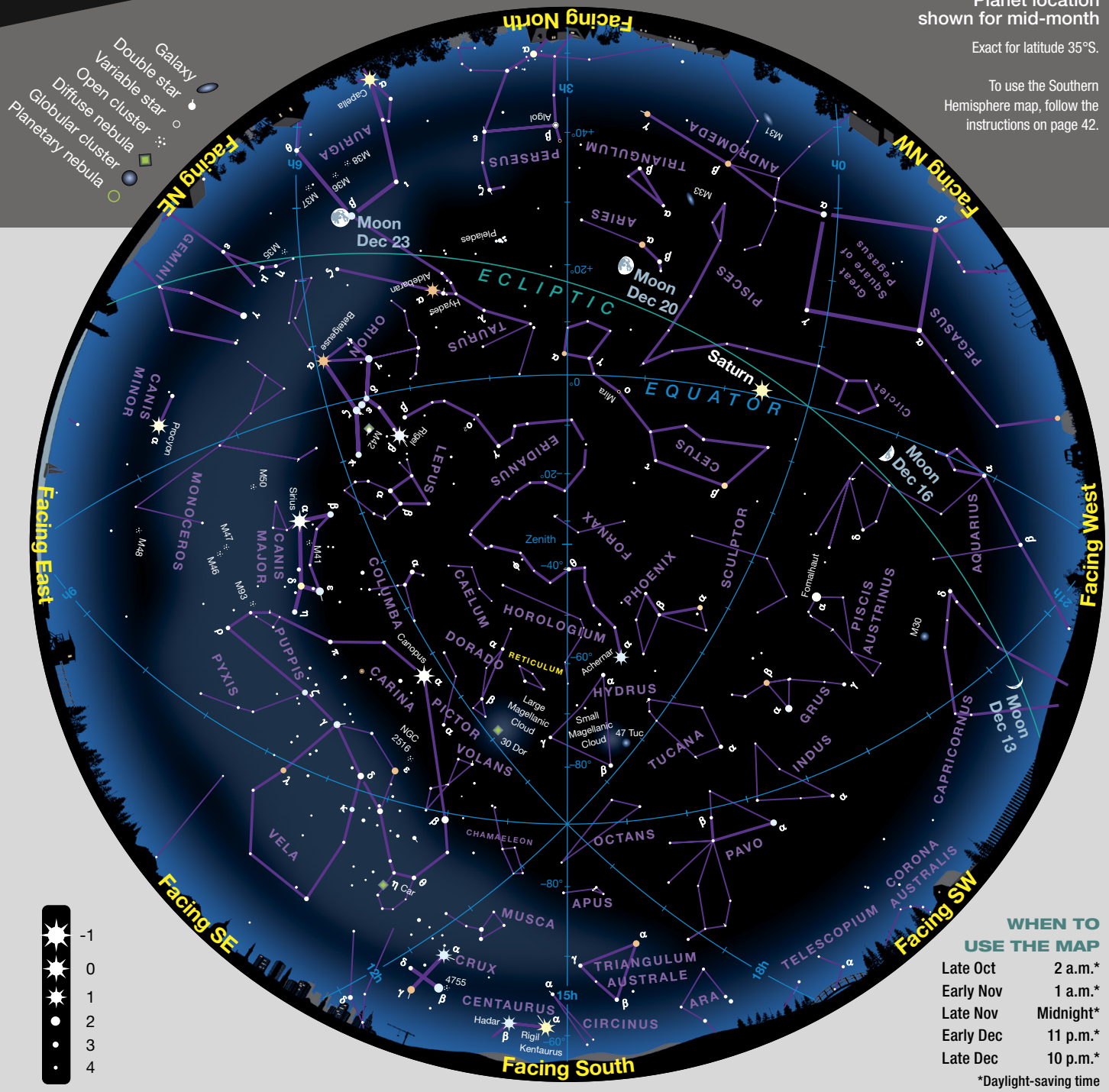
WHEN TO USE THE MAP

Late Oct	Midnight*
Early Nov	10 p.m.
Late Nov	9 p.m.
Early Dec	8 p.m.
Late Dec	7 p.m.

*Daylight-saving time

Southern Hemisphere Sky Chart

by Jonathan Nally



WHEN TO USE THE MAP

Late Oct	2 a.m.*
Early Nov	1 a.m.*
Late Nov	Midnight*
Early Dec	11 p.m.*
Late Dec	10 p.m.*

*Daylight-saving time

THE SMALL CONSTELLATION Reticulum represents a *reticle*, the crosshairs that used to be included within some telescope eyepieces and which were helpful for measuring the positions of astronomical objects. For such a compact star grouping, it comes with a respectable seven stars of magnitude 5.0 or brighter. Four are marked on the chart above.

Moving clockwise from top left, we start with Epsilon (ε), a binary star system of magnitude 4.4, composed of an orange, *K*-type giant and a very faint white dwarf. Delta (δ), at magnitude 4.6, is an aged red giant that has expanded to more than 50 times the size of our Sun. Beta (β) is a very tight binary (combined magnitude 3.8) comprising a *K*-type orange giant and what is probably a red dwarf. Finally Alpha (α), the brightest at magnitude 3.4, is a yellow giant. ■

Into the Void

Naked-eye challenge: Hunt down three dim, little-known constellations along the southern horizon.



▲ This section of Nicolas Louis de Lacaille's planisphere from his *Coelum Australe Stelliferum* (*Catalogue of Southern Stars*) — published in Paris posthumously in 1763 — shows Sculptor (Aparatus Sculptoris), Fornax (Fornax Chimiae), and Phoenix.

Turn to pages 42–43 and look at the Northern Hemisphere Sky Chart. Specifically, consider the area of sky south of Cetus, the Sea Monster — bordered to the east by Eridanus, the River, and to the west by Piscis Austrinus, the Southern Fish — where you'll find two complete constellations and a partial one. All three are part of the deep southern realm where the vast majority of constellations no longer abide by classical Greek mythological traditions, though some have weak links. Most of the stars belonging to these patterns are faint, between 3rd and 5th magnitude. Still, you may want to seek them out, especially if you like to collect constellations. Note that spotting them in nature requires being under a dark sky, especially as seen from mid-northern latitudes. They are not only dim but also so low in the sky that the stars appear even fainter due to atmospheric extinction.

Let's look first at the partial constellation, Phoenix. It was the creation of 16th-century Dutch navigators Pieter Dirkszoon Keyser and Frederick de Houtman while exploring the stars from the southern seas. It depicts the bird that, after 500 years of life, meets a fiery demise and is reborn from the ashes. Observers at mid-northern latitudes, who can see only part of the constellation, may wish to imagine those stars as a young Phoenix just emerging from a funeral pyre on the horizon.

Our other two constellations, Sculptor and Fornax, were, ironically, "filler" — two of 14 patterns in the stars created by French astronomer Nicolas Louis de Lacaille, who traveled to the Cape of Good Hope in South Africa in 1750 to study the far-southern skies. Lacaille used these constellations not only to fill the gaps between existing ones, but also to honor scientific and artistic advances during the Age of Enlightenment (the one exception was Mensa, named for Table Mountain near his observatory, *S&T:* Nov. 2025, p. 20).

Sculptor is curious in that, despite its name, there is no artisan envisioned among its stars. Lacaille originally named the constellation *l'Atelier du Sculpteur*, meaning the Sculptor's Studio. He later Latinized the French to *Apparatus Sculptoris*, meaning the Sculptor's Tools. His rendering of the constellation is highly detailed, including a bust — likely of Clio, the Muse of History — resting on a stool, next to a block of marble on which is placed a mallet and two chisels. In 1844, English astronomer John Herschel proposed that all Lacaille constellation names with two words be shortened to one; thus, in time, Sculptor was born. This month, Alpha (α) Sculptoris lies almost due south. And though you cannot see it, the south pole of our Galaxy's imaginary axis intersects the sky immediately north and slightly west of it.

Fornax is another truncated constellation name. Lacaille originally referred to it in French as *le Fourneau*, meaning the Furnace. He later Latinized it to *Fornax Chimiae*, meaning the Chemical Furnace — a tribute to the burgeoning field of chemistry, which had not become an independent, modern science until the late 17th century. His rendering depicts the distillation process: a wood-burning furnace heating a long-necked flask that leads to a receiving vessel.

By the way, Lacaille's tribute to modern science aside, Fornax was the goddess of bread-making in ancient Rome. She personified the oven, serving as a divine protector of grain during the parching and baking processes to prevent it from burning. So, you now have a choice as to how you'd like to see Fornax. Happy searching.

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

ETH-BIBLIOTHEK

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

Planets Adorn the Morning Sky

The year winds down with some lovely dawn gatherings.

TUESDAY, DECEMBER 1

If you're up at around 6 a.m. this morning, bundle up and head outdoors to take in a lovely array of celestial lights arcing nearly halfway across the sky. Scanning from the east-southeastern horizon toward the meridian, we have **Mercury**, **Venus**, **Spica**, the **Moon**, **Mars**, **Regulus**, and **Jupiter**. Mercury is hanging out near the horizon and shining at magnitude –0.6. Venus is continuing its reign as the Morning Star as it slowly drifts away from Spica. The planet gleams magnificently at magnitude –4.9, which is about as bright as it ever gets. Higher up, the Moon is a 47%-illuminated waning crescent, while Mars, Regulus, and Jupiter are arranged in a flattened, 5½°-wide triangle in Leo. Of the tight trio, Jupiter is by far the brightest, beaming at magnitude –2.2. Meanwhile Mars is at +0.5 magnitude, which makes it nearly a full magnitude brighter than Regulus.

SATURDAY, DECEMBER 5

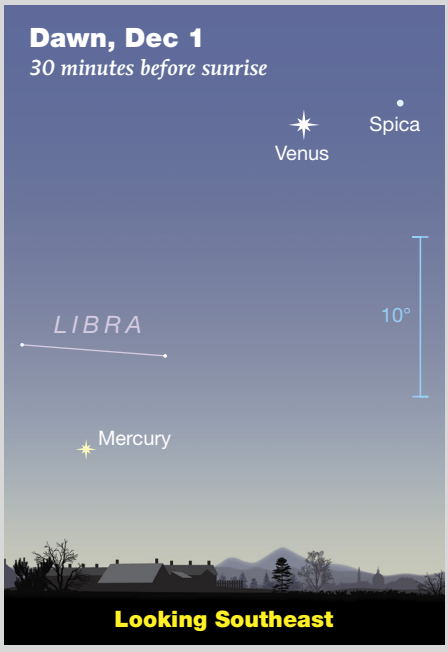
The celestial morning show continues today with the formation of a tidy isosceles triangle featuring the **Moon**, **Venus**, and **Spica**. The Moon, now a thin, 11%-illuminated crescent hangs 8° lower right of the brilliant Morning Star. You'll find Spica a bit more than 7½° upper right of Venus. Whenever the Moon and Venus get together, it's a striking sight. However, this morning's pairing is not particularly close. Indeed, it's the year's least favorable one — in November they were just 1.4° apart.

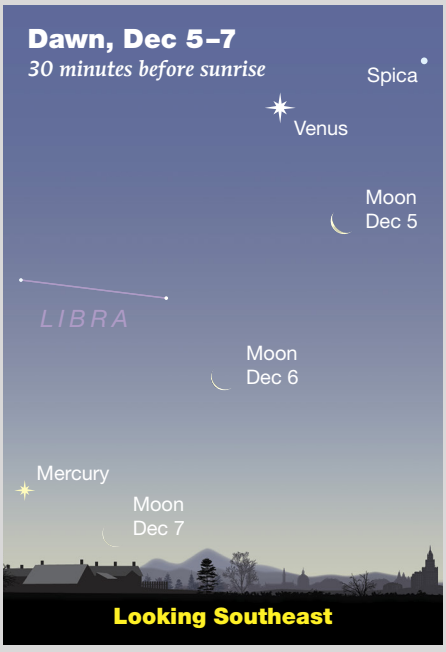
MONDAY, DECEMBER 7

It's time to bid farewell to **Mercury** once again. Dawn today is the little world's last hurrah as it winds down its finest morning apparition of 2026. Very low in the east-southeast it's joined by a thin crescent **Moon**, sitting 6½° lower right of Mercury. You'll need an unobstructed horizon to catch the duo — and binoculars will help as twilight brightens the sky. Indeed, it's hard to guess which of the two will be more difficult to spot. Mercury still shines at magnitude –0.6, while the lunar crescent is a mere 2% illuminated and just 36 hours from new. One or two mornings later, it will be all but impossible to catch Mercury without optical aid. But don't despair — it won't be gone for long. Mercury has its conjunction with the Sun on January 1, 2027, after which it pops up at dusk around January 19th.

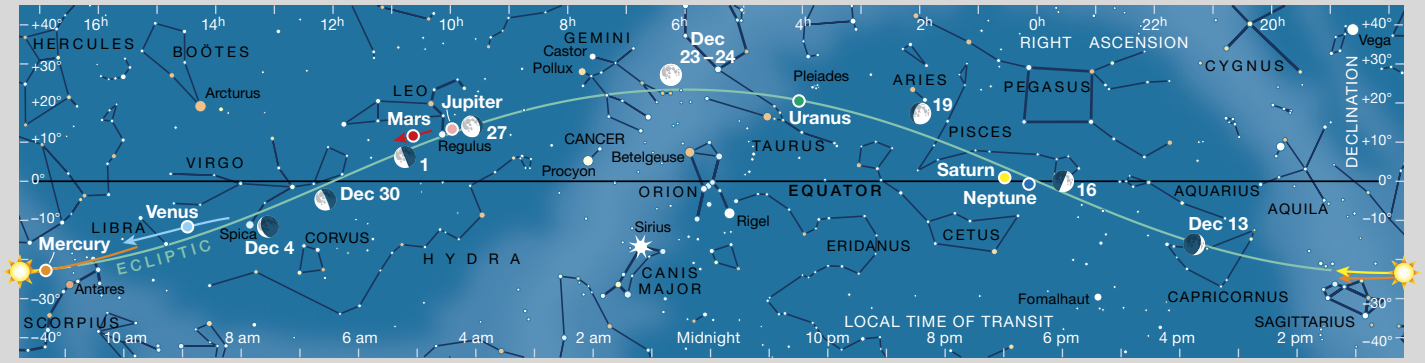
THURSDAY, DECEMBER 17

There's a lot of activity taking place at dawn, but one planet sits alone in evening sky: **Saturn**. The ringed wonder shines at magnitude +0.8 from the northwestern corner of Cetus, the Sea Monster (or Whale, if you prefer). Tonight it's joined by the waxing gibbous **Moon**, just one day past first-quarter phase. As the pair straddles the *meridian* (the imaginary line that joins north and south and passes through the zenith) in the early evening, the gap between them is roughly 6°. By the time they sink toward the western horizon 7 hours later (on the morning of the 18th), that distance has shrunk to about 5.7°. So, this isn't an espe-





▶ 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-December; 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.

cially close conjunction, but it is a good excuse to check in with Saturn. In a telescope it never fails to impress!

SUNDAY, DECEMBER 27

This morning the **Moon** has its closest encounter with a planet for the entire month when it edges closer and closer to **Jupiter** as dawn approaches. By the time twilight really gets going, the waning gibbous Moon is about 3° from Big Jove. They'll be slightly farther apart for observers on the East Coast, and slightly closer for those on the opposite side of the continent.

The Moon has a second act in store for today. In the late evening it rises in the east, attended by **Mars** and **Regulus**. The Moon is stationed 6½° upper right of the Red Planet and a bit more than 4° below Regulus. As the night of the 27th becomes the morning of the 28th, the Moon drifts slightly closer to Mars and farther from Regulus.

THURSDAY, DECEMBER 31

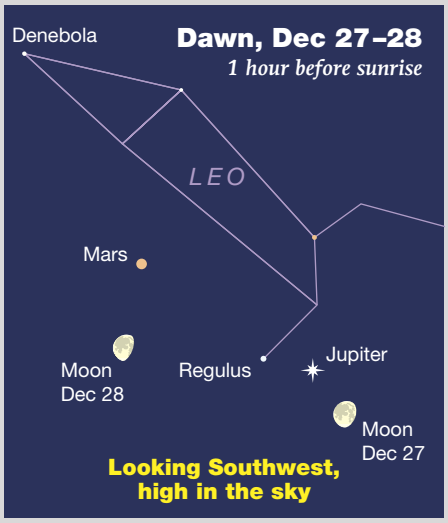
To celebrate the end of the year, let's have one last look at the dawn sky to note how much things have changed since the start of the month. The main event this morning is the waning crescent **Moon** sitting 6° right of **Spica**, Alpha Virginis. The pair crests the meridian at around 6:30 a.m. local time. It was **Venus** that was keeping Spica company at the beginning of December, but now the reigning Morning Star is some 29° farther east, in neighboring Libra. Meanwhile, the trio of **Mars**, **Regulus**, and **Jupiter** have dispersed slightly. Big Jove remains near Regulus — now positioned 3¾° to its right — but Mars has really put some distance between itself and the star. The space between them has grown from less than 2¾° to a full 10°. The Red Planet is also much brighter, having increased from magnitude +0.5 to –0.1. (As it happens, the next time it swings by Regulus, in May 2027, Mars will be magnitude +0.5 once again, having dimmed from its opposition-day peak of magnitude –1.2.)

Despite all these changes, the big-picture view remains striking — an array of bright lights stretching from the southeast to high in the southwest. It might be too early in the day to raise a glass of champagne, but you can certainly celebrate the New Year by drinking in this wonderful view!

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









Splendid Geminids!

December hosts yet another Moon-free meteor shower.

When it comes to meteor showers, 2026 has dealt us a pair of aces. The August Perseids peaked at new Moon. Now it's the Geminids' turn. When Earth passes through the densest part of the debris trail on Sunday night, December 13–14, the Moon is a 20%-illuminated crescent that sets around 9 p.m. local time, well before the shower kicks into gear. The Geminids are easily the year's richest annual meteor shower. For observers far from city lights, up to 150 meteors per hour rip across the sky. If you live closer to town (like I do) you'll see half to a third as many. My record is one meteor per minute during the 2023 peak. After the Perseids, the Geminids rank highest in *fireballs*, meteors equal to or brighter than Venus. If you're lucky you might catch sight of your shadow racing across the snow as a fireball blazes at your back. If you're luckier, you'll be facing the scintillating sight.

▲ In this composite image of the 2021 Geminids each meteor points back to the radiant in Gemini located to the right of Castor (top center). Orion appears at middle left near the horizon. If you'd like to create your own composite, see page 53 of our August issue.

Meteors stream from a *radiant* in Gemini about 2° northwest of 2nd-magnitude Castor, the fainter of the two Gemini twins. The radiant is a convincing illusion. The same way parallel railroad tracks appear to meet in the distance, distant meteors on parallel paths meet at the radiant point. As they enter the atmosphere, the slender streaks appear to fan across the entire sky. In truth, they follow straight paths. With some showers you have to wait until after midnight for the action to start. Not with the Geminids. The radiant is high enough to get a taste as early as 10 p.m. But if you stay up late, the rate ticks up as the hours pass. In the wee hours, with the whole sky as their canvas, the plasma paintbrushes create a real-time masterpiece.

After midnight, your location on Earth turns head-on into the direction of incoming meteoroids. Instead of looking out the back window waiting for them to catch up to us, we're pressed up against the front window. As we plow face-on in their direction, the material strikes the atmosphere with greater speed. Not only does that increase the number of meteors, but also their impact velocity, which brightens them up. The shower peaks around 14:00 UT (9 a.m. EST) on December 14th, so rates should con-

Five Double Shadow Transits at Jupiter

JUPITER ALWAYS finds a way to grab our attention. If you're a regular observer of the solar system's largest planet you've probably witnessed a shadow transit, when a Galilean moon crosses Jupiter and casts a dot of black shadow on its cloud tops. It's fun and mind-stretching to observe a live event occurring on another planet — in this case, a solar eclipse on Jupiter.

Date	Satellites	Ingress (EST)	Egress (EST)	Double Shadows
December 8	Europa, then Io	1:15, 3:29 a.m.	4:09, 5:45 a.m.	3:29 – 4:09 a.m.
December 15	Europa, Io	3:51, 5:22 a.m.	6:45, 7:38 a.m.	5:22 – 6:45 a.m.
December 22	Europa, Io	6:27, 7:15 a.m.	9:21, 9:32 a.m.	7:15 – 9:21 a.m.
December 24	Ganymede, Io	12:12, 1:43 a.m.	3:49, 4:00 a.m.	1:43 – 3:49 a.m.
December 31	Io, Ganymede	3:36, 4:10 a.m.	5:53, 7:47 a.m.	4:10 – 5:53 a.m.

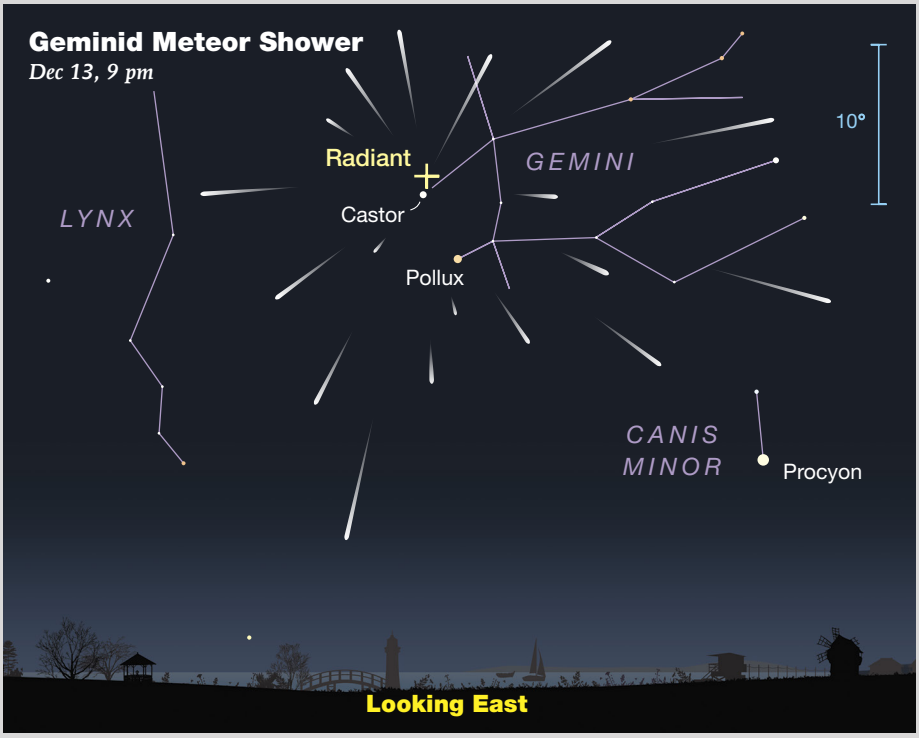
From Jupiter, the Sun's apparent diameter shrinks to a fifth as large as we see it from Earth, spanning about 6′ across. Since all of the Galilean moons have apparent diameters (as viewed from

GEMINIDS: IAU, DAI JIANFENG, CC BY-SA 4.0;
TABLE: LTE / PARIS OBSERVATORY

tinue to increase as dawn approaches. Observers on the West Coast and in the Hawaiian Islands are best placed see the peak. For Southern Hemisphere skywatchers, where Gemini rides low in the northern sky, the best viewing time is around 2 a.m., when the radiant crosses the meridian.

The Geminids have a broad maximum, with strong activity for 10 to 12 hours. Moreover, the shower is active from December 4–20, so even if the peak night is clouded out, you'll at least see a modest showing the night before and after. Brighter, more massive Geminids are typically observed toward the end of the maximum period.

Most meteor showers occur when Earth crosses the orbit of a comet. But sometimes an asteroid gets into the act. The Apollo-class near-Earth asteroid 3200 Phaethon is a contributor to this annual cosmic spitballing. Research shows that the Geminid stream likely originated in the disruption (possibly through impact) of an asteroid or comet 1,200 to 2,400 years ago. Phaethon appears to be one of its surviving remnants. The 5.8-kilometer (3.6-mile) rocky body gets so close to the Sun at perihelion that solar heating releases sodium gas from its interior, creating a temporary tail and likely wafting dust and rocks along its orbit. Every December, Earth crosses Phaethon's path, and particles ranging in size from sand grains to pebbles strike our atmospheric windshield at 35 km/s (22 miles per second, or 78,000 mph). Plowing through the air heats and vaporizes the fragments, transforming them into oohs and aahs.



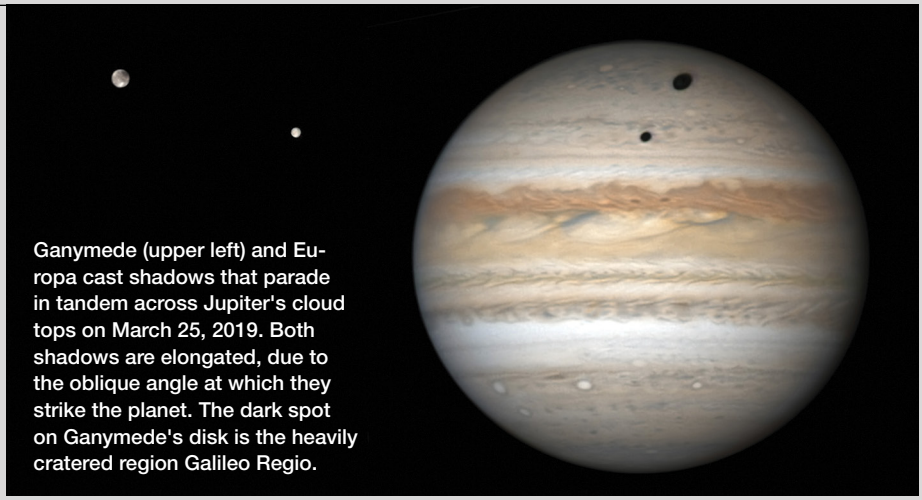
▲ Bundle up for the annual Geminid meteor shower, the year's richest. The December 13-14 peak coincides with a nearly moonless sky, ideal conditions for staying up late to take in the full experience. Shower members strike the atmosphere at 35 km per second (78,000 mph), about 40% slower than the Perseids. The shower is active from December 4th to the 20th.

As long as you're warmly dressed in a lounge chair under a warm blanket, watching the Geminids is a true thrill. Meteor rates can reach more than one-a-minute, then suddenly drop to zero. These meteor-free intervals make it feel like the show's over, but it's only a cosmic ruse. Stick around for two more minutes. Feel the anticipation. Believe. Soon enough, another arrow of light arrives, and you're an optimist again.

If you'd like to contribute your Geminid observations to further meteor science, visit the American Meteor Society (**tinyurl.com/AMS-observing**) where you'll find information and observing forms. Next year's shower occurs at full Moon. Take advantage, and clear skies!

Jupiter) significantly larger, from 9′ for Callisto to 36′ for Io, *very* total eclipses are the rule. No squeaky annular events like we see on Earth. Not only is the Sun well-hidden, but only a fraction of the corona is exposed during totality.

Double shadow transits, when two moons simultaneously cast shadows, are infrequent. When both moons are in transit across Jupiter's face at the same time as their shadows, it's even more of a kick. In December *five* double shadow transits are visible from the Americas. I hope you get to see at least one.



Ganymede (upper left) and Europa cast shadows that parade in tandem across Jupiter's cloud tops on March 25, 2019. Both shadows are elongated, due to the oblique angle at which they strike the planet. The dark spot on Ganymede's disk is the heavily cratered region Galileo Regio.

JUPITER DOUBLE SHADOW TRANSIT: DAMIAN PEACH

Mars Prep 101

MARS WON'T REACH opposition until February 19, 2027, but telescopic observing season traditionally begins when the planet's disk reaches 6″ across. That occurred in mid-October, when the most prominent surface details became apparent in 4- to 8-inch telescopes. The Red Planet swells from 8.0″ to 10.2″ and brightens from magnitude 0.5 to –0.1. Not only that, but both Jupiter and Mars currently share the same nook of sky in Leo. After checking out one of those double-shadow transits, why not hop over for a look-see at the fourth planet?

The 2026–2027 apparition occurs with Mars near *aphelion*, making this its most distant opposition in the current cycle. Right now, it's northern spring on Mars. The planet's northern hemisphere is tilted toward us, with the north polar cap in good view through mid-winter. Even a 3-inch scope will show it as a white dollop at the planet's pole. In the weeks ahead, the cap's seasonal layer of carbon dioxide ice will sublimate away, exposing the permanent, water-ice core ringed by dark sand dunes.

To aid your search try using a Wratten #25 deep-red or #23A light-red filter to increase the contrast of both the cap and dark albedo markings. I've found them very effective over the years. The largest and easiest locales to discern are Mare Acidalium and nearby Niliacus Lacus in the Northern Hemisphere and Syrtis Major and Mare Cimmerium in the Southern. Likewise, a Wratten #80A light-blue or #38A dark-blue filter helps to distinguish clouds and limb hazes, which appear as narrow, bright arcs along the eastern and western limbs.

When learning the constellations, most of us started with the bright, familiar ones before attempting the fainter groups. Identifying these prominent Martian markings builds the necessary visual and locating skills to see the smaller stuff in February.

Given how parsimonious Mars is when it comes to eking out details, every night counts. Dress warmly, pre-chill your telescope (but keep your eyepieces warm!) and prepare to meet the planet in which we've invested our fondest hopes for extraterrestrial life.

Minima of Algol

Nov.	UT	Dec.	UT
1	9:56	2	22:55
4	6:45	5	19:44
7	3:34	8	16:33
10	0:23	11	13:22
12	21:12	14	10:11
15	18:01	17	7:00
18	14:50	20	3:50
21	11:39	23	0:39
24	8:28	25	21:28
27	5:17	28	18:17
30	2:06	31	15:06

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**.



▲ Perseus approaches the zenith during evening hours in December. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Estimate its brightness with respect to the comparison stars, whose magnitudes are shown in this chart without the decimal point (e.g., 29 = 2.9).

Action at Jupiter

ON DECEMBER 13TH, Jupiter reverses course and begins *retrograde motion*, moving westward with respect to the background stars. This accelerates its transition from a morning object to an evening one — by month's end it rises at 8:30 p.m. local time. The giant planet's satellite system is aligning with Earth's orbit as well, which means telescope observers will see more shadow transits (see page 48).

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

Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Standard Time is UT minus 5 hours.) Best viewing is 50 minutes before to 50 minutes after these times.

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.

December 1: 7:02, 16:58; **2**: 2:54, 12:49, 22:45; **3**: 8:41, 18:36; **4**: 4:32, 14:28; **5**: 0:23, 10:19, 20:15; **6**: 6:10, 16:06; **7**: 2:02, 11:57, 21:53; **8**: 7:49, 17:44; **9**: 3:40, 13:36, 23:32; **10**: 9:27, 19:23; **11**: 5:18, 15:14; **12**: 1:10, 11:05, 21:01; **13**: 6:57, 16:52; **14**: 2:48, 12:44, 22:39; **15**: 8:35, 18:31; **16**: 4:26, 14:22; **17**: 0:18, 10:13, 20:09; **18**: 6:05,

16:00; **19**: 1:56, 11:52, 21:47; **20**: 7:43, 17:39; **21**: 3:34, 13:30, 23:26; **22**: 9:21, 19:17; **23**: 5:12, 15:08; **24**: 1:04, 10:59, 20:55; **25**: 6:51, 16:46; **26**: 2:42, 12:38, 22:33; **27**: 8:29, 18:25; **28**: 4:20, 14:16; **29**: 0:11, 10:07, 20:03; **30**: 5:58, 15:54; **31**: 1:50, 11:45, 21:41.

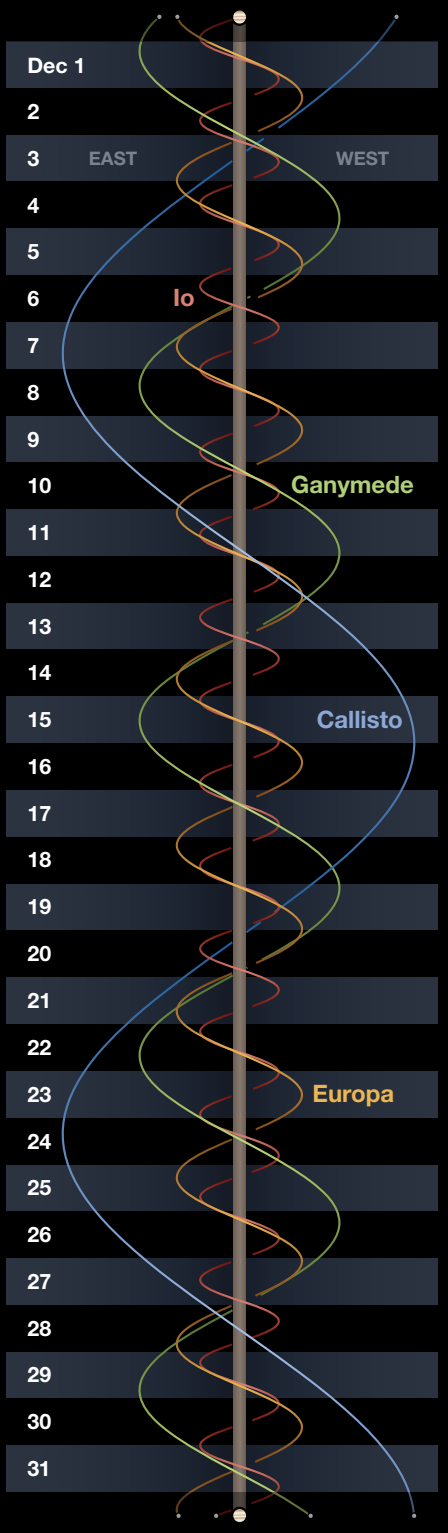
These times assume that the spot will be centered at System II longitude 95.5° on December 1st. If the Red Spot has moved elsewhere, it will transit 1²⁄₃ minutes earlier for each degree less than 95.5° and 1²⁄₃ minutes later for each degree more than 95.5°.

Phenomena of Jupiter's Moons, December 2026

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

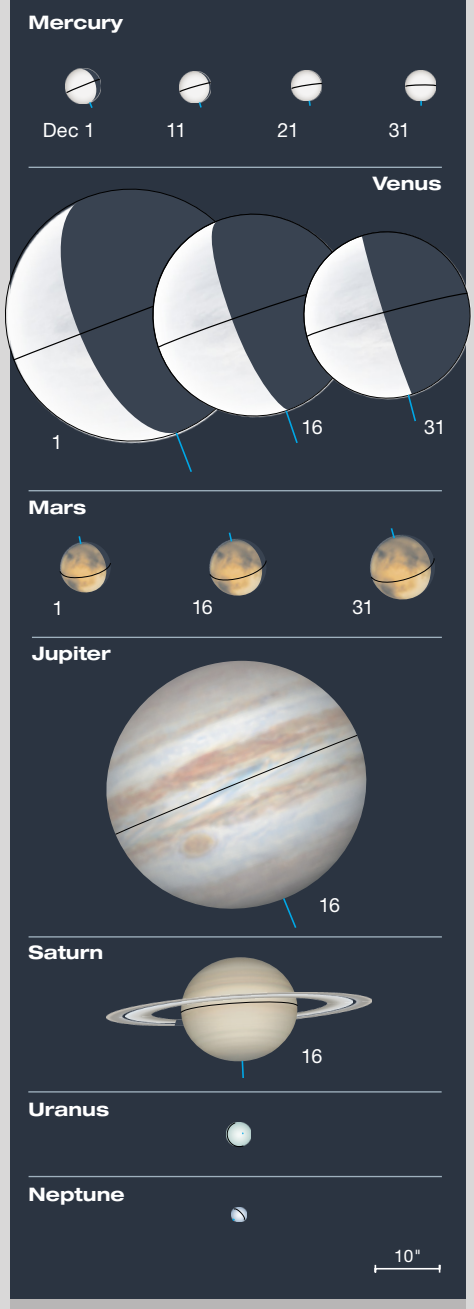
Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy 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 until the 10th • **Venus** visible at dawn • **Mars** and **Jupiter** rise in the late evening and are visible all month • **Saturn** visible at dusk and sets early morning.



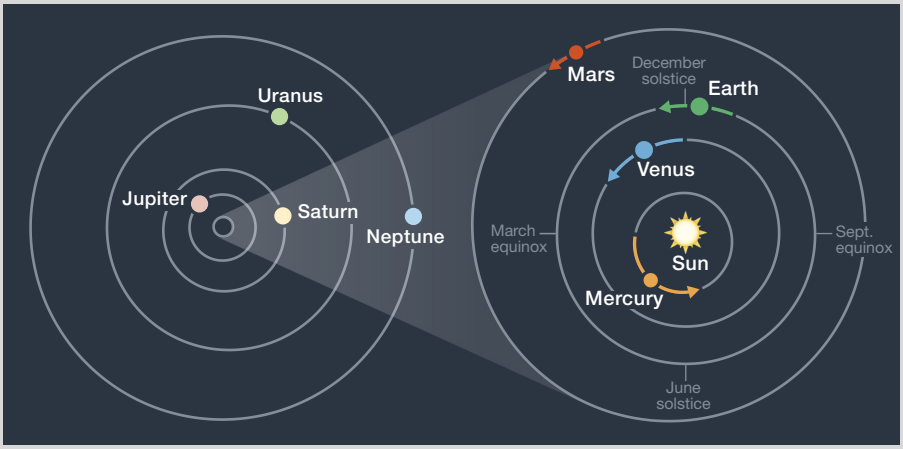
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

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

December Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$16^h\ 26.7^m$	−21° 42′	—	−26.8	32′ 26″	—	0.986
	31	$18^h\ 38.9^m$	−23° 08′	—	−26.8	32′ 32″	—	0.983
Mercury	1	$15^h\ 18.7^m$	−16° 41′	17° Mo	−0.6	5.5″	85%	1.218
	11	$16^h\ 19.7^m$	−21° 05′	12° Mo	−0.7	5.0″	94%	1.357
	21	$17^h\ 25.7^m$	−23° 59′	7° Mo	−0.9	4.7″	98%	1.428
	31	$18^h\ 34.9^m$	−24° 51′	2° Mo	−1.3	4.7″	100%	1.442
Venus	1	$13^h\ 44.7^m$	−9° 16′	41° Mo	−4.9	39.1″	28%	0.427
	11	$14^h\ 11.6^m$	−10° 34′	44° Mo	−4.8	33.6″	36%	0.497
	21	$14^h\ 44.7^m$	−12° 38′	46° Mo	−4.7	29.2″	42%	0.570
	31	$15^h\ 22.4^m$	−15° 02′	47° Mo	−4.6	25.8″	48%	0.646
Mars	1	$10^h\ 17.7^m$	+13° 05′	97° Mo	+0.5	7.9″	90%	1.178
	16	$10^h\ 36.7^m$	+11° 43′	107° Mo	+0.2	8.9″	91%	1.047
	31	$10^h\ 48.7^m$	+11° 03′	120° Mo	−0.1	10.2″	93%	0.922
Jupiter	1	$9^h\ 55.7^m$	+13° 28′	102° Mo	−2.2	39.2″	99%	5.033
	31	$9^h\ 54.7^m$	+13° 41′	133° Mo	−2.4	42.7″	100%	4.618
Saturn	1	$0^h\ 32.2^m$	+0° 39′	119° Ev	+0.7	18.7″	100%	8.896
	31	$0^h\ 33.0^m$	+0° 53′	89° Ev	+0.8	17.7″	100%	9.373
Uranus	16	$4^h\ 01.7^m$	+20° 31′	159° Ev	+5.6	3.8″	100%	18.506
Neptune	16	$0^h\ 06.7^m$	−0° 47′	98° Ev	+7.9	2.3″	100%	29.730

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.**

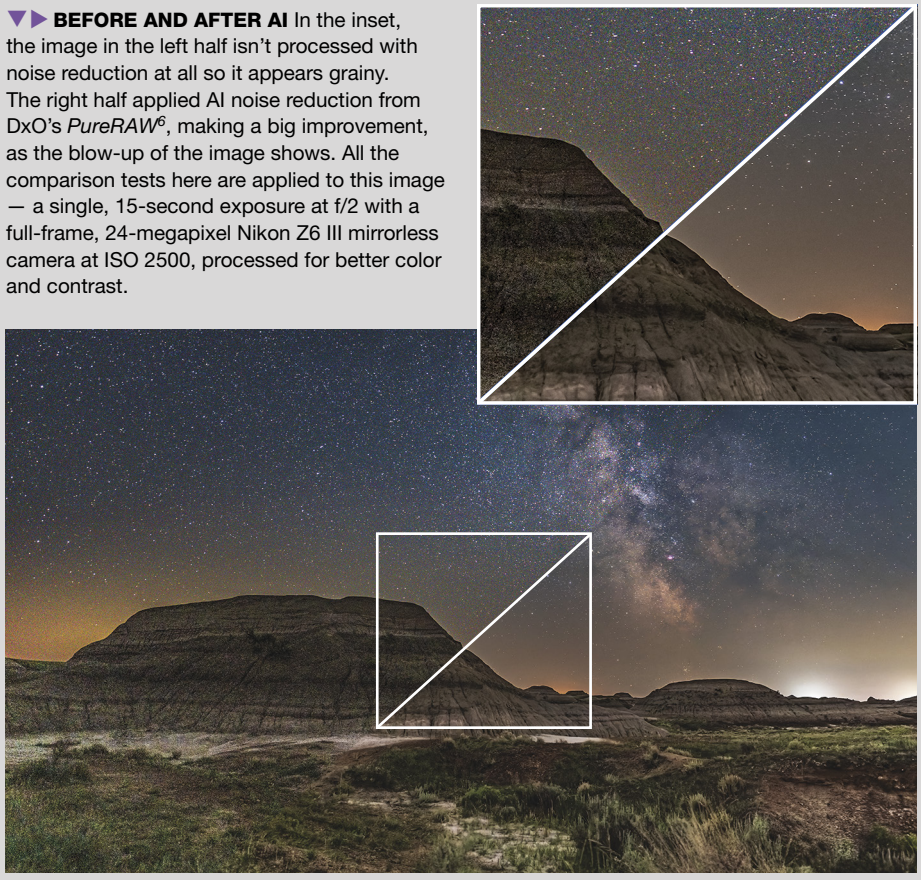


Take Advantage of AI Noise Reduction

Put the power of artificial intelligence to work in improving your nightscape photos.

As astrophotographers, we're always battling with noise. The desirable signal from our dim targets is often buried in our cameras' unwanted, random electronic noise. That's particularly true of nightscapes, where landscapes are lit only by starlight.

The best way to beat noise is to maximize the signal when we shoot the images — see my complementary article, "Getting the Correct Exposure for Nightscapes"(*S&T:* Oct. 2026, p. 53). Yet despite our best practices in the field, our images might still be marred by nasty noise. Fortunately, there's a suite of new software tools to help us. All use *artificial intelligence* (AI) to apply a level of noise reduction and detail recovery not possible with older, traditional tools. (For a summary of the use of AI in amateur astro-imaging, see the November 2025 issue, page 64.)



▼▶ **BEFORE AND AFTER AI** In the inset, the image in the left half isn't processed with noise reduction at all so it appears grainy. The right half applied AI noise reduction from DxO's *PureRAW*[6], making a big improvement, as the blow-up of the image shows. All the comparison tests here are applied to this image — a single, 15-second exposure at f/2 with a full-frame, 24-megapixel Nikon Z6 III mirrorless camera at ISO 2500, processed for better color and contrast.

ALL PHOTOS ARE BY THE AUTHOR

The Pros and Cons of AI

All noise-reduction routines — trained or not — lower both *luminance noise* that adds a general graininess to the image, and *chrominance noise* that adds colored speckling and splotchiness. Both forms of noise are worse in the dark areas of a picture, such as the starlit foreground of a nightscape, as shown in the accompanying examples.

The new AI programs promise to better separate the noise we don't want from the content we desire. This machine intelligence can distinguish specks of noise from tiny stars. Ideally! Most of these noise-reduction routines also include some level of AI sharpening to restore details lost amid the noise of high-ISO images.

Therein lies the danger. While older, non-AI noise reduction could wipe out detail, AI can instead *invent* it! In addition, I've found AI noise reduction applied to starry skies, especially to star trails, can add odd, squiggly structures or other artifacts. It pays to *pixel peep* — that is, to zoom in on an image to 100% magnification or higher to examine it at the pixel level — to make sure your image doesn't suffer from these "AI hallucinations"!

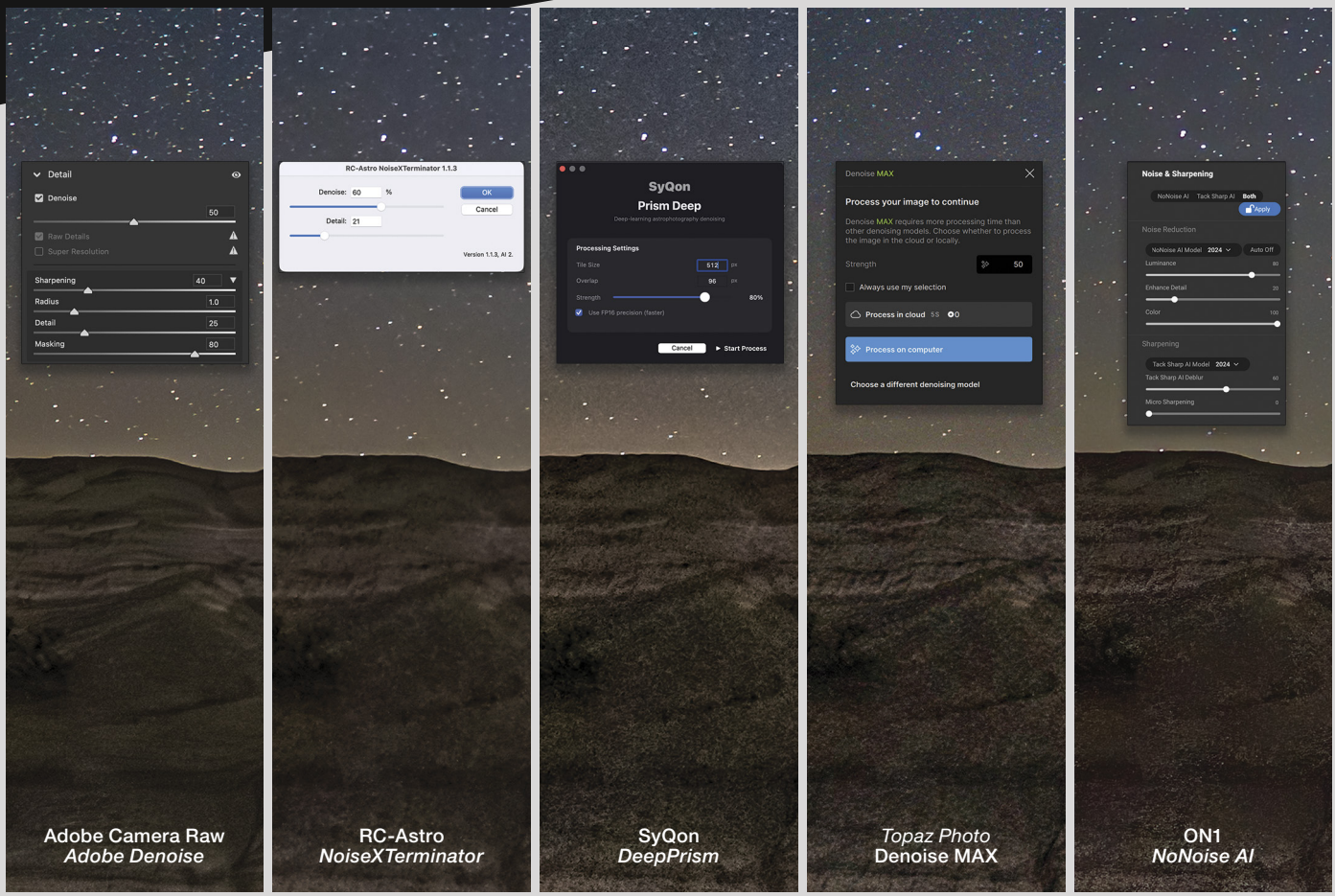
That said, by applying AI noise reduction judiciously, perhaps backing off the strength or the level of detail recovery, these new tools can work wonders. But which AI program is best for our astrophotos? I tested several, with the best and best known, described here.

Comparing Plug-Ins

First, I analyze programs that can install as plug-ins within *Adobe Photoshop* (**photoshop.adobe.com**) to run as third-party filters. I compare them to what I consider the reference standard, *Adobe Denoise*, which is applied only to RAW files from within *Adobe Lightroom*, *Lightroom Classic*, or Adobe Camera Raw before bringing the image into *Photoshop*.

Of the programs I cover here only two — RC-Astro's *NoiseXTerminator* and SyQon's *DeepPrism* — are designed for astrophotography. However, they work best for deep-sky images, not nightscapes.

RC-Astro *NoiseXTerminator.* Russell Croman's suite of *XTerminator* plug-ins (**rc-astro.com**) has revolutionized deep-sky image processing, especially when used within the specialty



▲ **PLUG-IN FILTERS COMPARED** At far left is the *Adobe Denoise* version compared to four AI noise-reduction filters installed and applied as *Photoshop* plug-ins. *NoiseXTerminator* does a good job on the sky. With other contenders, noise remains, especially in *Topaz Photo's* Denoise MAX model. ON1's *NoNoise AI* did a good job but was still somewhat patchy.

program *PixInsight* (**pixinsight.com**). *NoiseXTerminator* is installed as a plug-in for both *Adobe Photoshop* and *Canva Affinity* (**www.affinity.studio**), where it often does a superb job smoothing out noise in the sky without harming stars. However, I find it has limited benefit on nightscape foregrounds — not surprising as that's not what its AI is trained on.

SyQon *DeepPrism*. Similarly, the program *DeepPrism* from the new company SyQon (**syqon.eu**) based in Italy is designed for deep-sky images. *DeepPrism* (aka *Prism Deep*) promises to enhance detail and contrast as well as reduce noise. I tested the *Photoshop* plug-in version and found that, while it might work well on nebulae, it didn't work well on nightscapes, leaving a lot of visible noise. But SyQon's products are new and evolving quickly (they also have the *Starless* star-removal app).

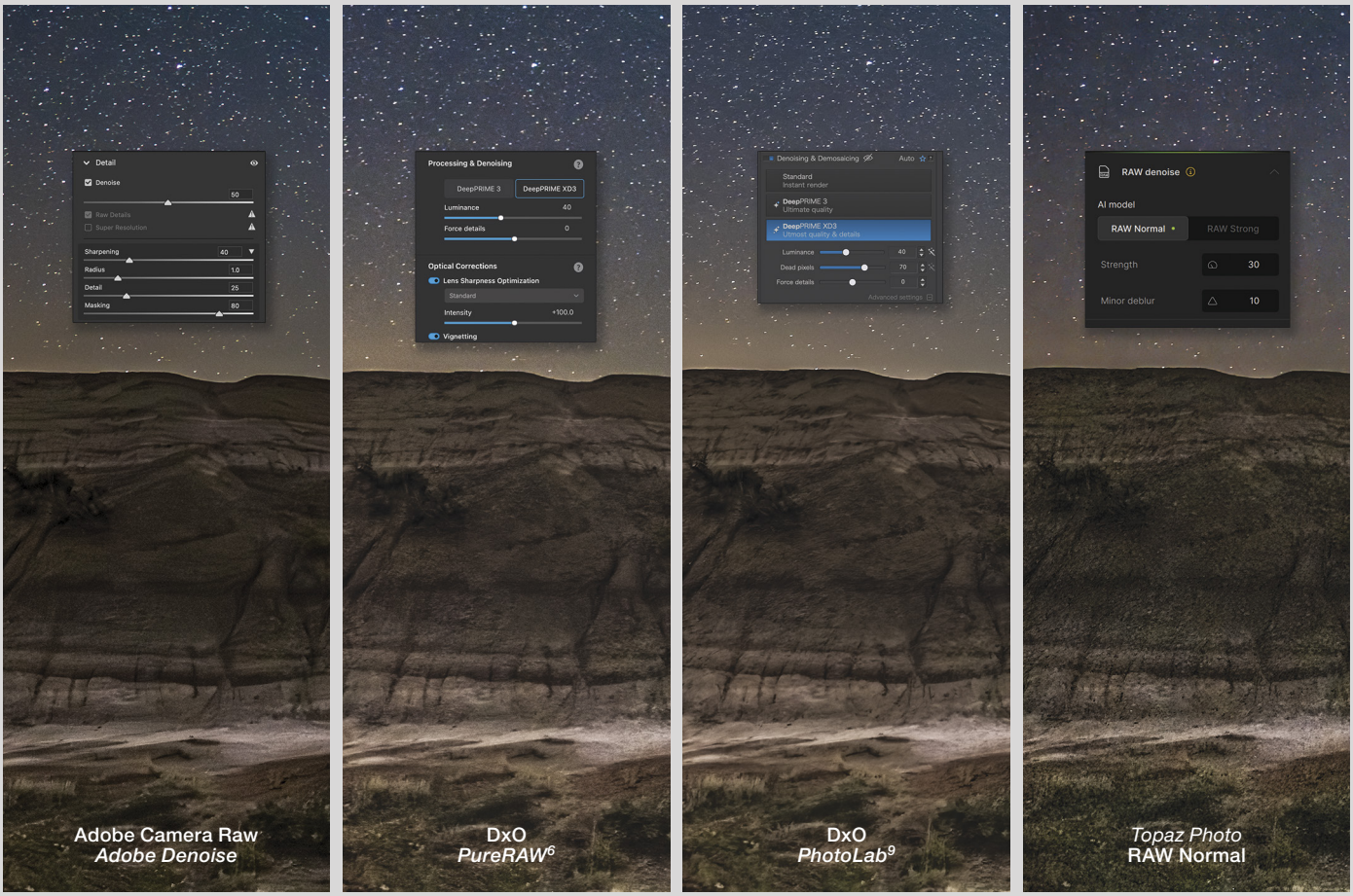
Topaz Labs *Topaz Photo*. Topaz Labs (**topazlabs.com**) pioneered AI noise reduction with their plug-in *DeNoise AI*. In 2022, Topaz phased it out in favor of *Photo AI*, which merged their three AI programs for noise reduction, sharpening, and upscaling into a single app. In 2025, Topaz discontinued that app, too, in order to release the similar *Topaz Photo* as part of a larger, subscription-based *Topaz Studio* suite. You can install *Topaz Photo* as a standalone app or as a plug-in for *Photoshop*, *Lightroom Classic*, or *Canva Affinity*. I found its Normal noise-reduction model exhibited patchy artifacts. The new Denoise MAX model (shown above applied at 50%), while more uniform, still left a lot of noise. Applying the model at greater than the 50% level wiped out stars.

ON1 *NoNoise AI*. ON1 (**on1.com**) offers *Photo RAW*, a full-featured application designed to replace both *Adobe Lightroom* and *Photoshop*. Included within *Photo RAW*, but also available as a separate plug-in, is *NoNoise AI*. I found *NoNoise* could do a good job on the sky, but not so well on the ground where it introduced sharpening artifacts and patchy noise reduction.

Standalone Apps

The following programs run as standalone apps and work only on RAW files straight from the camera. All can export Digital Negative (.DNG) files, a format that keeps the image "raw" for further editing in other programs.

DxO *PureRAW*⁶. The French company DxO (**www.dxo.com**) has gained a lot of fans with its *PureRAW* app that provides lens correction, detail recovery, and a superb level of AI noise reduction. As its name implies, it works only on



▲ **STANDALONE APPS COMPARED** This evaluates *Adobe Denoise* against DxO's two options: the standalone PureRAW[6] application and its RAW editor app *PhotoLab*[9]. Both use the latest DeepPRIME XD3 training model for excellent and identical results. *Topaz Photo's* RAW Normal, which works only on camera RAW files, left a lot of noise and patchiness.

camera RAW files and should be applied at the start of an editing workflow.

I tried earlier versions and was never happy with the results as it added an odd, mosaic pattern to the sky visible at the pixel level. Introduced in early 2026, *PureRAW*[6] fixes that flaw and produced superb results in my nightscape tests using its latest DeepPRIME XD3 (eXtra Detail) model. It does tend to over-sharpen, making some hot pixels in long-exposure images even more visible. *Adobe Denoise* reduces most hot pixels but doesn't eliminate them all.

DxO *PhotoLab*[9]. The features of *PureRAW*[6] are built into DxO's image-editing software *PhotoLab*[9], a competitor to *Lightroom* (but not to *Photoshop* as *PhotoLab*[9] doesn't have image layers). But for developing RAW files, *PhotoLab*[9] is one of the best non-subscription alternatives to Adobe. Its noise reduction results are identical to *PureRAW*[6], as both use the same DeepPRIME XD3 training model.

Topaz Labs *Topaz Photo*. When used as a standalone app for opening RAW files, *Topaz Photo* applies a special "RAW Denoise" routine. I found the results no better than when using *Topaz Photo* as a plug-in filter from within *Photoshop*.

Recommendations

Which program you use depends on your workflow and whether you accept or abhor subscriptions! I prefer to keep my workflow within the Adobe family, so I usually apply *Adobe Denoise* to the RAW files. Then, in *Photoshop*, I might apply a touch of *NoiseXTerminator* or *NoNoise AI* as a nondestructive "smart filter" if further smoothing or sharpening is needed. But with the improvement in its latest version, DxO's *PureRAW*[6] is now a powerful first-step option in your nightscape-processing workflow. Further processing requires a good RAW editor such as *Lightroom*, *Lightroom Classic*, or Adobe Camera Raw (or just use *PhotoLab*[9] alone).

However, don't take my word for it. With the exception of SyQon and Topaz Labs products, all these plug-ins and apps are available as free trial copies. Newer versions of the programs I tested — and no doubt others to come — will certainly feature improved AI models for even better results. If you've avoided AI on principle, don't — for noise reduction, the machine can be your friend!

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

Goodnight, Moon

Reflections on my more than a half century of lunar interest.

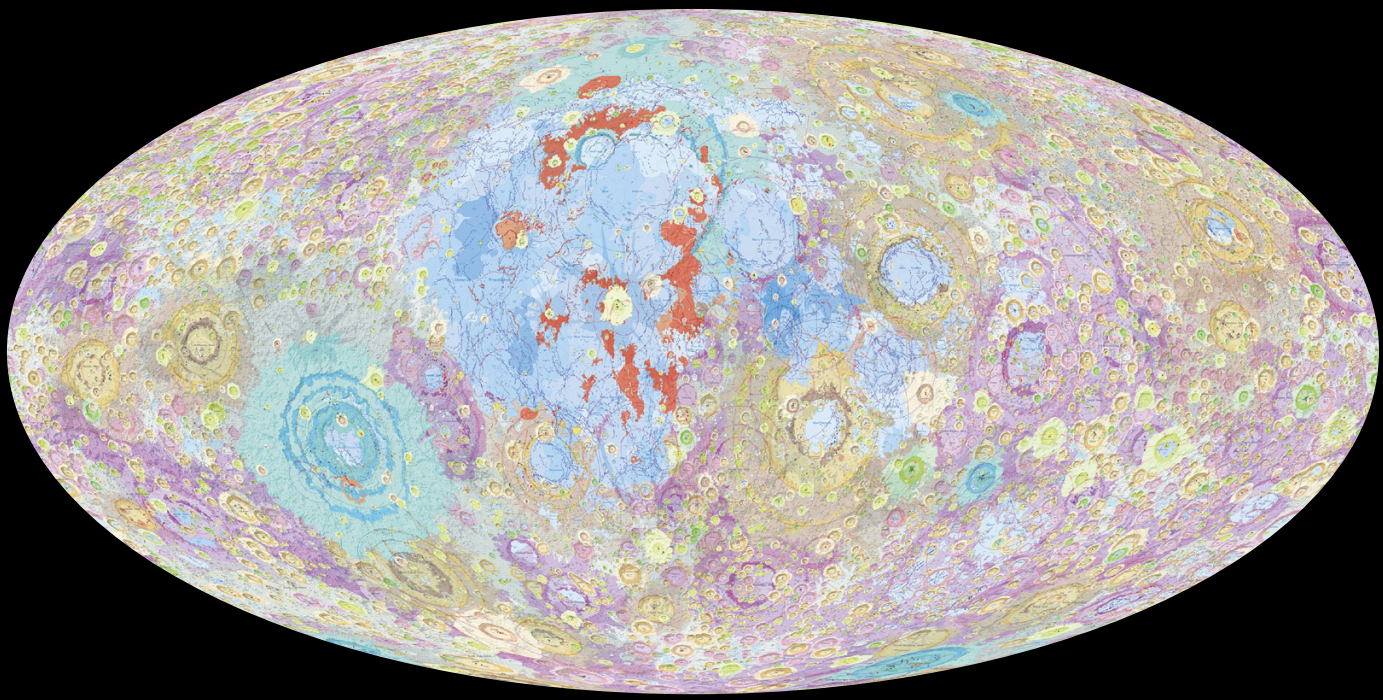


▲ The Lunar Reconnaissance Orbiter's Narrow Angle Camera imaged each of the Apollo landing sites, including that of Apollo 17 seen above. The image resolves the Challenger descent stage at center as well as the footprint and rover trails made by the astronauts more than 50 years ago.

APOLLO 17 LANDING SITE: NASA / GSFC / ARIZONA STATE UNIVERSITY; CHINESE GEOLOGIC MAP: JINZHU JI ET AL. / INSTITUTE OF GEOCHEMISTRY / CHINESE ACADEMY OF SCIENCES

The Moon isn't leaving, but I am. For the last 27 years I've written columns for *Sky & Telescope,* connecting modern scientific lunar discoveries with what amateurs could observe at the telescope. It's been an exciting and challenging adventure that forced me to pay attention to explaining science. Now my aging eyes are failing, and the goal of lunar exploration has evolved from my specialty of geologic science to practical concerns such as resource utilization and human habitability, of which I have little expertise.

Since my teenage years in the 1950s, I've dreamt about human exploration of the Moon and for a long time hoped to be one of its pioneers. While that didn't happen, I instead immersed myself in the geology of the Moon and found ways I could make my own contributions to modern lunar and planetary science. In my undergraduate days, I helped compile the first space-age catalog of lunar craters at Gerard Kuiper's Lunar and Planetary Laboratory



The 1:2,500,000 scale geologic lunar map released by the Chinese Academy of Sciences is the most detailed so far.

at the University of Arizona, and later conducted research with Jim Head's planetary geology group at Brown University. Additionally, my on-the-ground experience exploring Earth's volcanoes and rift valleys provided me with practical understanding of planetary geologic processes. Throughout my decade-long stint as a space scientist at NASA's Johnson Space Center in Houston, I interacted with astronauts, the U.S. Geological Survey Astrogeology group, and the international space science community. What a lucky, Earth-bound life I've led!

My Lunar Notebook and Exploring the Moon columns from 1999 through 2026 (briefly appearing as Exploring the Solar System) span much of the interval between the first golden age of space exploration and a currently emerging second period of human lunar exploration. A series of extraordinary lunar robotic spacecraft highlighted the first quarter of the 21st century, resulting in discoveries that continue to surprise and delight. Major lunar missions in this period include NASA's Lunar Reconnaissance Orbiter and LCROSS missions in 2009, and its GRAIL mission in 2011. Japan's JAXA launched the Selene orbiter in 2007, better known by its nickname Kaguya. India's growing ISRO space program targeted the Moon with its Chandrayaan 1 and 3 missions in 2008 and 2023, respectively. And China's CNSA launched a series of six Chang'e lunar missions from 2007 to 2024. Major discoveries flowed from each.

The most transformative finding, based on new spacecraft data provided by both the Chandrayaan and LCROSS missions, as well as samples returned by various missions, is that water in some form exists on the Moon. That immediately focused future exploration at the lunar south polar region, where permanently shadowed craters preserve ice. A second important discovery was the dating of the 2-billion-year-old mare lava sample (returned by Chang'e 5) that filled a nearly 2-billion-year-long gap between the known ages of mare rocks and the youngest craters dated from Apollo samples.


Charles A. Wood

The mission that simply keeps on giving is the Lunar Reconnaissance Orbiter, having so far provided 17 years of high-resolution imaging. The constant scanning of the lunar surface by this Energizer-bunny-like spacecraft has documented the formation of hundreds of new impact craters. In addition, it has mapped the precise locations of successful landings and crashes. LRO, along with other Moon-wide ultra-high-resolution imager systems, have resolved meter-scale impact melts, miniature fault ridges, and peculiar volcanic pits. This unprecedented, global resolution provides evidence of geologic processes that would previously have been available only to on-the-ground geologists.

China used its own lunar imaging from the Chang'e spacecrafts and combined it with other international missions' data to assemble the second geologic map of the entire Moon (*S&T:* Aug. 2023, p. 52). And NASA's two GRAIL satellites precisely mapped the Moon's gravity field. The results clearly defined barely visible lunar basins and also revealed perhaps the largest tectonic structure on the Moon — a completely unsuspected nearside ring of subsurface magmatic dykes.

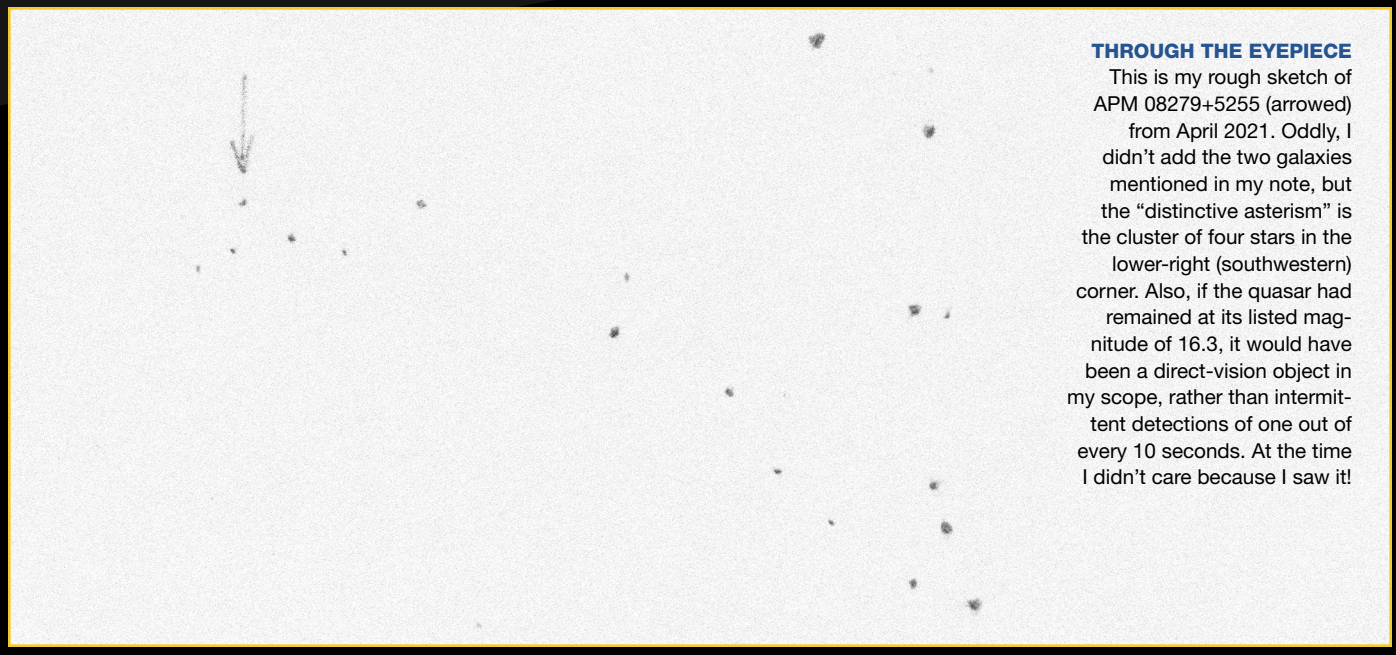
We've recently begun the process of returning to the Moon, with the Artemis II mission flying behind it earlier this year. A landing is planned for some time in the next few years that will attract billions of Earthlings' eyes to the Moon. Identifying the landing sites or at least the area they'll be located near the south pole will undoubtedly challenge amateur observers. But the need to maximize solar energy and Earth communication requires large solar arrays and radio dishes, so that astronaut bases on high, sunlit peaks might be visible in some fashion. And of course, the rest of the nearside lunar surface will remain as mesmerizing as it has been forever. As a passionate, lifetime student of the Moon, I'll continue observing with my backyard telescope as long as I can. I hope you will too.

■ Contributing Editor **CHUCK WOOD** is eternally grateful for the editorial help over the years by *S&T* editors Kelly Beatty, Gary Seronik, and Sean Walker.



▲ The Japan Aerospace Exploration Agency (JAXA) Selene spacecraft (also known as Kaguya) took HDTV video and images of the Moon from an unusual perspective. This view shows the nearside, 153-km-wide crater Ptolemaeus as the orbiter approached from the north.

AUTHOR PHOTO: CHUCK WOOD; FLYOVER VIEW FROM KAGUYA: JAXA / NHK



THROUGH THE EYEPIECE
This is my rough sketch of APM 08279+5255 (arrowed) from April 2021. Oddly, I didn't add the two galaxies mentioned in my note, but the "distinctive asterism" is the cluster of four stars in the lower-right (southwestern) corner. Also, if the quasar had remained at its listed magnitude of 16.3, it would have been a direct-vision object in my scope, rather than intermittent detections of one out of every 10 seconds. At the time I didn't care because I saw it!



Snagging Quasars

Read on for how you, too, can spot a variable quasar (or two!).

Light from the highly luminous quasar **APM 08279+5255** comes to us from the early universe. Its redshift (*z*) of 3.912 corresponds to a light-travel time of 12.22 billion years, and, assuming the universe is 13.79 billion years old, means the light from this quasar has been on its way to us for 89% the age of the universe.

Let that soak in.

Amazingly, observers have spotted it visually with telescopes as small as 16 inches. More on that later, but first . . .

▲ **WIDE VIEW** This image covers a slightly larger area than my sketch — 15th-magnitude UGC 4438 is the obvious galaxy on the far right with "distinctive asterism" to its lower left. You can follow the same trail of stars in my sketch to the location of APM 08279+5255 in the upper left. North is up in all images.

Um, What's a Quasar Again?

Although first proposed in 1964 by Edwin E. Salpeter and Yakov Zel'dovich, it took decades of research to determine that quasars are powered by an accretion disk around a supermassive black

SKETCH: HOWARD BANICH; FIELD OF SKETCH: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

hole. The massive energy output of this system, or more precisely, the efficiency of gravitational energy release by accretion, depends on the rotational speed of the black hole — the faster it rotates, the more energy it releases. Its efficiency of converting matter to energy ranges from 5.7% (non-rotating) to 32% (rotating). Compare that to the 0.7% for the nuclear fusion that powers stars — it's no wonder quasars are so luminous.

The true color of an accretion disk is a white-hot blue. However, depending on the dust environment around the disk as well as its distance from us, it will typically appear as yellow-orange or orange-red.

Most visual observers assume that quasars are impossible to detect. They're *sooooo* far away that even the very brightest ones are faint and starlike in our telescopes. But we *can* see the brightest ones, even when they're incomprehensibly distant.

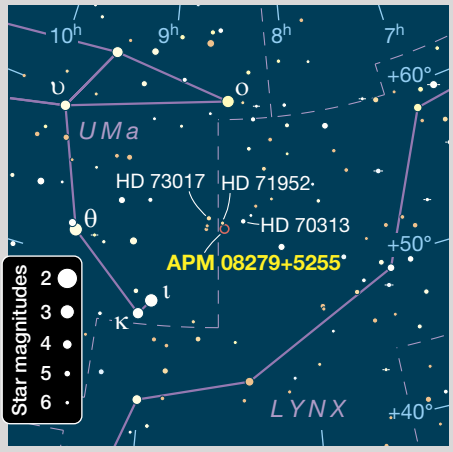
The Quasar's Specs

The APM part of our target's name comes from the Automatic Plate Measuring Facility survey dedicated to finding cool carbon stars in the galactic halo. During the search, APM 08279+5255 was serendipitously identified as a distant quasar based on its spectrum. The numbers — as with many modern targets — are derived from its position in right ascension and declination, in this case in 1950 coordinates.

The host galaxy is a giant starburst, ultra-luminous infrared galaxy with copious amounts of gas and dust. The supermassive black hole at the core weighs in, depending on who's doing the calculation, at a whopping 10 to 23 billion solar masses.

At the very least its event horizon is about 0.003 light-years in diameter, or 190 astronomical units. In solar system terms, that's between the Kuiper Belt and the Oort Cloud. Hey, it's not called a supermassive black hole for nothing!

Even though APM 08279+5255 is one of the most intrinsically luminous objects known, its brightness is further amplified four times by gravitational lensing via an inclined spiral galaxy



▲ **FAINT QUASAR** Look for APM 08279+5255 in eastern Lynx, on the border with Ursa Major. The target's coordinates are right ascension $08^h\ 31.7^m$, declination +52° 45′. Use my sketch as well as the finder image on page 58 to home in on your target. Start at any of the 6th-magnitude HD stars noted in the chart above to find the 13th-magnitude galaxy UGC 4438 (in the image at left), and from there hop to the quasar.

around 6.5 billion light-years away, exactly along our line of sight. This lensing also split the quasar's light into three separate images, the first time an odd number of lensed images was recorded.

Although APM 08279+5255 is classified as radio-quiet, it does have a relativistic jet that emits X-rays blasting out at 76% the speed of light, and an outflow of interstellar gas launched by its accretion disk at around 10% to 20% the speed of light. This outflow will eventually slow star formation in its host galaxy.

Over the quasar's 12 billion years of light-travel time, the universe was expanding, and now APM 08279+5255 is around 23.7 billion light-years away — what we call its *co-moving radial distance*. The current radius of the observable universe is 46 billion light-years, so the quasar is about halfway "out."

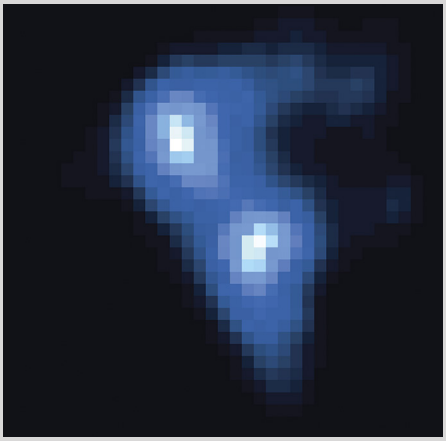
Finally, let's think about photons for a moment. They're massless particles traveling at the speed of light and do not experience time. By definition, they embody the most extreme example of *time dilation*. At light speed, time stops. So, from the perspective of the photon — as if a photon could have a perspective — it's emitted by the quasar in the same instant it reaches us. From our perspective it's taken more than 12 billion years, but then this isn't intuitive, it's general relativity.

Observations

As the farthest object any of us is ever likely to see in the eyepiece of a telescope, APM 08279+5255 looks like a very faint star. *S&T* Contributing Editor Steve Gottlieb observed the quasar twice, in 2005 and 2006, with his 18-inch reflector and estimated its magnitude to be around 16. I later learned that in 2012 a highly experienced observer with a 16-inch telescope on an excellent night was able to detect it (**tinyurl.com/APM-16inch**).

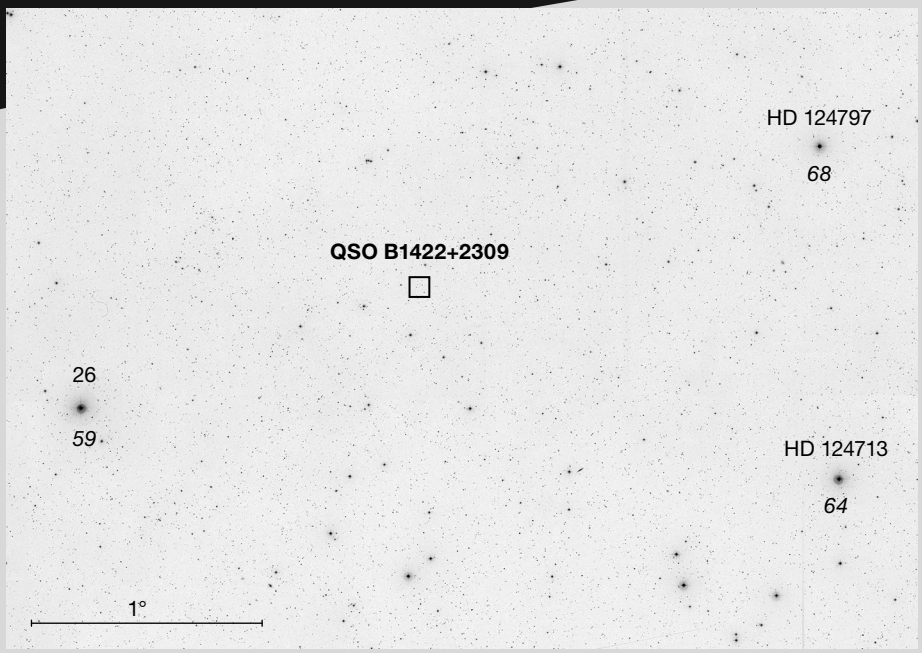
All this spurred me on to try it for myself. I pointed my 28-inch reflector at the quasar in 2021, when it was obviously fainter:

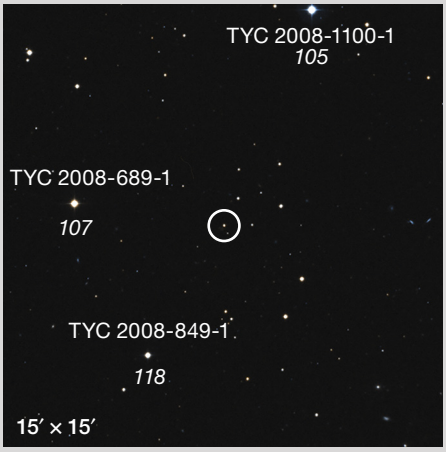
> *Holy smokes, I saw it — light from nearly the beginning of the universe. A tiny, difficult-to-see dot that popped in and out of view once I found the correct field — I can see it about 1 out of every 10 seconds.*
>
> *I started by finding [the galaxy] UGC 4438, which was obvious at 155×, and in the same field of view is a distinctive asterism. I then used these stars to point me to [the galaxy] SDSS J083114.54+524224.7, which helped me identify the fainter field stars that led me to the quasar. I'm*



▲ **X-RAY EMITTER** The Chandra X-ray Observatory obtained this image of APM 08279+5255, which shows the gas outflow from the accretion disk.

X-RAY IMAGE: NASA / CXC / PSU / G. CHARTAS





▲ **DOUBLE TREAT** Look for QSO B1422+2309 in Boötes at right ascension 14^{h} 24.6^{m} and declination +22° 56′. The 6th- and 7th-magnitude stars noted above should guide you to your quarry, then zoom in using the chart at right. At magnitude 15.8, QSO B1422+2309 is currently bright enough to be seen with a 12-inch scope by an experienced observer with excellent conditions.

gobsmacked — and so glad I'm here right now. 408×, 22.04 SQM [Sky-Quality Meter]

"Here" means Chickahominy Reservoir in central Oregon. And boy oh boy, the sky couldn't have been any darker. Transparency was almost as good, but the seeing was neither sharp nor mushy. I estimate the magnitude of the quasar then was about 17.0 to 17.3.

Given these four visual observations, it's clear that the quasar's listed visual magnitude of 16.3, determined in 2000 by the Sloan Digital Sky Survey, was no longer correct.

Regardless, I had several episodes of chills as I was glued to this barely seen sight for over an hour, entranced by the trickle of those ancient — yet new to me! — photons becoming an image in my brain. In a very real sense, each one of those photons became uniquely mine after all that time, and in no time at all.

Fainter Still

In May 2026, I joined Steve, Akarsh Simha, and Jimi Lowrey in West Texas for several nights of observing with Jimi's wonderful 48-inch reflector. APM 08279+5255 was at the top of my observing list, and we checked in on it on the best night of the five we observed together. My notes read:

Ok, I'm staggered again. Surprisingly dim, the soft seeing made seeing the quasar's image detectable about 50% of the time. No hope to see its color, but this observation strongly suggests that the quasar's luminosity is variable enough to impact its V mag. Now that's interesting! 488×, 21.89 SQM

The four of us discussed this in context with Steve's observations from 20 years ago. None of us could imagine seeing the quasar at its current magnitude in an 18-inch scope given how difficult it was in the 48-inch. In light of past observations of other faint star-like objects in Jimi's 48-inch, my guess is that the quasar was no brighter than 18th magnitude.

A few hours later, Steve suggested we have a look at a similarly distant quasar, **QSO B1422+2309** (at a redshift of 3.620) for comparison. That's a light-travel time of 12.06 billion years. It's more strongly lensed than APM 08279+5255 and is significantly brighter at visual magnitude 15.8. At first glance it was apparent that the listed magnitude of QSO B1422+2309 was still correct:

This is in the same (z) neighborhood as the APM quasar — and is way brighter. Direct vision. This is how I expected the APM quasar to look . . . Supposedly V mag 15.8, that fits with what I'm seeing. 375×, 21.93 SQM

After this observation, we were confident that APM 08279+5255 was significantly fainter than at any time since 2012.

It's well known that quasars are variable. How variable has APM 08279+5255 been between the observations above? As a clue, a 1999 study showed it brightened by 0.2 magnitude in 100 days, so it's possible that its brightness has fluctuated quite a bit since then. Apparently, I can deduce from my observations that the overall trend has been for dimming.

Seeing an object halfway to the edge of the observable universe in our backyard scopes — and detecting changes in its brightness in only a few years — seems implausible. But that's just how the universe works sometimes.

■ Contributing Editor **HOWARD BANICH** plans to keep watching and hopefully will see APM 08279+5255 brighten in the future. Just as interesting will be to never detect it again! He can be reached at **hbanich@gmail.com**.

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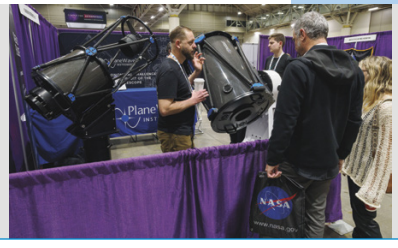





◀ DUAL-SCOPE MOUNT

PrimaLuceLab announces a powerful mount for astrophotographers. The Saturn HD-20 is a compact, strain-wave-geared mount head capable of carrying a 20-kg (44-lb) payload. The mount slews at a maximum speed of up to 19° per second, and magnetic encoders with 1.3-arcsecond resolution are incorporated into both axes to produce extremely low periodic error that can be further reduced with autoguiding. The mount features dual saddles that accept both Vixen- and Losmandy-style dovetail plates allowing users to attach two optical tubes to double their imaging output each night. The Saturn HD-20 operates in both alt-azimuth and equatorial modes and is treated with a protective ceramic coating for enhanced durability in outdoor environments. Price yet to be determined.

PrimaLuceLab
1108 Championship Rd., Oceanside, CA 92057
442-218-4507; primalucelab.us



◀ TINY OBSERVING STATION

ZWO unveils its most powerful smartscope to date. The Seestar S50 Pro ($999) is built around two optical groups: a 50-mm f/5.2 apochromatic quadruplet refractor and a 6-mm wide-angle lens. Each is paired with a CMOS color sensor having a 2,160 × 3,840 array of pixels. The optics and internal electronics ride along in a compact, alt-azimuth Go To mount that also supports equatorial mode for long exposures. The Seestar S50 Pro is controlled by the *Seestar* app, which runs on Android or iOS smartphones or tablets and connects with either Wi-Fi or Bluetooth. Images are saved in both JPEG and FITS format on 128GB of internal memory. The device is powered by an internal, rechargeable lithium-ion battery that can run the unit for up to nine hours. Each purchase includes a field tripod, USB-C charging cable, magnetic solar filter, and soft case.

ZWO
6 Moon Bay Rd., Suzhou Industrial Park, Jiangsu Province, China
Phone: +86-512-65923102; zwoastro.com



◀ OFF-AXIS GUIDER PLUS

William Optics now offers the Elite Drawer OAG Kit ($388) that combines two accessories into one. This off-axis guider also incorporates a filter drawer to permit adding light-pollution or other filters for telescopes that don't offer an internal filter provision. The unit accepts autoguiding cameras with 1¼-inch nosepieces and also includes M42 threads to hard-mount the camera. Focus is adjusted with a stationary helical focuser. The guider's pick-off prism can be adjusted between 7.5 and 19 mm from the field center to avoid encroaching on the imaging camera's sensor. Its magnetic filter drawer allows users to quickly switch between 48-mm-format filters. The Elite Drawer OAG Kit requires 37.5 mm of back focus and connects to cameras with M54 or M48 threaded adapters.

William Optics
williamoptics.com

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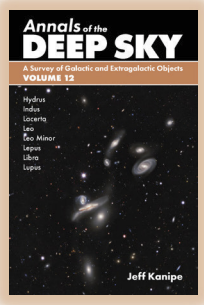

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Image: NGC 6891, a bright, asymmetrical planetary nebula in the constellation Delphinus, the Dolphin. (NASA)



Discovering Our Gal

We inhabit a collection of galaxies that boasts two great spirals, Andromeda and our own Milky Way. When astronomers first recognized the Local Group in 1935, they knew of only nine definite denizens. Today we have more than 100 to study. This is the story of the Local Group's initial discovery and its enormous growth since.

▲ **NEAR PEERS** Shining only 2.5 million light-years from Earth, the Andromeda Galaxy *(left)* is the closest giant to our own Milky Way *(right)*. Within the Local Group, only the Andromeda Galaxy exceeds the Milky Way in size and luminosity. Together the two giants rule more than 100 other galaxies in the Local Group. These superpowers rank in the top 2% of all galaxies in the universe.

Gauging Galaxies

Unveiling the Local Group hinged on measuring distances to galaxies. Only by knowing whether other galaxies swarm around our own can anyone assert that we even belong to a group, let alone ascertain which galaxies are its members.

A major step toward this goal occurred in 1907 (*S&T:* Dec. 2021, p. 12), at a time when most astronomers thought no galaxies existed except our own. When Henrietta Leavitt, an astronomer at Harvard University, was examining photographic plates of the Magellanic Clouds, she uncovered hordes of Cepheid variables, luminous yellow stars that periodically brighten and fade.

For 16 Cepheids in the Small Magellanic Cloud (SMC), she measured how many days their light took to wax and wane. She found a striking relation: "It is worthy of notice that . . . the brighter variables have the longer periods," she wrote in *Annals of Harvard College Observatory*. Because these Cepheids all reside in the SMC, the differences in their brightness do not arise from their distances — indeed, all of them are about equally far from Earth. Thus, the brighter Cepheids must also be intrinsically brighter. Since no one then knew how far the SMC was, no one knew the Cepheids' intrinsic brightness, either. But gauging the distances of Cepheids near the Sun revealed how much light a Cepheid of a particular period radiates, transforming them into "standard candles" that helped calculate the distance to any object containing Cepheids.

Meanwhile, also in 1907, Swedish astronomer Karl Bohlin published measurements he said he had made "with extreme accuracy." He discerned the parallax of what was then called the Andromeda Nebula. It was a small object within our galaxy, he claimed, a mere 19 light-years from Earth. This distance supported the prevailing view that spiral nebulae such as Andromeda were newborn solar systems inside the Milky Way.

Five years later, strong evidence to the contrary emerged. In 1912, Lowell Observatory astronomer Vesto Slipher succeeded in the arduous task of recording Andromeda's spectrum (*S&T:* Sept. 2023, p. 20). The galaxy's Doppler shift held a shocking revelation: Andromeda is rushing toward the Sun at an astonishing 300 kilometers per second (670,000 mph), faster than any star then known.

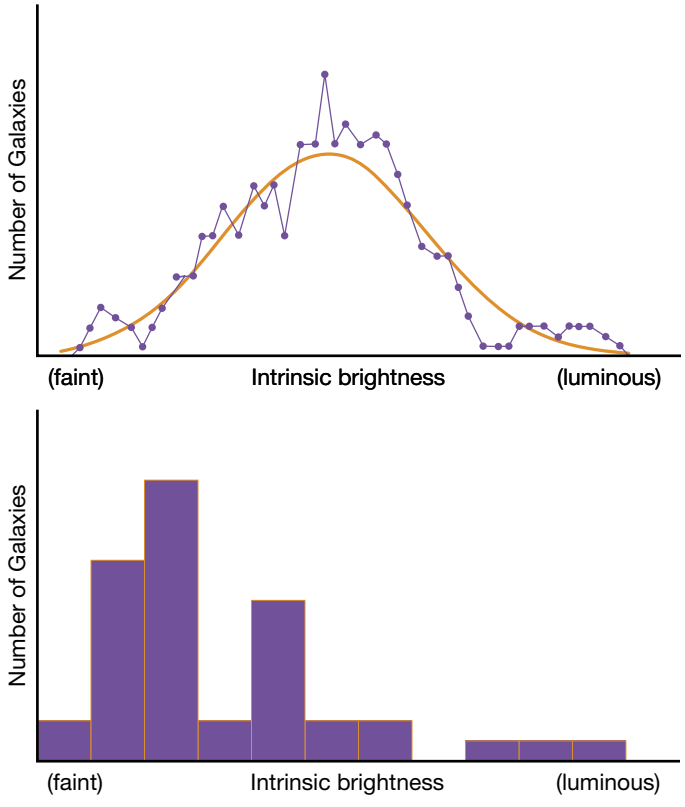
"It looks as if you had made a great discovery," wrote Slipher's boss, Percival Lowell. "Try some more spiral nebulae for confirmation." Slipher did, finding high velocities for them as well. True solar systems in the Milky Way should move through space about as fast as its stars. Perceptive astronomers like Lowell realized that such speedy objects probably weren't part of the Milky Way but instead separate systems far beyond.

TONY HALLAS



actic Family

Meet the galactic gathering that includes the Milky Way and more than 100 other members.



▲ **HUBBLE'S ERROR** Whereas Edwin Hubble thought that galaxy luminosities follow a bell curve (top), modern data for the Milky Way and its many satellites demonstrate that the true luminosity distribution is skewed in favor of dim galaxies, as Hubble's colleague Walter Baade had suggested (bottom).

MILKY WAY: ALAN DYER; HUBBLE'S LUMINOSITY FUNCTION: BEATRIZ INGLESSIS / S&T; SOURCE: EDWIN HUBBLE / *THE REALM OF THE NEBULAE* (1936); MODERN LUMINOSITY FUNCTION: BEATRIZ INGLESSIS / S&T; SOURCE: A. DRLICA-WAGNER, ET AL. / *ASTROPHYSICAL JOURNAL* 2020

Proof came a decade later — from Cepheids, which are so luminous that astronomers can see them across vast distances. In 1923, Edwin Hubble at Mount Wilson Observatory in California spotted a Cepheid in Andromeda. By measuring the star's period and apparent brightness and exploiting Leavitt's period-luminosity relation, Hubble demonstrated that Andromeda resides well outside the Milky Way and is therefore a galaxy (*S&T:* Sept. 2023, p. 26).

Hubble's breakthrough spelled bad news for Harvard astronomer Harlow Shapley, who six years earlier had discovered that our galaxy is big and the Sun far from its center. Shapley maintained that no galaxies existed outside our own enormous one. "There are not many of you who can remember the time when there were, so to speak, no galaxies," recalled Shapley's former student Cecilia Payne-Gaposchkin during a dinner commemorating 20 years of his leadership at Harvard College Observatory. "I remember it very well. I remember the day Dr. Shapley said: 'My universe has been shattered.'" (*S&T:* Dec. 1941, p. 12).

Gathering the Galaxies at Hand

By observing Cepheids in other galaxies, Hubble determined which of them lie near our own. Luminous though Cepheids are, Hubble couldn't see them in galaxies far away. There he used more powerful objects, such as novae and blue supergiant stars, to measure distances.

In 1929, by coupling his distance estimates with Slipher's velocities, Hubble announced his greatest discovery: The farther a galaxy is, the greater its redshift and so the faster it moves away from us. Today we interpret this correlation as a

sign of the universe's expansion, but Hubble was more cautious, referring to the link between redshift and remoteness as simply the "velocity-distance relation."

In the autumn of 1935, Hubble delivered a series of lectures at Yale University. They form the heart of his book *The Realm of the Nebulae*, published the following year. As the title suggests, Hubble didn't care for the word "galaxies" (see sidebar below), so throughout the book he uses "nebulae" to mean galaxies and "the galactic system" to mean the Milky Way.

Here Hubble introduced the Local Group, though he didn't capitalize it the way we do today:

> *The small-scale distribution of nebulae is very irregular. Nebulae are found singly, in pairs, in groups of various sizes, and in clusters. The galactic system is the chief component of a triple nebula in which the Magellanic Clouds are the other members. The triple system, together with a few additional nebulae, forms a typical, small group that is isolated in the general field of nebulae. The members of this local group furnished the first distances, and the Cepheid criterion of distance is still confined to the group.*

In other words, only in the Local Group could astronomers of Hubble's era see Cepheids.

In addition to the Milky Way and the Magellanic Clouds, Hubble's Local Group had six definite members. Three make up another "triple nebula" of Andromeda plus its two close satellites, M32 and NGC 205 (now also known as M110). The other three are the spiral galaxy M33 in Triangulum; NGC 6822, an irregular galaxy in Sagittarius that American astronomer Edward Emerson Barnard had spotted in 1884; and IC 1613 in Cetus, another irregular galaxy.

Three more galaxies, Hubble said, may possibly inhabit the Local Group as well. All three lie near the Milky Way's dusty plane, which by absorbing the galaxies' light made their distances difficult to determine. Today we know that only one, the irregular galaxy IC 10 in Cassiopeia, is a genuine Local Group resident. Hubble's other two suspects have proved to be too distant: the beautiful spiral NGC 6946 straddling the border of Cepheus and Cygnus, famous today for its many supernova explosions; and IC 342, a lovely spiral galaxy in Camelopardalis.

Beyond the Local Group, Hubble also recognized far grander gatherings in the distance: the great galaxy clusters. These averaged about 500 members. In galaxy clusters, he said, "All types of nebulae are represented, but in contrast to the general field, the earlier types, and especially the elliptical nebulae, predominate." Field galaxies are those that are on their own, neither in groups nor in clusters, and most are spirals.

At that time, some astronomers thought that galaxies began life as ellipticals and turned into spirals. If so, elliptical galaxies would be younger than spirals. From this idea and the difference between the elliptical-rich clusters and the spiral-rich field, Hubble reasoned that galaxies might originate in clusters, because they had the youngest galaxies, the ellipticals. Over time, then, clusters must disintegrate and split into individual galaxies. To Hubble's credit, he called this theory "speculation" and said "many more data will be required before it can be seriously considered." Today astronomers think the progression is just the opposite: Galaxies start off as individuals and then, under the force of their gravity, gather into groups, some of which merge further to create

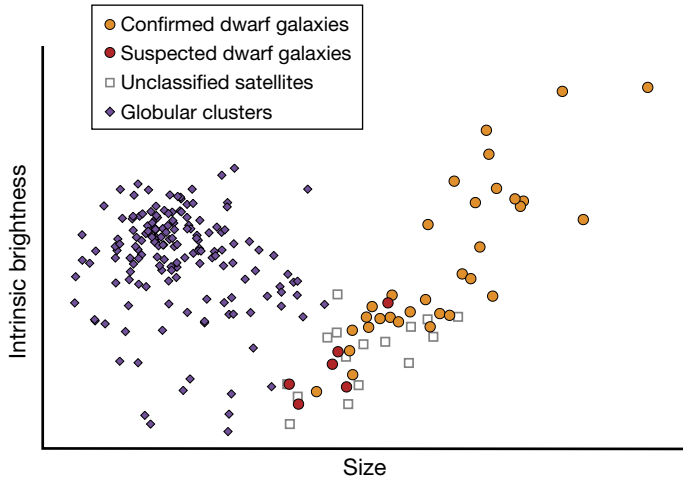
Hubble Didn't Like *Galaxies*

Ironically, although Edwin Hubble proved that other galaxies exist, he wasn't fond of the word and therefore called them *nebulae* instead: "The term *nebulae* offers the values of tradition; the term *galaxies*, the glamour of romance," he wrote, adding, "The *Oxford English Dictionary* gives the established definition of *galaxy* ('a luminous band or track, encircling the heavens . . . ; the Milky Way'), and states that the transferred and figurative use is 'now chiefly applied to a brilliant assemblage or crowd of beautiful women or distinguished persons.'"



ANDROMEDA SATELLITE The third-largest galaxy in the Local Group, M33 lies in the constellation Triangulum and is a likely satellite of the Andromeda Galaxy.

PROCESSING: ROBERT GENDLER, DATA: HUBBLE LEGACY ARCHIVE / KPNO / NOIRLAB, NSF / AURA / ROBERT GENDLER



▲ **GALAXY OR STAR CLUSTER?** It's hard to know whether some of the dimmest stellar systems are galaxies or star clusters. But as this diagram shows, true galaxies tend to have larger diameters than star clusters. The former have half-light diameters exceeding 100 light-years.

clusters. In addition, ellipticals don't become spirals; in fact, if two spirals collide, they can create an elliptical galaxy.

Surprisingly, Hubble arrived more firmly at another incorrect conclusion. He claimed that very faint dwarf galaxies are "relatively rare objects." Why? Because he didn't see them beyond the Local Group. Within the group, he said, three of the nine definite members then known fell into this category: Barnard's Galaxy, IC 1613, and NGC 205. "Their presence in the local group appears to be a unique feature of the group, and they detract from its significance as a fair sample of nebulae in general," he wrote. He thought that galaxies follow a bell-shaped curve: Most have a middling luminosity, while a few are much brighter and a few much fainter. He failed to realize that the Local Group, where we can detect even hard-to-see objects because of their proximity, was actually signaling a profound profusion of feeble galaxies throughout the cosmos.

"Queer Companions"

In fact, no one had yet spotted even one example of the most common galaxy type. That occurred soon afterward when, in 1938, Hubble's rival Shapley reported the presence of two mysterious objects in the Local Group. In his book *Galaxies* — Shapley had no problem with the word — he called them "Queer Companions in Sculptor and Fornax," noting, "Two hazy patches on a photograph have put us in a fog."

The first ghostly glow of widely separated stars shimmered in the constellation Sculptor. "The swarm looked suspiciously like a darkroom unhappiness — fingerprints during development, perhaps, or a misadventure with the photographic film during its manufacture," Shapley wrote. But when the same smudge turned up on another photographic plate, he knew the object was real. It looked like a globular star cluster, but it was several thousand light-years across, like a small galaxy. So was it a star cluster or a galaxy? Distant galaxies shone behind the strange object, so whatever it was, it had little or no dust to block their light.

Meanwhile, a similar smudge appeared on a photographic plate of Fornax, a constellation just east of Sculptor. The Fornax system proved more illuminating, because it had star clusters. Thus, Shapley said, it is a galaxy, not a star cluster. After all, a dog can have fleas, but a flea can't have fleas. Likewise, a galaxy can have star clusters, but a star cluster can't. The Sculptor and Fornax systems must therefore



MAGELLANIC MAGIC Unique among the Milky Way's many satellite galaxies, the Magellanic Clouds still create new stars, probably because the pair swung close to our gas-grabbing galaxy only recently and so have held on to their interstellar gas and dust, the raw material for forging stars.

GRAPH: BEATRIZ INGLESSIS / *S&T*; SOURCES: J. D. SIMON, *ANNUAL REVIEW OF ASTRONOMY & ASTROPHYSICS* (2019) / HARRIS, *ASTRONOMICAL JOURNAL* 1996 (GLOBULAR CLUSTERS); MAGELLANIC CLOUDS: ESO / S. BRUNIER

What Is the Closest Galaxy to Earth?

This simple question once had a simple answer: the Large Magellanic Cloud, some 160,000 light-years from Earth. Although this galaxy remains special as by far the most luminous and the most massive Milky Way satellite, it's no longer the closest known galaxy to Earth.

Unfortunately, the current answer to the question is complicated, for two reasons. First, we can't always state with certainty that one galaxy is closer than another, because measuring the distance to a galaxy using only a few stars results in large uncertainties. Second, some alleged galaxies may actually be star clusters.

If we boldly ignore both complications, then the current champ is Draco II, discovered in 2015 and lying about 70,000 light-years from Earth. The good news? This distance is secure. The bad news? Draco II could be a star cluster rather than a galaxy. Still, a recent study calls it a likely galaxy, even though it's so tiny that half of its light emerges from a region just 110 light-years across. Its total luminosity is a mere 180 times that of the Sun.

The next nearest galaxy is probably Segue 1, located 75,000 light-years from Earth in Leo, a constellation rich in Milky Way satellites. Segue 1 is indeed a galaxy, though its few stars emit only 280 times more light than the Sun. However, the galaxy's distance is more uncertain than we'd like.

Finally we have the well-known Sagittarius dwarf spheroidal, the galaxy the Milky Way is ripping apart. An analysis in the *Astrophysical Journal* of April 20, 2026, used Gaia spacecraft data to determine that this galaxy's core is 80,000 light-years from Earth.

Fortunately, the question "What is the closest galaxy to the Milky Way?" does have a simple answer: the Sagittarius Dwarf Spheroidal. Because it's on the far side of the Mily Way, its core is closer to our galaxy's heart — only 55,000 light-years away — than to us.

Two decades ago, astronomers claimed that a closer galaxy lay in Canis Major (*S&T:* Feb. 2004, p. 22). But the stars in this supposed galaxy turned out to belong to the Milky Way instead.

Oh, and if you run across a website stating that the nearest galaxy is Andromeda (the internet can be a dangerous place), you might want to invest your time elsewhere, such as by reading this magazine!

be galaxies of a new type, which astronomers now call *dwarf spheroidals*.

The Sculptor and Fornax dwarf spheroidals orbit the Milky Way just as the much brighter Magellanic Clouds do, but they lie farther away. Shapley searched more than a third of the sky for other dim, diffuse, dust-free galaxies and came up dry: "Probably others will be found, in our neighborhood or not far beyond; but not numerously." Those last three words, however, would not survive subsequent discoveries.

The first astronomer to recognize the predominance of dim galaxies was probably Hubble's Mount Wilson colleague Walter Baade. In 1943, by exploiting the dark wartime skies along the West Coast fostered by the lack of outdoor lighting, Baade photographed NGC 147 and NGC 185 in Cassiopeia and succeeded in detecting their stars, which meant both galaxies must be nearby.

"They are new members of the local group of galaxies," Baade wrote in the *Astrophysical Journal*, where he listed all known members of the group.

> *The list shows that the dwarfs now outnumber the giants almost in the ratio of two to one. Since it is certain that all the giant members of the group are known, future additions will only increase this ratio. Although caution is necessary in basing conclusions on a sample as small as the local group, there seems little doubt that the large percentage of dwarf systems is significant and that the symmetrical form of the luminosity function hitherto adopted has to be replaced by a skew distribution.*

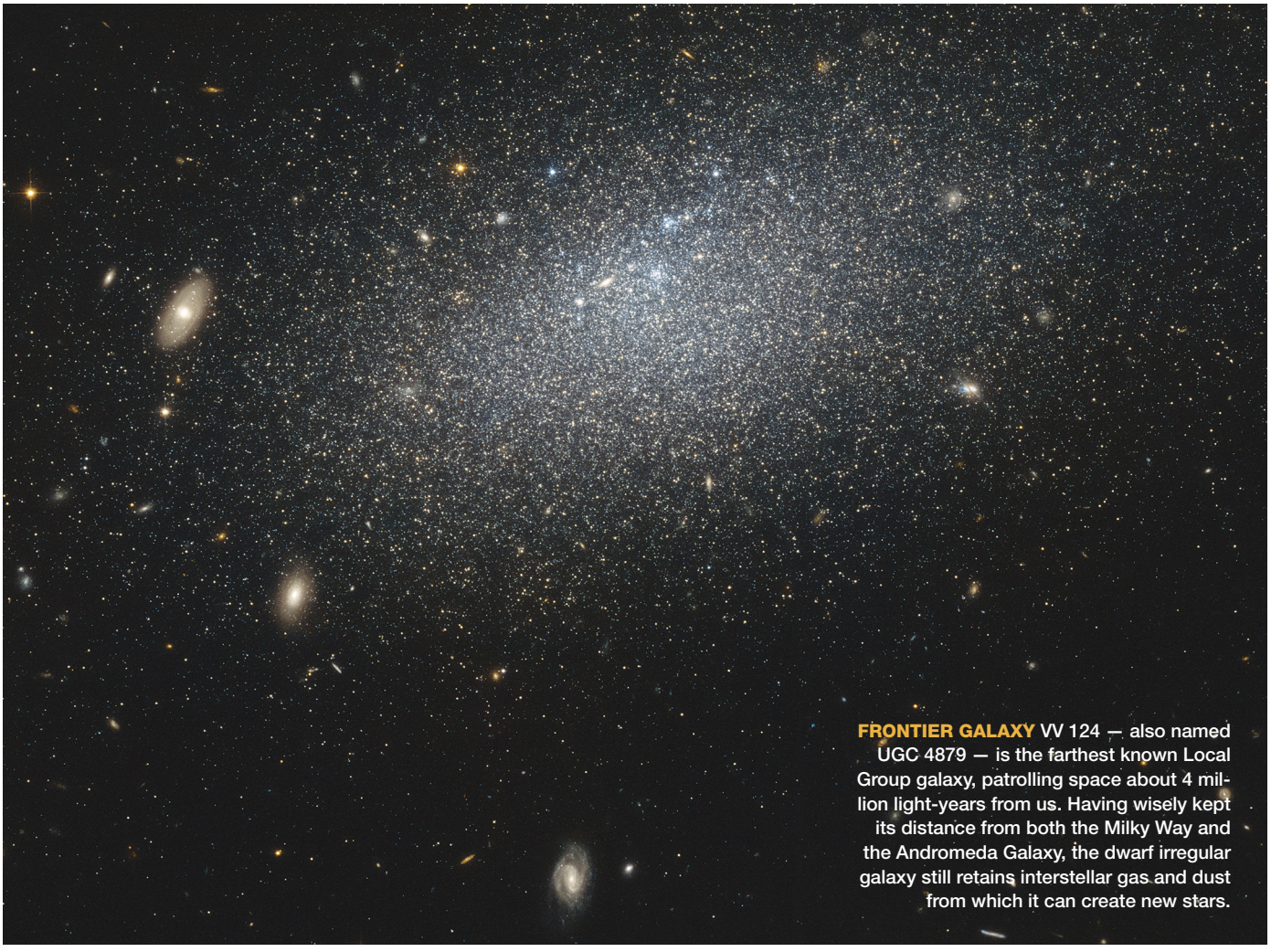
Whereas Hubble had claimed that the luminosity distribution was a bell-shaped curve, Baade realized that feeble galaxies outnumber all the rest.

The Local Group proved Baade correct. Astronomers detected two dwarf spheroidal galaxies in Leo and one each in Draco and Ursa Minor during the 1950s; one in Carina in 1977; and in 1990 a dwarf spheroidal in Sextans so diffuse it took a scanning machine connected to a PC to spot the subtle excess of stars that betrayed the obscure galaxy on a photographic plate. "Without the computer, there's no way Sextans would have been found," said the discoverer, Mike Irwin (University of Cambridge, UK). All these galaxies orbit the Milky Way.

The most dramatic discovery came in 1994, when Rodrigo Ibata (then at Cambridge), Gerry Gilmore (also at Cambridge), and Irwin spotted a group of stars on the other side of the galaxy, in the constellation Sagittarius, all moving in the same direction. The stars mark a dwarf spheroidal that our galaxy is shredding. The Sagittarius dwarf spheroidal is the closest known galaxy to the Milky Way's center, though probably not the closest to Earth (see sidebar at left).

The Meek Inherit the Local Group

In 2005, astronomers began discovering even dimmer dwarf spheroidal galaxies (*S&T:* Mar. 2017, p. 16). Now called ultra-



FRONTIER GALAXY VV 124 — also named UGC 4879 — is the farthest known Local Group galaxy, patrolling space about 4 million light-years from us. Having wisely kept its distance from both the Milky Way and the Andromeda Galaxy, the dwarf irregular galaxy still retains interstellar gas and dust from which it can create new stars.

faint dwarfs, each emits less light than 100,000 Suns would; the brightest star clusters actually outshine them. Dozens of these faint galaxies orbit the Milky Way.

By measuring the motions of stars, astronomers can usually tell which of these dim stellar systems are galaxies and which are merely star clusters. In faint objects that are true galaxies, the stars move so fast that they would escape their homes were it not for the additional gravitational attraction of dark matter. Star clusters, on the other hand, don't have any dark matter. Still, the status of some of the dimmest systems is currently unclear.

Today the Local Group contains more than 100 known galaxies. Most are satellites of Andromeda or the Milky Way, but about a dozen orbit neither. The two giant spirals are 2.5 million light-years apart, and altogether the Local Group spans some 8 million light-years. Gravity tethers its galaxies together, so they will remain close to us even as the universe expands.

The member galaxy farthest from the Local Group's center is VV 124, which Russian astronomer Boris Vorontsov-Veliaminov cataloged in Ursa Major during the 1950s. Harvard astronomers later measured a redshift indicating that the galaxy lay tens of millions of light-years away, far beyond the Local Group. But in 2008 another Russian astronomer, Alexander Kopylov, became suspicious when he noticed that Sloan Digital Sky Survey images revealed the galaxy's stars, a sign of its proximity.

Sure enough, VV 124 is our neighbor. In fact, the galaxy has a blueshift rather than a redshift, which means it actually moves *toward* the Sun. The dwarf galaxy's distance from Earth is about 4 million light-years. Far from the Milky Way, far from Andromeda, yet bound to both giants by the invisible force of gravity, VV 124 patrols the Local Group's frontier, the dividing line between our cozy galactic family and the wilds beyond, where other galaxy groups and clusters, caught in the universe's relentless expansion, dash away from us.

■ Contributing Editor **KEN CROSWELL** earned his PhD for studying the Milky Way. He is the author of *The Universe at Midnight*, a book about galaxies and cosmology, as well as *The Alchemy of the Heavens*, a book about the Milky Way.

FURTHER READING: To learn more about the faintest dwarf galaxies, see Joshua Simon's article in the 2019 *Annual Review of Astronomy and Astrophysics*, **tinyurl.com/AnnRev-JDSimon**.

ESA / HUBBLE / CC-BY-SA 2.0

You're a Nebula, Harry

Have you ever seen a painting that you can stare at forever and still never see all the details? NGC 7380 is the nebula version of that. Technically, it's a young cluster of stars embedded in an emission nebula. Stellar winds blowing off these nascent stars have sculpted the surrounding gas and dust over 5 million years into these intricate shapes. And the stars' intense ultraviolet radiation ionizes that gas, creating the magnificent glow astro-imagers love to highlight.

Astrophotographers have nicknamed this star-forming cloud the Wizard Nebula for its appearance in long exposures. The roughly cone-shape feature above a somewhat humanlike face and hands, followed by a sweeping, cloaklike cloud of ionized gases, bring to mind ancient spellcasters such as Merlin from Arthurian legend, as well as some more recent fantasy characters like Gandalf from *The Lord of the Rings* and Albus Dumbledore from *Harry Potter*.

NGC 7380's proximity to Polaris means stargazers at northern latitudes can enjoy it pretty much year-round. In December, you'll find it near the zenith. More specifically, this wizard resides in Cepheus's left arm approximately 2½° east of Delta (δ) Cephei. It can be a challenge to spot visually, as its 7.2-magnitude glow is spread out across half a degree, or an area about the extent of the full Moon. You'll need a very dark sky and a doubly ionized oxygen filter to catch this elusive magician. While a small scope or even binoculars will highlight the cluster well, to spot the Wizard's nebulosity observers may require a scope as large as 8 inches — and bigger will always be better.

Caroline Herschel discovered the cluster in 1787 with her 4.2-inch reflector, but she didn't mention the associated emission nebula. She is occasionally called out in historical texts as the notetaker and assistant of her better-known brother, William Herschel, but Caroline was an astronomer and deep-sky observer in her own right — in fact, she discovered eight comets and 14 deep-sky objects, including NGC 7380.

Whether studying the Wizard Nebula historically, visually, scientifically, or photographically, this diffuse patch of dusty sky hides a great deal worth exploring.
—SABRINA GARVIN





Photograph by
David Gluchowski / Flickr / CC BY-NC 4.0

ZWO's AM7 Mount

This compact, lightweight mount can handle a heavy load at an attractive price.

AM7 Harmonic Equatorial Mount

U.S. Price: $2,999*
zwoastro.com

What We Like

Operates in equatorial and alt-azimuth modes

App control doesn't require hand controller

Seamless compatibility with other ZWO products

What We Don't Like

Difficulty balancing payload

SkyAtlas app limited to one-star alignment

Requires third-party counterweights

**Prices subject to change*

IN LITTLE MORE THAN a decade, strain-wave-driven telescope mounts have gone from an exotic curiosity into a full-blown manufacturing trend. I've used a few of them, including the Rainbow Astro RST-135 (*S&T:* Aug. 2023, p. 68) and Sky-Watcher's Wave 150i (*S&T:* Aug. 2025, p. 68), and the appeal isn't hard to understand. These mounts are small, surprisingly strong, and in many cases let you leave the counterweights in the garage. That last part is especially attractive to imagers who have spent years lugging cumbersome steel disks around in the dark.

ZWO's AM line of strain-wave mounts is perhaps the most visible example of this new mount category. The AM3 and AM5 (the latter reviewed in the April 2023 issue, page 64) are already popular with imagers using small to mid-sized astrographs and the company's ASIAir control systems. The AM7 is its newest, largest model, intended for heavier optical tubes and longer focal lengths while keeping the quick setup and no-frills operating character that made the smaller mounts so attractive. ZWO loaned us an AM7 head for this review, and I was anxious to get it out under the stars as soon as weather permitted.



◀ The ZWO AM7 is the latest entry in the company's growing line of strain-wave-geared telescope mounts. Here it's seen on a Starfield pier and carrying an Astro-Physics 92-mm Stowaway refractor.

Fit and Finish

The AM7 arrived in a box hardly bigger than the head itself. Inside was the mount's dark gray, expanded polypropylene foam case made of the same material that the company's SeeStar S50 case is manufactured from. This stuff is extremely lightweight and protects its contents very well. The interior is custom-fitted to hold the mount, its cables and hand paddle, and an optional counterweight shaft (which was also provided for this review).

The AM7 follows the familiar red-and-black-anodized finish of virtually all ZWO cameras, mounts, and accessories (apart from the SeeStar series smartscopes). The head weighs 6.75 kg (14.9 pounds), yet ZWO states it can bear a payload of 20 kg without a counterweight and up to 30 kg with one. The right ascension axis is driven with a 100:1 strain-wave gear that includes a power-off safety brake — this ensures your scope and other equipment won't come crashing into the tripod or pier in the event of a power failure. The declina-

ALL PHOTOS BY THE AUTHOR



▶ The AM7 mount comes with a joystick hand controller, a USB-A to USB-B cable, and a small wrench for changing the latitude range. An optional, 25-mm-diameter counterweight shaft was provided for this review, though ZWO doesn't currently offer counterweights. Note that the mount also doesn't include a power cable.



▶ The rear of the mount contains its latitude-adjustment knob and azimuth adjustments. Note the power and USB-C ports on the rear of the saddle plate. The power port provides power for connected equipment though the USB-C only permits connecting a computer and cannot be used as a USB hub or passthrough port.

tion axis is also driven by a similar 100:1 strain-wave gear though it lacks a safety brake. ZWO describes the system as strain-wave gearing with the addition of synchronous belts providing a 300:1 reduction ratio on each axis. The company notes that each axis is equipped with a specialized astronomical harmonic reducer to achieve a periodic error consistently within ±10 arcseconds. That last part is notable, as most strain-wave mounts have non-repeatable errors that can vary quite a bit.

The mount uses a mechanical home position that's easy to return to after an unexpected power failure (extremely important for remote operation).

The mount's saddle plate accepts both Losmandy-D and Vixen-style dovetail bars, which is exactly what I want to see on a mount in this capacity class. The optional counterweight shaft is a 25-mm (1-inch) diameter, 250-mm-long stainless-steel rod with M16 threads that attaches to the bottom of the declination axis opposite the saddle (a silver-threaded cap covers the hole). However, ZWO didn't provide any counterweights, and that omission mattered more than I expected. The company really promotes the strength of its strain-wave drives not requiring counterbalance, and that's true when using smaller instruments (it drove my Astro-Physics 92-mm Stowaway just fine like this). But I wanted to test the AM7's capabilities at the upper end of its weight capacity by pairing the mount with the Stellarvue SVX180T-2 refractor I was reviewing at the time (*S&T:* Oct. 2026, p. 72). It weighed in at a little more than 20 kg with a camera and other imaging accessories, and that required counterweights.

Unfortunately, ZWO doesn't currently offer its own counterweights for the AM7 shaft, and the smaller AM5 and AM3 counterweights don't fit. Third-party options with a 25-mm bore are hard to find, and that leaves the buyer to sort out a critical accessory. (Luckily, the counterweights for SkyWatcher's AZ-EQ6 that I had on hand fit the AM7 shaft perfectly.) Also not included is a power cable. Users must provide their own 12-volt, 5-amp DC power supply for the mount.

The latitude and azimuth adjustments used for polar alignment work well, but there are a few things you may need to adjust indoors before heading out in the dark. The AM7 has two positions for latitude ranges: 0° to 60° and 30° to 90° (note that 30° to 60° fall within both ranges). Fine latitude adjustments are made using the silver latitude-adjustment knob. For azimuth adjustments, use the pair of black, opposing push knobs on the back of the mount base. Tighten one knob while loosening the other and then tighten both when finished polar aligning.

The AM7 has several ports along the polar-facing panel. From left to right are: a USB 2.0 port for connecting to a computer; a 6-pin, ST-4-compatible autoguider port; a 4-pin connection for the hand paddle; and a 12-volt,

▼ *Left:* The mount comes in a form-fitted, expanded polypropylene foam case with a slot for the optional counterweight shaft.
Center: The front of the mount (facing the celestial pole) is where most of the electronics connect. From left to right are the Bluetooth power button and status light; a USB-B input to connect a control computer; an auto guide port; the input for the hand controller; a center-positive 12V, 5A power input; and the mount's status indicator light.
Right: The left (or western) side of the AM7 includes its power button. Note the latitude gear-adjustment screws located in the short, curved slot below the black latitude-locking knob. This as well as the one on the other side need to be moved to a different position when switching from equatorial to alt-azimuth operation.







5-amp DC (center-positive) power input. A small, black button at the bottom-left corner activates the on-board Bluetooth connection, which has a small indicator light below, and a status indicator light for the mount itself is found at bottom right. The rear of the saddle includes a 12-volt power output and a USB-C port. While this might appear at first glance to be through-the-mount cable management, the USB-C port isn't a full USB hub pass-through. The USB connection is strictly for connecting a control computer, either from the base or from a controller (like the ASIair Plus) riding piggyback on the telescope. You can use one or the other but not both, and neither are a general-purpose device hub. That distinction mattered during my testing.



▲ The saddle plate on the AM7 accepts both Vixen- and Losmandy-standard dovetail bars.

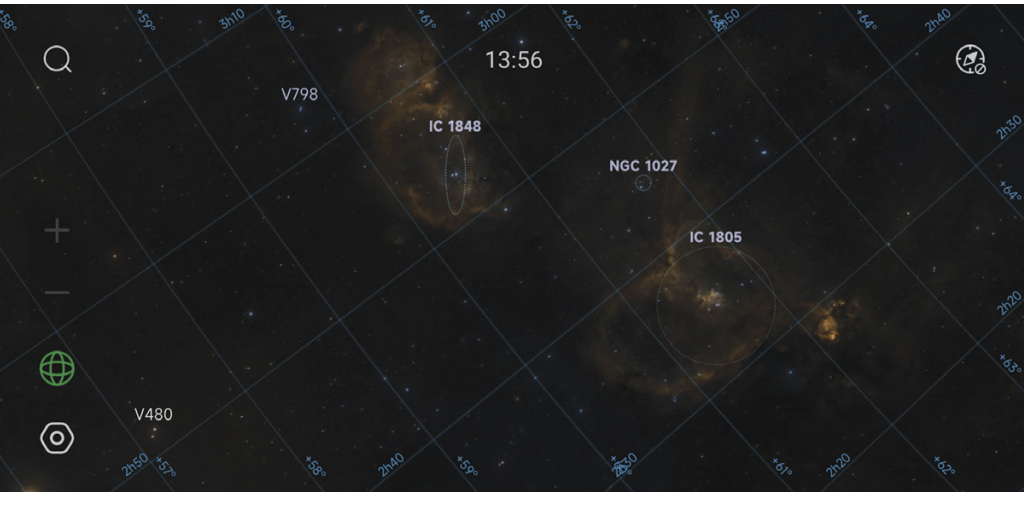
Use in the Field

The process of setting up the AM7 in the field is typical of any equatorial mount, but balancing the payload is a challenge as the mount lacks any clutch or gear-release system, which isn't unusual for mounts driven by strain-wave gearing. However, it becomes more consequential when your payload is at or near the 20-kg, no-counterweight payload limit. ZWO's own instructions warn that "the barycenter [common center of mass] of your OTA may deviate from the tripod if no counterweights are attached." In other words, the mount can tip over under certain conditions without some weight offsetting the telescope load. While using the big, heavy Stellarvue 180-mm refractor, that wasn't an academic point. ZWO didn't provide a tripod, so I attached the AM7 to a Starfield Optics Tri-Pier I own and balanced the scope as best I could by experience, but a true balance release would have been welcome. The mount's RA power-off safety brake engages when the AM7 is powered down, though ZWO advises returning it to its park position at the end of the night to reduce strain on the gearing.

With the smaller 92-mm Stowaway, the AM7 performed at its best. I paired it with the ZWO ASI2600MC Air camera (reviewed in the March 2026 issue, page 70) and controlled the entire system from an iPad. This is clearly the user experience ZWO has in mind — one power cable feeds the mount and the wireless camera/control system rides with the telescope. The result is neat, quick, and delightfully boring — meaning there are no surprises or problems when an imaging run is underway. Guiding errors were consistently lower than an 1″, often less than 0.5″, according to the software, producing nice, round stars with every exposure.

Small scopes with short focal lengths will guide better than a big, heavy scope with a long focal length. Strain-wave mounts often have a lot of non-repeating errors compared to conventional, worm-gear-driven mounts, so they usually require short and aggressive guide settings — often around a second or so. The trouble is that short guide exposures are also more influenced by seeing. A pretty guiding graph is nice, but the real question is simpler: Are the stars round in the image? With the AM7 and the Stowaway, they are. I used 1- to 2-second guide exposures with either setup, each producing well-guided subexposures with round stars.

The bigger test was the Stellarvue SVX180T-2, a 7.1-inch refractor coupled with a full-frame camera, filter wheel, and piggybacked guidescope. For this setup I used the two counterweights from the Sky-Watcher mount, giving me 20 pounds on the shaft. I also used Software Bisque's *TheSkyX* on a Windows computer along with the free program *PHD2* to handle guiding (users who aren't using the ASIair system can download this ASCOM driver from the company's website, **openphdguiding.org**). The setup worked very well — *PHD2* calibrated fine, *TheSkyX* controlled the mount without a hitch, and the AM7 carried the big refractor without complaint. In fact, the guiding was slightly better than with the smaller scope, hovering around 0.5″ RMS as reported by *PHD2*, and my 90-second test exposures showed round stars. The autoguiding



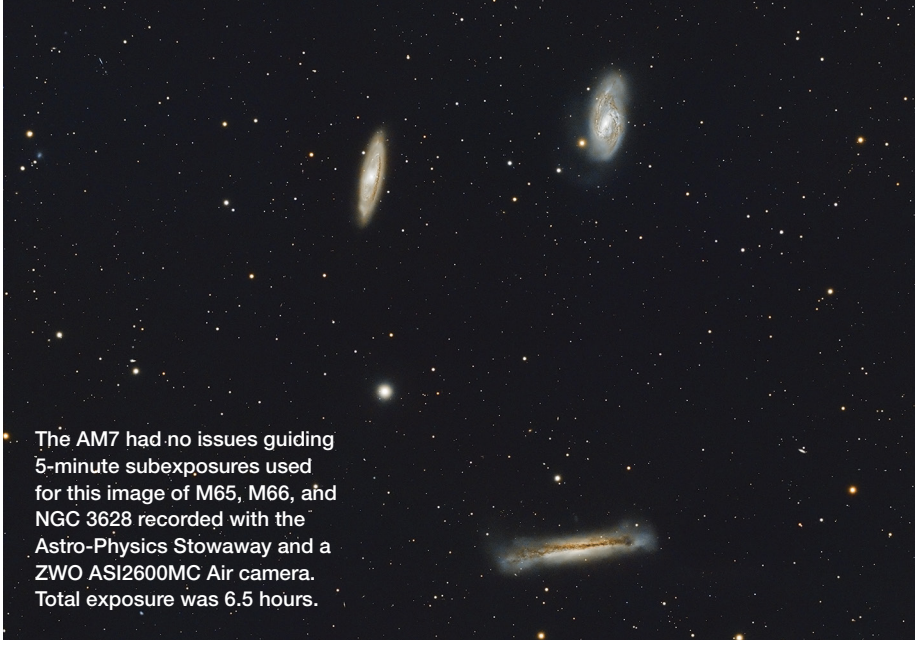
▲ For visual use, the mount is controlled via the *SkyAtlas* app for Android and Apple devices. The app contains a photo-like planetarium program that provides more detail and information as you zoom into targets.

graph was informative, but this is the result that really matters.

A big caveat when using the AM7 outside of the ZWO ecosystem is cable management. With the all-ZWO setup, the AM7 feels clean and modern with just a power cable going to the mount itself, another power cable passing from the mount to the camera, and a USB-C going from the mount to the camera and its onboard ASIair controller. With third-party imaging and guide cameras, auto focuser, and laptop, that clean look disappears quickly. I used the lower USB port for mount control through ASCOM but still had separate USB cables for the main camera, guide camera, and focuser hanging from the back of the telescope to my laptop. I also had to split the saddle's power output to feed more than one device. None of these prevented a successful imaging run, but it's the difference between a system that feels designed as a whole and one that's being adapted to work.

The hand controller provided with the AM7 is a small, joystick-style unit. An indicator light below "FAST" turns red when using high slew rates and pressing the joystick cycles through its various speeds. The T button toggles tracking, and the bottom button cancels commands and also returns the mount to its home position. The joystick was useful for coarse control and setup chores. An important detail to remember is that the joystick contains the mount's Wi-Fi and needs to be plugged in if you intend to connect to it wirelessly. Bluetooth, on the other hand, works without it. When pairing over Bluetooth, the app prompts you to press the Bluetooth button on the mount's panel, which then glows blue to confirm the connection.

ZWO's *SkyAtlas* app (available for iOS and Android) controls the AM7 over either Wi-Fi or Bluetooth. I preferred the Bluetooth connection since it was easier to set up: Just open the app, select the nearby mount, and confirm by pressing the button on the mount. The app includes a simple sky chart, object search, tracking-rate controls, mode settings, parking, and home-position utilities. For imaging with the ASIair system, most users will connect using the *ASIair* app, which contains a more robust planetarium. For visual use, however, it suffices.



The AM7 had no issues guiding 5-minute subexposures used for this image of M65, M66, and NGC 3628 recorded with the Astro-Physics Stowaway and a ZWO ASI2600MC Air camera. Total exposure was 6.5 hours.

I tried the AM7 in alt-azimuth mode for some solar observing. Switching from equatorial mode requires turning the mount into its 0° latitude orientation (and loosening the latitude gear-adjustment screws if you aren't in the 0° to 60° position), changing the mount's drive mode in *SkyAtlas* or *ASIair*, and then cycling the power. In alt-azimuth mode the black front plate of the mount faces south, with the telescope pointing east in its home position, and the front status indicator changing from red for equatorial mode to green for alt-azimuth mode.

Once running, *SkyAtlas* has the look and feel of a slightly simplified *ASIair* sky chart for visual observing. The only shortcoming at the time of writing is that *SkyAtlas* offers only one-star alignment — really more of a syncing position — rather than a multi-star pointing model. One single alignment point isn't enough to determine a telescope's orientation, and thus pointing ability, beyond the small area of sky where the point was initially established. When using the *SkyAtlas* method, your setup needs to be perfectly level, and you need to input the time and location accurately to ensure your scope's mounting hardware and optical path are perfectly parallel with the AM7's mounting hardware. I did a quick alignment without ensuring the mount was level, and sure enough, objects on the opposite side of the sky weren't landing squarely in the eyepiece field.

For casual solar or lunar work this is fine, or for a quick setup to just look at one target. However, for visual observers expecting the AM7 to behave like a polished alt-azimuth Go To mount, I'd call the current *SkyAtlas* alignment routine incomplete.

Closing Thoughts

The AM7 is a very capable mount, particularly for astroimagers exclusively using ZWO equipment. Users will revel in the mount's high load capacity and general ease of use. If your astrophotography world is built around cameras, focusers, hubs, and desktop software from various vendors, the mount works very well, but you may find the cable-management compromises annoying. Its payload capacity is accurate, but always remember that hefty optical tubes demand a serious pier or tripod, counterweights, and careful cable routing. For me, the AM7 is an excellent portable imaging platform when operating in the ZWO ecosystem, and a very good one for visual use.

■ Contributing Editor **RICHARD S. WRIGHT, JR.** is still waiting for the mount that routes every cable exactly where he wants it.

Glass Gambles: Buying Mirrors Sight Unseen

Mystery mirrors sometimes pay off. Here are a few of my stories.



▲ The author's 6-inch f/3 reflector under construction in his home workshop.

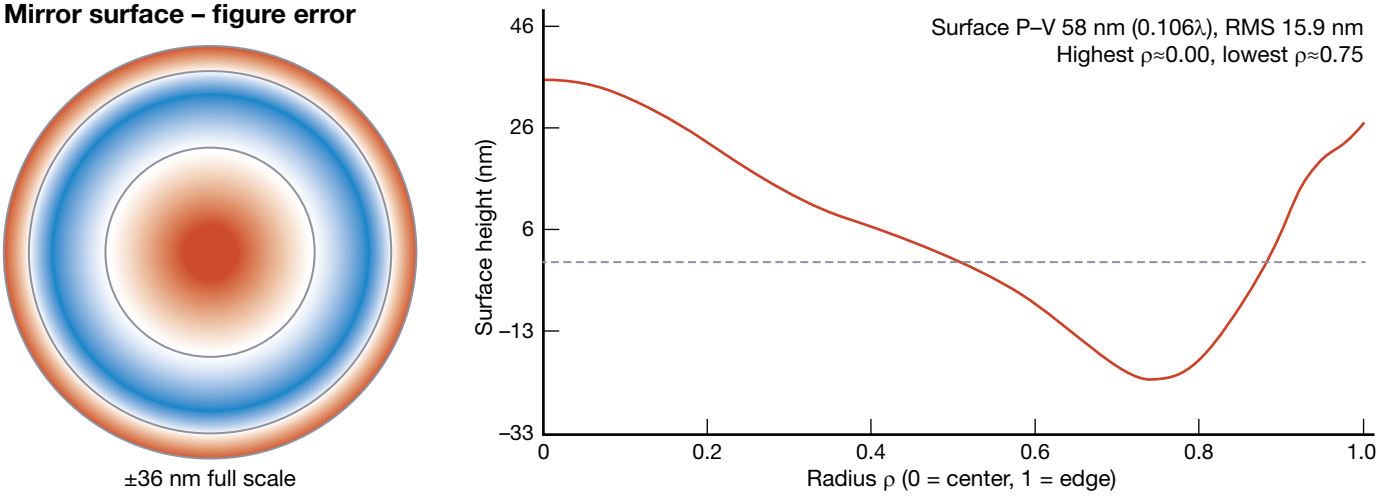
ONE OF MY FAVORITE feelings in this hobby is when optical bets pay off. I'll never forget the 16-inch (40-cm) primary I nabbed for $100 in an online auction on eBay (*S&T:* Oct. 2025, p. 74), how it amazed me, and how it let me down. They don't always work out, but without these mystery mirrors, I never would've built my favorite telescope.

My first real optical gamble was much smaller in aperture. Many nights I found myself reaching for a 4½-inch f/8 reflector, which I 3D-printed and named Hadley (*S&T:* Jan. 2023, p. 70). The scope had earned its place; I didn't want to fuss with assembling a truss or wheeling out some sarcophagus of wood and metal at 4 a.m. to catch glimpses of a planet. But what it couldn't do well, with its middling focal length and 1¼-inch focuser, was to go wider.

The original Hadley was easy to make, and I found listings for a parabolic f/4 mirror with the same aperture. This would be my first sight-unseen mirror purchase, and boy did it pay off. That and a cheap secondary from retailer Agena Astro produced a sweet, sweeping scope that comfortably fits the fat 2-inch eyepieces I used with my larger Dobsonian. An AstroTech 20-mm XWA eyepiece and a GSO 1.1× coma corrector produced a field of view of more than 4° at 25×, whereas a 40-mm Plössl in the original f/8 was a meager 1¾° at 23×. The scope's first real test came when I sat in a Bortle 5 field, taking in the fall Milky Way. And that 4° field could fit the entire Veil Nebula.

This is what optical speed buys us in a visual instrument. A 40-mm eyepiece at f/8 will show a view with similar surface brightness to a 20-mm eyepiece at f/4, but 20-mm eyepieces come in all sorts of styles and can be made much wider within the specs of a 2-inch focuser. But you pay for it, both for those nicer eyepieces and elsewhere.

In pursuit of speed, my next optical gamble was a doozy: about $400



▲ This shows a preliminary analysis of the 6-inch f/3 mirror performed by a Ronchigram-analyzing software that the author's friend is developing. "The analysis, though not empirical, shows a shockingly good figure for this optically demanding mirror," says the author.

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for a 6-inch f/3 primary. Like the far cheaper 4½-inch f/4, it was a product listing on eBay from an optician in China, rather than an old, used mirror. It was advertised as "lambda/4" as a minimum quality.

This was the idea taken to its logical conclusion, both risky sight-unseen mirrors and trawling the night sky at 450-mm of focal length. Such a fast Newtonian would also serve me well for analog night-vision astronomy, which in most cases prefers a fast instrument; this was another driver of the project. The mirror came quickly, and I was able to verify with a Ronchi test that it was at minimum, optical in nature. (For information about Ronchigrams, see **tinyurl.com/reading-ronchigrams**.)

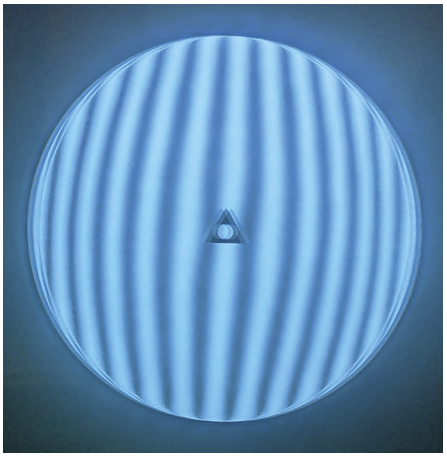
The scope came together in a weekend, and the first result was that the coma was downright comical. Warp speed would describe the feeling of looking into it, with stars vanishing into a blur toward the edges. But with a coma corrector (this time, I used a TeleVue Paracorr 2) in the focuser, and that same 20-mm eyepiece, I could comfortably fit the entire Pleiades cluster. The views were definitely better than the 4½-inch f/4: I enjoyed wide, sharp fields of stars. I could see M33 under local skies for the first time, and I had never seen so many stars in an eyepiece — due to a combination of aperture and true field size. And with my night-vision device stuck in, it was nothing short of magical. Enormous emission nebulae filled the screen, and sweeps across Sagittarius brought me some of my absolute favorite views — I saw dense stellar carpets and inky black clouds of dust set in stark relief.

On the other hand, I've never tried the planets in this 6-inch f/3. Its focuser is really a glorified Paracorr holder, collimation is brutally difficult at f/3, and so is fine focus. And even if I did ace alignment and focus, the central obstruction is enormous (42% by diameter), which softens stars and planets at high magnification. But desires for a true "do-anything" telescope aside, the views in this gallon-sized sky stroller never left me wanting for higher power than 25×.

They aren't all diamonds in the rough. Wanting to make a fatter cousin or binocular to that 4½-inch, I ended up sourcing three 5.1-inch f/5 mirrors from different places. Each one was worse than the last: sphere, sphere with turned edge, and an indeterminate mushy shape. There were other mirrors and lenses too — many of these enjoying a second life as fascinating paperweights — but none as sobering as the big binocular project I had to shelve.

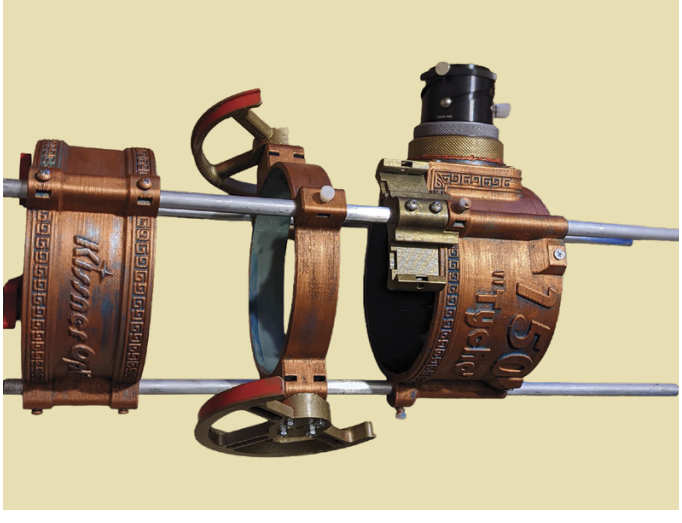
That 16-inch mirror ultimately turned out to be astigmatic. I determined this after rotating the primary in its cell, which caused flattened stars to rotate in kind. But it was still a useful optic as the stars were sharp at low powers in hand-grenade eyepieces, and aside from not reaching extreme high magnification, it did the job that a 16-inch should. I could detect the Ring Nebula's central white dwarf star, see faint galaxies in detail, and the star colors were especially nice.

Not all my optical gambles pay off, but enough do. My favorite scope yet turned out to be a one-trick pony. But it's a pretty good trick.



▲ A quick-and-dirty Ronchigram taken the day the 6-inch mirror arrived shows that its surface isn't just smooth and optical, but at least slightly parabolic in nature.

■ Contributing Editor **JONATHAN KISSNER** is trying to ignore a listing for a 12-inch optical testing flat.



▲ The author applied an imitation antique bronze process to the 3D-printed telescope tube of his 6-inch.



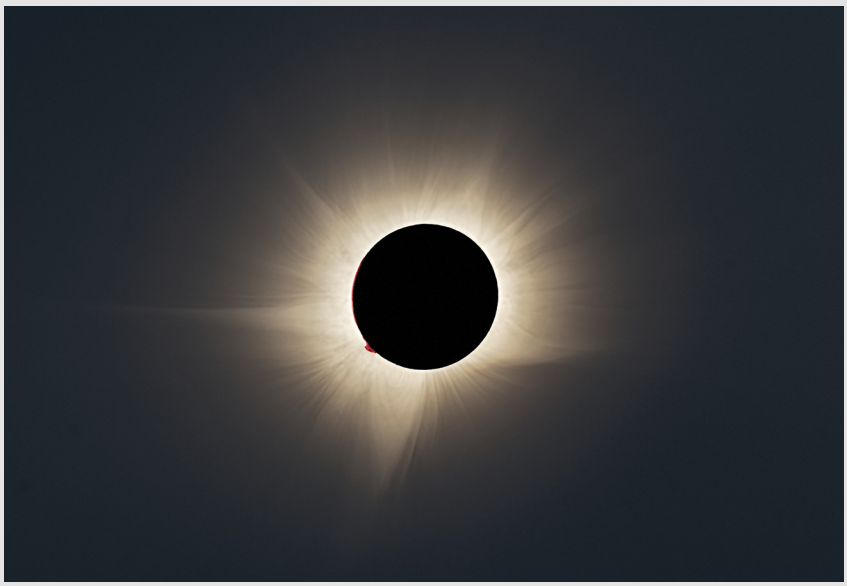
▲ The optical tube of the author's 4½-inch f/8, his original star-sweeper, weighs only 4½ pounds and is easy to transport to dark, rural sites.

▷ WARM CORONA

Alson Wong

The Sun's outer atmosphere appears reddened in this deep composite image due to its low elevation of about 5° as seen from the Castillo de los Calatravos in Alcañiz, Spain. A large, reddish prominence shimmered along the Sun's eastern limb, seen at lower left. Also of note is the lack of long coronal streamers along the lower-right limb, which is indicative of a coronal hole at the time of totality.

DETAILS: *Nikon D7500 DSLR with 80-to-400-mm zoom lens at 400 mm. Composite of 18 exposures ranging from ½₅ to 1.6 seconds at f/8, ISO 560.*



HESPERIA TOTALITY

Stan Honda

The low eclipsed Sun adds a wonderfully surreal element to this view above the cemetery at the Church of Villarroañe in Spain.

DETAILS: *Sony Alpha 7 III mirrorless camera with 24-to-70-mm zoom lens at 37 mm. Total exposure: ¼ second at f/8, ISO 640.*



THE YOUNG AND THE OLD

Massimo Di Fusco

Straddling the border between Sagittarius and Corona Australis is the ancient globular cluster NGC 6723 (top right), lying just ½° from the stellar nursery and reflection nebula NGC 6729 (left).

DETAILS: *AstroSystemAustria ASA 500-mm Newtonian with FLI PL16803 CCD camera. Total exposure: 54 minutes through color filters.*

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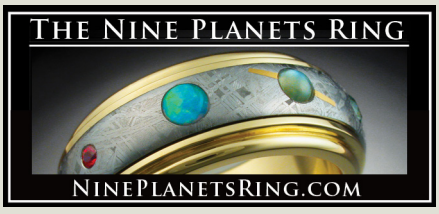

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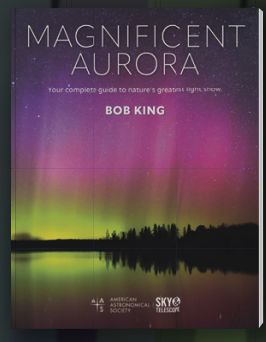

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The Quietest Place in China

The author visits a remote radio dish.

QIANNAN BUYIZUMIAOZUZIZHIZHOU is a town as strange as its name. At first glance, it might pass for a run-of-the-mill rural Chinese village. But then you notice the street lamps shaped like flying saucers.

This is no Chinese Roswell, though. What makes Qiannan B special is that it sits at the edge of the Zhongguo Tianyan Quiet Area, a radio-quiet zone some 30 kilometers (19 miles) in radius that shields the world's largest single-dish radio telescope, the Five-hundred-meter Aperture Spherical Telescope (FAST).

As most readers of this publication know, radio telescopes search for the top FM radio hits on other planets. Just kidding. No, what most readers *do* know is that radio waves are a form of light invisible to the human eye. Stars, gas-gobbling black holes, and other celestial objects emit these waves. Their wavelengths range from millimeters to many kilometers. For reference, visible light has a wavelength roughly 1/200 the thickness of a sheet of printer paper.

To catch photons with such large wavelengths, radio telescopes must be large, too, and they must be far from the chatter emitted by our modern electronics. So astronomers build these instruments in remote locations and surround them in radio silence.

I managed to visit Astronomy Town (as it's called) back in 2020, during the days of COVID-19 lockdowns and draconian travel policies. Thankfully, I had a friend in Qiannan B who went by Tony.



Tony ran a hotel in Astronomy Town, which the government had promised would be the next big thing because FAST — also known as the Tianyan ("Eye of Heaven") Telescope — had recently opened its site to public visitors. Entrepreneurs like Tony bought up Astronomy Town property, assuming globetrotters would flock to this marvel of modern science.

However, there was a problem.

China built the telescope in the most remote corner of the most remote province in the country. Then they threw down the welcome mat — apparently without considering how people might get to Qiannan Buyizumiaozuzizhizhou, much less pronounce it.

Business was so slow that Tony had time for a six-hour roundtrip drive to Guiyang to pick me up. After arrival, I set out to see the dish.

To get to the telescope, you pass through a security checkpoint right next to the No. 9 Universe Sky Eye Museum in Astronomy Town before boarding a bus. They ensure you're not carrying any electronics—phones, computers, digital cameras, iPods (basically anything that might scare the aliens).

It takes a solid hour for the bus to struggle up and down the karst mountain range between Astronomy Town and the telescope. Finally, you come to a trailhead that leads to the overlook. I hoofed it up the mountain feeling cheated because I hadn't been allowed to bring my camera. *What's the point of seeing the world's largest anything if you can't take a selfie with it?*

Thankfully, a vendor patrolling the path rented out old Fuji film cameras that didn't require electricity, and so were allowed near the telescope. I paid the deposit, and she looped that dinosaur of a camera around my neck.

I crested the peak and saw the telescope. I couldn't comprehend its size. With a half-kilometer diameter, it dwarfs the surrounding mountains. Its dish covers an area roughly equal to 30 football fields. However, its true size didn't hit me until I saw a lone scientist walking the circumference. I snapped away with the Fuji film.

Before I headed back down, I looked at the telescope one last time. It's a rare and marvelous thing to observe the mysteries of the universe being unveiled in real time — even if it's happening at a wavelength invisible to the naked eye. And thus it will continue. Long after the tourists board the buses and the mountains fall silent, the great dish will remain fixed on the sky, listening.

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PHOTOS: NATHAN SMITH; ILLUSTRATIONS: LEAH TISCIONE / S&T

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