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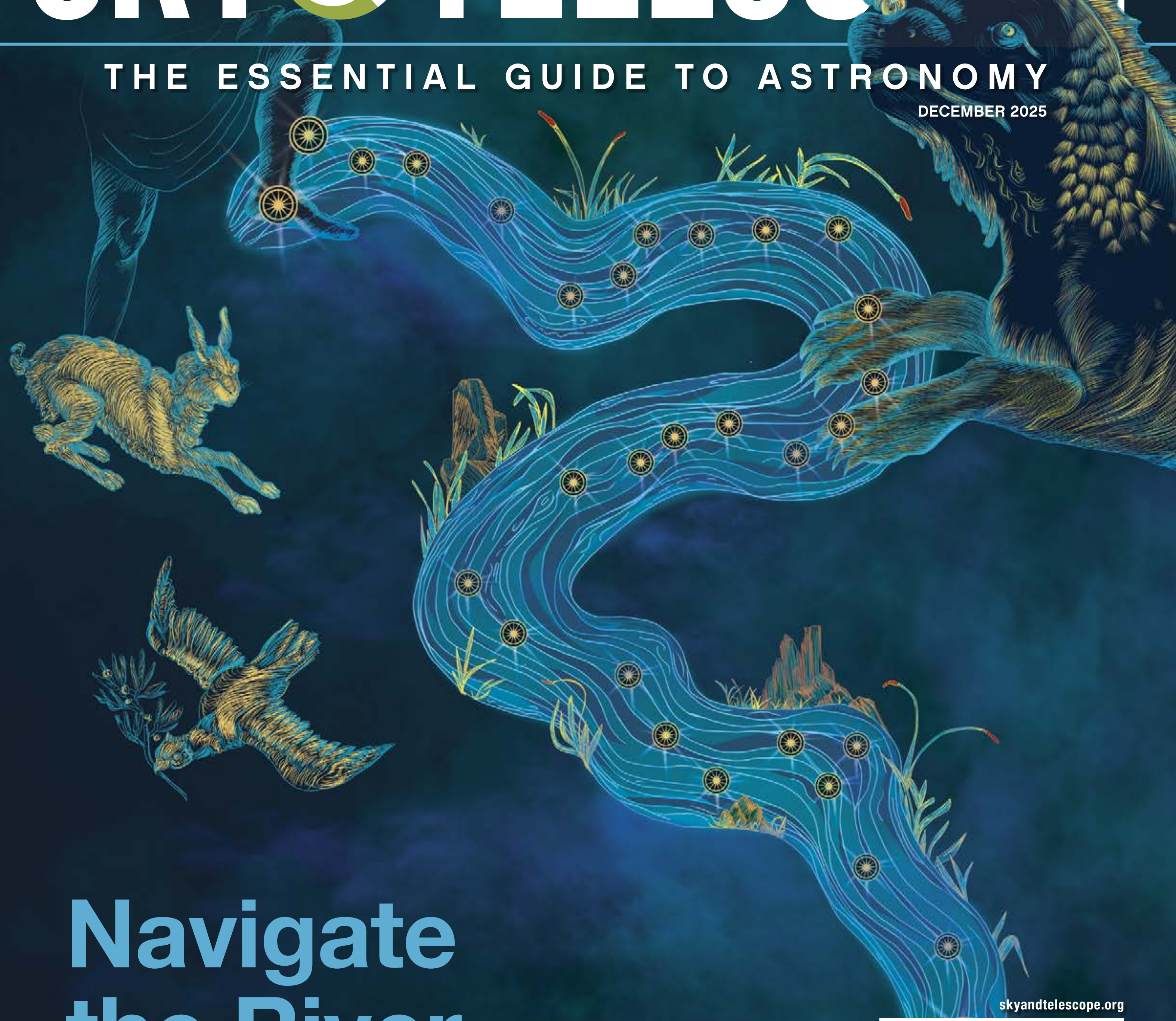
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

DECEMBER 2025



Navigate the River of Stars

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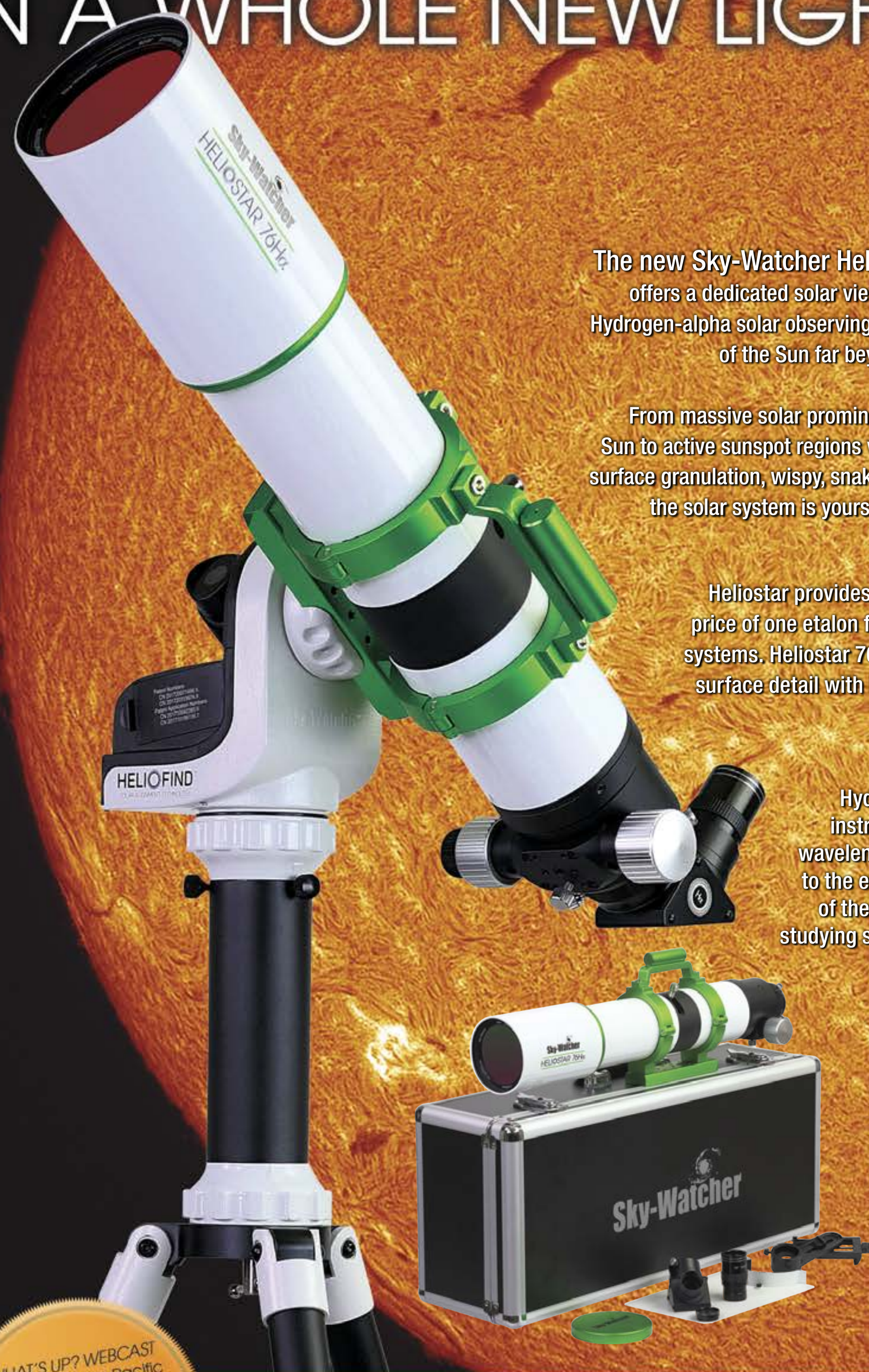

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ON THE COVER

Artist's illustration of the constellation Eridanus
BEATRIZ INGLESSIS / *S&T*

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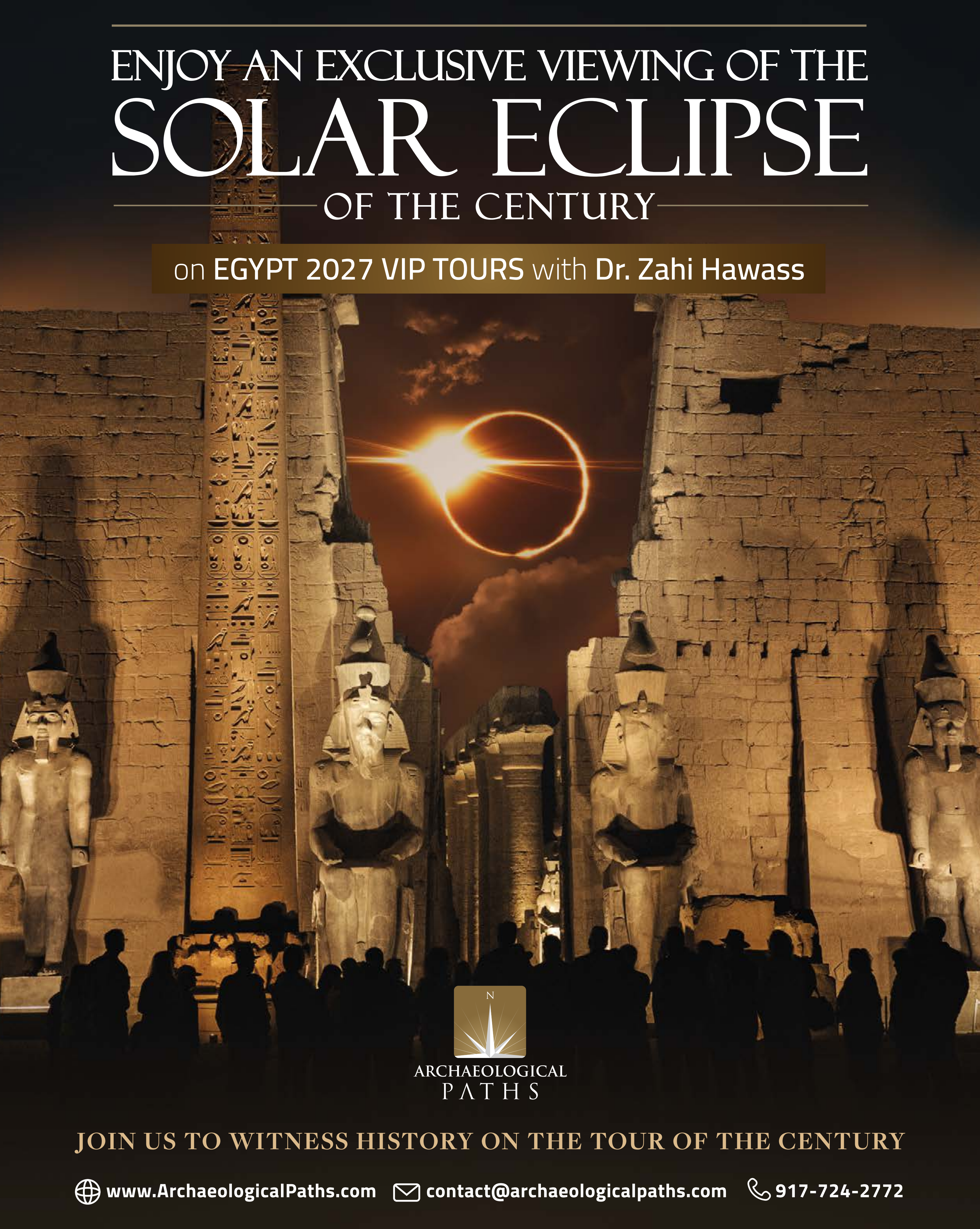
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The Solstice Is Upon Us

DECEMBER IS THE MONTH that marks the winter solstice in the Northern Hemisphere. Heliophiles rejoice, for the solstice ushers in lengthening days and the promise of ever-increasing sunshine.

But stargazers revel as well this time of year, for winter skies — at least at the cold, more northerly latitudes — provide crisp views of twinkling stars in some of the more iconic constellations that parade across the night sky. One of these constellations is, undoubtedly, the Hunter of Greek mythology, Orion.

If you were to ask some random person what their favorite constellation is, I bet that many (most?) would say, "Orion." It could be because of the startling resemblance to a humanlike figure that the chance positioning of stars both near and far gives us. It could also be because Orion contains two of our favorite asterisms (Belt and Sword) as well as some truly remarkable objects. Who isn't waiting for the red supergiant Betelgeuse to go kaboom?

▲ The Orion Nebula

Orion is indeed resplendent on cold, winter nights. But let's not forget that there are other celestial figures lurking in the darkness, waiting to be explored. Even if most people might not reply "Eridanus" to the "favorite constellation" question, don't overlook this lesser-known grouping of stars. Contributing Editor Ted Forte takes us on a river cruise of this starry waterway — starting on page 22, he leads us to targets in the northern reaches of the constellation.

December is also the month that, 30 years ago exactly, an intrepid team of scientists did something remarkable. They trained the Hubble Space Telescope's eye onto a patch of seemingly empty space for 10 whole days. The sea of galaxies they saw wowed the world and changed the way we view the universe. Read how the Hubble Deep Field image came about in Nicole Boeck's article on page 14. A star chart depicts the location of the HDF and its successors in the sky — when you step outside on these winter nights, you can lay your eyes on the exact spot that revolutionized our "understanding of the cosmos," as Boeck writes.

Most of us don't have access to a space telescope, but that shouldn't stop us from snapping photos of our favorite objects. Sarah Mathews provides insightful tips (page 55) on how to capture the Orion Nebula (there's Orion again!) using the simplest of gear and techniques. (And, take heart, it doesn't take 10 days.)

Whether you'll be spending your winter nights photographing the Orion Nebula, or peering at that apparently empty spot of sky that's actually teeming with myriad galaxies, or fishing for objects as you sail down a celestial river, enjoy the long dark nights that December provides. Happy Solstice!

Diana

Editor in Chief

SARAH MATHEWS

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The Essential Guide to Astronomy

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

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LEAH TISCIONE / S&T

Sharing the Sky

Thank you for the stories on outreach in the July 2025 issue. I love giving naked-eye sky tours at public star parties and other gatherings.

To understand what we see in the sky, we need to know where we are on Earth and how Earth is moving. I start by inviting people to feel their feet on the ground and notice the weight of their bodies. Then we look around at our immediate environment and orient ourselves to the cardinal directions. I explain that Earth is a planet, round like a ball, turning on its axis from west to east. This makes the Sun, Moon, planets, and most of the stars appear to rise somewhere along our eastern horizon, move east to west across the sky, and set somewhere along our western horizon.

Now we're ready to consider the orbit of the Moon around Earth and the orbit of both together around the Sun. From Earth's nighttime side, we look out away from the Sun toward different parts of the Milky Way Galaxy. The other planets in our solar system are also orbiting the Sun, two nearer the Sun and moving faster than Earth does, the rest farther out and moving more slowly.

Each tour is different depending on what is visible in the sky, but we always start by feeling our feet on the ground. Over the years I've had many people tell me that orienting themselves here on Earth and working our way out has helped them understand the sky in a new way.

Anthony Barreiro
San Francisco, California

I read Ted Forte's "Summer Outreach Treasures" (*S&T:* July 2025, p. 22) with great interest. My wife and I often share views of the night sky with passersby in our hometown both on our own and with the Bluewater Astronomy Society. Forte's delight in sharing the wonders of astronomy resonated with me: Witnessing people's reactions to their first view through a telescope is highly rewarding.

The most memorable night for us was when a very proper, elderly woman stopped by. She said she had heard we were inviting people to look at the Moon through our telescopes, which was something she had never done before. We invited her to the eyepiece of our 12-inch Dobsonian. After a pause, and a gasp, she let loose a torrent of profanity-laced exclamations of wonder. Then she looked up and covered her mouth in horror at what she had heard herself say. It was a brilliant illustration of the shocking, spectacular, sometimes overwhelming experience that a telescope can provide.

Steve Ritchie
Owen Sound, Ontario

I enjoyed Ted Forte's list of outreach targets and recognized many objects that I've shown at events big and small over the years. However, his list omitted one object guaranteed to get a reaction at a star party every time: the double star Albireo. Its gold and blue members are split at low power and sit in a crowded field of stars. Many people are fascinated to learn that a single star they see in the sky can be split into two colorful components.

Ryan Weiss
Midland, Michigan

I loved July's Inspiring Outreach issue. It has really helped me improve my astronomy outreach efforts for our members of the Boys & Girls Clubs of San Francisco's residential summer camp, Camp Mendocino (**campmendocino.org**).

We are so lucky to have a dark-sky site available in the redwood forest of Mendocino County. I always get a thrill when our kids and young adults peek through the eyepiece for the first time and scream, "Wow!" Most of them have never seen the Milky Way, let alone looked through a telescope.

Of course, the Moon and planets make the viewing more interesting, but when they aren't available there's a lot more to see, such as Albireo's blue and orange binary. I enjoy explaining the difference in temperature that causes the contrasting colors. I'll light a match and show how the color near the fuel is hotter (thus bluer) than the orange tip, which is cooler due to it being farther away from the source.

Thanks again for an inspiring and helpful topic!

Fernando Aguilar
San Francisco, California
Boys & Girls Clubs of SF Volunteer

I got into astronomy back in the early '90s. I bought a Meade 16-inch Dobsonian that I found for sale in a local paper. At the time, I had no idea where it would lead me, the stories I would hear, or the people I would meet.

I thought Halloween would be a great time to show off the sky. Luckily, Halloween night was clear that year.

At the time, I lived in a subdivision loaded with kids. I set up the telescope near the garage. I handled the telescope while my wife held the bowl of Halloween candy. In no time at all, I had a line of kids and parents lined up to look through the telescope. I remember my wife asking the kids, "Don't you want some candy?" The usual reply was, "We want to look through the telescope first!" Of course, Saturn was a huge hit.

The highlight that night was when a little boy, I'm guessing around seven years old, looked through the eyepiece and saw Saturn for the first time. He exclaimed, "Oh Wow!" Then, as he stepped down from the stool, he said in an excited voice, "Mom! I just saw Saturn! My life is complete now!"

That's something I'll never forget. It brought such joy to my heart. Share the night sky with others. You'll never know how it'll touch them and you.

Mark Drexler
Lowell, Indiana

FOR THE RECORD

- In the July 2025 issue on page 65, the paragraph discussing the signal-to-noise (SNR) ratio of multiple stacked exposures incorrectly states that the noise increases by the square root of the number of exposures stacked. Although the signal multiplies with the number of exposures, it's the square root of the total signal, not of the number of exposures, that determines the SNR.
- In "How Empty is Space" (*S&T:* Sept. 2025, p. 72), the molecular density of Earth's atmosphere is 30 million trillion molecules per cubic centimeter.

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

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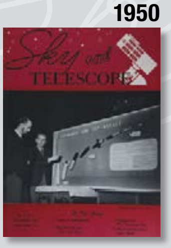
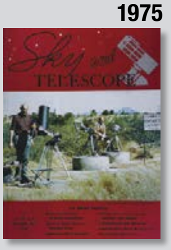
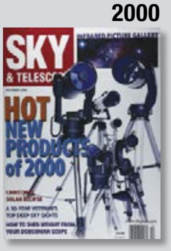


1975



2000



◖ December 1950

Crater Ruins "Discovery of arrow points and other [Native American] artifacts on the rim of [Arizona's] Meteor Crater, in 1939 and 1948–49, led to archeological investigations at the crater this past summer, by the Institute of Meteoritics and the department of anthropology of the University of New Mexico. [Ruins] were discovered high on the crater rim. A one-room structure was completely excavated. This and other nearby dwellings were built of Coconino sandstone thrown out from the crater by the meteor's impact, and are estimated to have been built before 1300 A.D."

◖ December 1975

First Peek "On October 22nd, the centuries-old quest for a glimpse of the surface of Venus succeeded. Venera 9, an unmanned Soviet spacecraft, transmitted photographs and other data for 53 minutes after setting down on the surface amid the lethal extremes of heat and pressure present there. Three days later, another probe, Venera 10, landed 1,375 miles away from its twin and returned its findings for 65 minutes. Historic photographs from both spacecraft — the first ever taken from the surface of another planet — were released. . . . The double success of Veneras 9 and 10 had been preceded by a stream of other missions to the vicinity of Venus, including Mariners 2, 5, and 10 . . . in 1962, 1967, and 1974, respectively. . . .

"Cornell scientist Carl Sagan expresses surprise that some of the rocks were rounded, as processes for terrestrial erosion are not expected to be present on Venus."

◖ December 2000

Gravitational Lens "Several billion light-years away in Corona Borealis lies a tiny, anonymous dot of a 24th-magnitude galaxy. . . . [A] humble, run-of-the-mill dwarf star [sits] in the galaxy's outer halo with about half the mass of the Sun — a star seemingly beyond all hope of human knowledge or recognition, with its estimated brightness of magnitude 51. Yet this lone star wrote its signature onto an astronomical event that occurred far behind it and caught the attention of astronomers last March (including a group of amateurs) . . .

"The event was a gamma-ray burst that . . . left an afterglow at many wavelengths, including a 20th-magnitude spark of visible light . . . A few days into its fade it brightened a bit — equally at all wavelengths — before resuming its decline. GRB afterglows aren't supposed to do that.

"Peter Garnavich (Notre Dame) [and colleagues] think they have figured it out. The afterglow was briefly magnified by the gravitational field of a foreground star that happened to be extremely close to our line of sight to the burst."

By studying the afterglow's light curve, Garnavich's team gleaned details with a resolution better than 1 microarcsecond.

◀ An artist's concept shows a Saturn-mass planet in the foreground, with Alpha Centauri A and B in the background.

EXOPLANETS

Alpha Centauri Might Have a Planet

WITH THE JAMES WEBB SPACE TELESCOPE, astronomers have directly imaged what appears to be a Saturn-mass planet in the habitable zone of Alpha Centauri A. While the gas giant itself wouldn't be habitable to life as we know it, moons around it could be.

The Alpha Centauri triple system is made up of a pair of close-orbiting, Sun-like stars, named A and B, as well as the red dwarf Proxima Centauri. Astronomers have already found three planets around Proxima Centauri. The newly discovered world appears to lie about 2 astronomical units away from Alpha Centauri A, as reported in two papers that will appear in *Astrophysical Journal Letters*.

"These are incredibly challenging observations to make, even with the world's most powerful space telescope," says team co-lead Charles Beichman (Caltech). "These stars are so bright, so close, and move across the sky quickly."

The team made the discovery using Webb's Mid-Infrared Instrument (MIRI). It has a *coronagraph*, a device that masks out a star's intense glare in order to observe fainter planets in the vicinity. Blocking starlight is a tricky feat in a multiple system; the

EARLY UNIVERSE

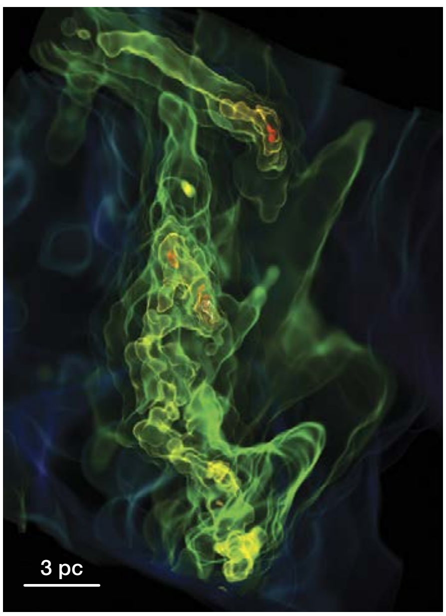
The First Stars Might Not Have Been That Massive

CHAOTIC TURBULENCE in primordial gas clouds might have prevented the formation of extremely massive stars, according to new simulations.

The early universe consisted primarily of hydrogen and helium atoms. These simple atoms, in contrast to heavier elements, don't radiate much. Gas clouds therefore had trouble cooling down enough to form stars, as the pull of gravity had to fight against higher gas pressure. For that reason, most astronomers think the universe's very first stars were behemoths, hundreds of times as massive as the Sun.

But according to Ke-Jung Chen (Academia Sinica Institute of Astronomy and Astrophysics, Taiwan) and colleagues, that simple picture is incomplete. Their detailed computer simulations reveal that those collapsing clouds experienced *supersonic turbulence* — with most gas moving at five times the speed of sound. The shock waves that resulted stirred the gas clouds, breaking larger clumps into smaller fragments and compressing gas so that it could more easily collapse into stars.

To come to this conclusion, the team adapted IllustrisTNG, a supercomputer simulation of our cosmos, to focus on a single mass concentration in the early universe. In the zoomed-in simulation, published in the August 1st *Astrophysical Journal Letters*, infalling gas becomes highly turbulent at scales of hundreds of light-years, resulting in multiple dense clumps that spawn stars as puny as 8 solar masses.



▶ This 3D frame from the team's simulation shows dense clumps (yellow and red). One of these is collapsing into a star that will have eight times the Sun's mass.

Cosmologist Rien van de Weygaert (University of Groningen, The Netherlands) is impressed by the new work, especially with its ability to see fine detail on processes that take place on the scale of millions of light-years.

But van de Weygaert also cautions that the work isn't quite finished yet. "For instance, Chen and his colleagues don't incorporate radiation processes — something you really can't ignore on these scales," he says.

There have been other indications that massive stars were relatively rare in the early universe. Stars between 80 and 260 solar masses are expected to end their brief lives in *pair-instability supernovae*, which should leave traces in the composition of subsequent generations of stars. But those chemical fingerprints are less abundant than expected — and these new computer simulations might explain why.

■ GOVERT SCHILLING

astronomers also had to subtract Alpha Centauri B's light, using Epsilon Muscae as a reference star.

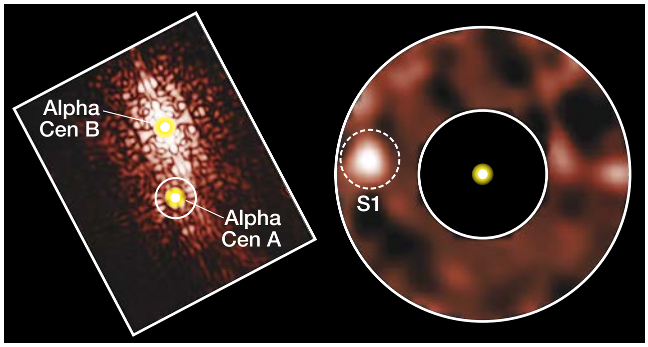
Interestingly, the planet's position matches a tentative detection made in 2019 by the Very Large Telescope's New Earths in the Alpha Centauri Region (NEAR) experiment, raising the possibility that both sightings correspond to the same object. That planet failed to show up in two follow-up Webb observations, but there's a chance the planet had simply moved too close to the star to be seen. Its orbit might be moderately elongated and tilted compared to the orbital plane of Alpha Centauri, further complicating the search.

"Of all the directly imaged planets, this would be the closest to its star seen so far," says co-lead Aniket Sanghi (Caltech). It'd also be the first planet directly imaged around a star the same age and temperature as the Sun. "[The discovery] will give us an opportunity to start to compare the composition with the gas giants in our solar system," says Sarah Casewell (University of Leicester, UK), who wasn't involved in the study.

If confirmed, the discovery would impact our theories of how planetary systems are born and grow. "Its very existence in a system of two closely separated stars would challenge our understanding of how planets form, survive, and evolve in chaotic environments," Sanghi says.

For now, we'll have to wait and see. The team hopes to follow up with Webb in August 2026 and with the Nancy Grace Roman Telescope when it launches later this decade.

■ COLIN STUART



◀ Webb's Mid-Infrared Instrument used a coronagraph to block light from Alpha Centauri A, which produces the complex patterns seen in the left panel. Those patterns and the light from Alpha Cen B have been mostly removed in the right panel, revealing a spot of light from the planet candidate.

STARS

Has Betelgeuse's Companion Been Found?

ASTRONOMERS MIGHT HAVE finally spotted a close companion to Betelgeuse, the bright red star at Orion's shoulder. A partner could help explain the supergiant's changing brightness, but it's still a highly tentative discovery.

For decades, astronomers have suspected that Betelgeuse isn't alone. And last year, a team led by Morgan MacLeod (Center for Astrophysics, Harvard & Smithsonian) suggested a companion would even help explain Betelgeuse's brightness and motion across the sky (*S&T:* Feb. 2025, p. 9).

Searches with the Hubble Space Telescope and Chandra X-ray Observatory came up empty. But in the August 1st *Astrophysical Journal Letters*, Steve Howell (NASA Ames Research Center) and colleagues report that they've found it: a spot of light six magnitudes fainter than Betelgeuse. They used the Gemini North telescope in Hawaiʻi and a technique called *speckle imaging*, in which ultra-short exposure times cut through the blurring effects of Earth's atmosphere.

However, the discovery is on weak footing. There's a roughly 10% chance the source is just variations in the speckles. "The fact of the matter is that the signal-to-noise of this effect is quoted to be 1.6," says René Oudmaijer (University of Leeds, UK), who wasn't involved in the research. "Such values are widely regarded as non-detections."

If the companion does exist, it's likely still forming and will eventually become an *F*-type star. At just 4 astronomical units from Betelgeuse, the putative protostar is inside the giant star's extended atmosphere, which means drag and tidal forces should send the companion spiraling into Betelgeuse in the next 10,000 years.

Howell's team plans to monitor Betelgeuse in the coming years for more concrete evidence of a star in tow. But until then, big question marks remain.

■ COLIN STUART

◀ Betelgeuse (at center) might have a companion star (lower left), which appears blue in this image from the Gemini North telescope due to its high temperature.

ZOOMING IN ON ALPHA CEN AB: NASA / ESA / CSA / ANIKET SANGHI (CALTECH) / CHAS BEICHMAN (NEXSCI, NASA / JPL-CALTECH) / DIMITRI MAWET (CALTECH), IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI); BETELGEUSE AND COMPANION: INTERNATIONAL GEMINI OBSERVATORY / NOIRLAB / NSF / AURA, IMAGE PROCESSING: M. ZAMANI (NSF NOIRLAB)

IN BRIEF

New Mission to Study Sun-Earth Connection

The twin Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS), launched on July 23rd, will probe the sudden reorganization of magnetic fields, called *magnetic reconnection*, in the region of space where the solar wind connects with Earth's magnetic field. The twin TRACERS spacecraft will complete a low-Earth orbit every 90 minutes, taking measurements as they pass through the *polar cusps*, where solar particles stream into our planet's upper atmosphere. The primary mission will last one year, though fuel reserves could support extended science operations. (As of press time, one of the tandem satellites is experiencing difficulties, but recovery efforts are under way.) "TRACERS will capture data from over 3,250 encounters with the northern magnetospheric cusp, where Earth's magnetic field opens to the solar wind," says mission lead David Miles (University of Iowa). The result, he adds, is a statistical understanding of the ways in which the solar wind couples to near-Earth space.

■ DAVID DICKINSON

SPACE & SOCIETY

Satellite Constellations Are Too Bright for Astronomy

THE INTERNATIONAL ASTRONOMICAL UNION (IAU) has recommended brightness limits for satellites, but companies aren't abiding by them.

Major "constellations" of communication satellites — including Starlink, OneWeb, BlueBird, Qianfan, Guowang, and Kuiper — are being launched at breakneck pace, with several thousand satellites already in orbit. In response to the problems this creates for astronomy, the IAU created the Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference. The Centre has recommended that satellites at altitudes up to 550 km (340 miles) should be no brighter than 7th magnitude; somewhat fainter satellites are required at higher altitudes. But most companies aren't following those limits.

To study the brightness of large satellite constellations, we (Richard Cole and Anthony Mallama) combined amateur visual estimates with professionals' recorded data. Except for two satellite types — OneWeb and Starlink Mini satellites at 485 km — all of the satellites are brighter than 6th magnitude, making them visible under dark skies. And every constellation except OneWeb exceeds the 7th-magnitude limit.

The BlueBird satellites, operated by AST SpaceMobile, are the brightest of the bunch, but they are far fewer in number than the other constellations.

SpaceX's Starlink V2 Mini satellites are about the same brightness as the (now-discontinued) first-generation versions — even though the V2 Minis have more than four times the surface area. That accomplishment illustrates the success of the company's brightness-mitigation efforts.

Meanwhile, the constellations Qianfan and Guowang are too bright even at their current high orbits, around 1,000 km. Later launches will aim for lower orbits of 300 to 500 km, which would make the spacecraft 1 to 2 magnitudes brighter than they are now.

The Kuiper spacecraft, from Amazon, are the newest constellation. Amazon has applied brightness mitigation, and we are currently collecting data to assess its effectiveness. Amateur observers are invited to participate by recording satellite magnitudes (*S&T:* Jan. 2023, p. 10).

■ **ANTHONY MALLAMA**

Read more: skyandtelescope.org/sats.

SOLAR SYSTEM

Update on Interstellar Comet 3I/ATLAS

◀ The Hubble Space Telescope imaged Comet 3I/ATLAS on August 7th, when the object was still 3.8 au from the Sun.

ASTRONOMERS have been following the third-ever interstellar object seen inside our solar system, Comet 3I/ATLAS, with both ground- and space-based telescopes.

Comet 3I/ATLAS is zooming through the solar system far faster than either of the previously detected interstellar objects. Also unlike them, it's on a trajectory very close to the *ecliptic* — tilted less than 5° from the plane of planets.

Initial follow-up by Bryce Bolin (Eureka Scientific) and colleagues, reported in the September *Monthly Notices of the Royal Astronomical Society: Letters*, suggested that the interstellar object is a cometary object with a faint, dusty coma and a tail.

Images from the Vera C. Rubin Observatory serendipitously confirmed the coma when the Rubin team realized that they'd caught the object during commissioning activities, starting 10 days before its discovery. Colin Chandler (University of Washington) and coworkers reported the images on the astronomy arXiv preprint server.

The Rubin observations show hints of a cometary tail but, oddly, the elongation points *toward* the Sun. Typically, the Sun's radiation pushes a comet's tail out behind the nucleus, so that the tail always points away from the Sun. But in this case, the ejected particles might be too massive to be blown back, instead leading the comet in its orbit.

From later follow-up with the Hubble Space Telescope, astronomers estimate the nucleus spans between 320 meters and 5.6 km (1,000 feet to 3.5 miles).

Astronomers will continue following the comet as it approaches the Sun, but around perihelion on October 30th (which hadn't yet passed when this issue went to press) the comet will be hidden from Earth's view. For astronomers to catch any fragmentation, spacecraft such as the Jupiter Icy Moons Explorer will fill the gap.

■ **DAVID L. CHANDLER**

IN BRIEF

Some TESS Planets Bigger Than Thought

More than 200 planets in the TESS catalogs are bigger than originally estimated — potentially putting initially Earth-size planets into the super-Earth category. The Transiting Exoplanet Survey Satellite (TESS) detects planets indirectly via their *transits*, revealing a planet's silhouette. But stray light can influence the silhouette's measured shape, making planets appear larger than they are. Each of TESS's camera pixels spans 21 arcseconds on the sky, which means that pixels can pick up stray light in crowded stellar fields. Te Han (University of California, Irvine) and colleagues, publishing in the July 20th *Astrophysical Journal Letters*, cross-referenced TESS data with Gaia's more precise stellar positions and brightnesses. The team found that planetary radii were on average underestimated by 6%, leading to density estimates one-fifth larger than they should be. According to Han, this has important knock-on effects. "We may have actually found fewer Earth-like planets so far than we thought," he says.

■ **COLIN STUART**

NASA / ESA / DAVID JEWITT (UCLA), IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI)

SCIENCE POLICY

Congress's NASA and NSF Budgets Counter Trump, Fund Science

CONGRESS RELEASED funding plans for NASA and the National Science Foundation (NSF) in July, a key — and hopeful — step to having a final budget signed into law by President Trump by the end of the fiscal year on September 30th.

In a strong rebuttal of the White House's request to slash NASA's science budget by 47%, the Senate draft proposed keeping NASA science funding at roughly current levels ($7.3 billion). The House version suggested 18% cuts (down to $6 billion).

The Senate's plan would fund programs on Trump's chopping block, including the Lunar Gateway and the DAVINCI and VERITAS missions to Venus as well as partnerships with the European Space Agency on the LISA gravitational-wave observatory and the Rosalind Franklin ExoMars Rover. The Senate would also fund extended missions such as those for Juno (at Jupiter), New Horizons (in the Kuiper Belt), MAVEN (at Mars), and the Chandra X-ray Observatory. The budget for the Nancy Grace Roman Telescope would nearly double from the White House request, which would aid an on-time launch, currently set for 2027.

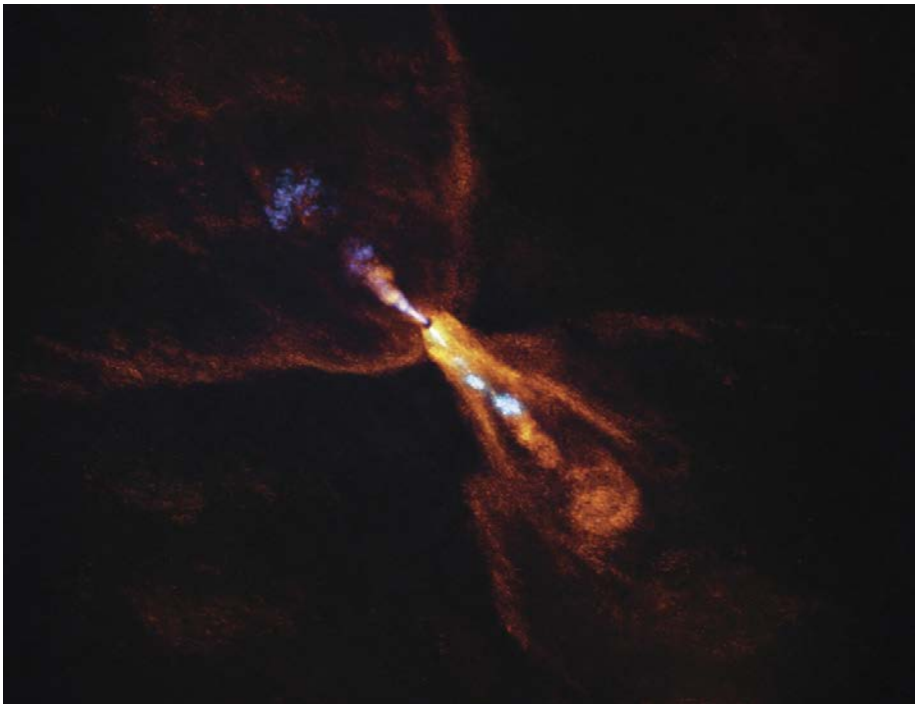
The NSF, which funds projects such as the Laser Interferometer Gravitational-wave Observatory (LIGO), would lose more than half its funding under Trump's budget. The Senate instead suggested funding NSF at a steady $9 billion, which includes funding both of LIGO's detectors rather than closing out one of them (*S&T:* Oct. 2025, p. 10). The House, meanwhile, put funding at $7 billion (a 23% cut).

Even though appropriations are ongoing as of press time, the Trump administration has already instructed NASA science programs to formulate "closeout plans" and to stop issuing press releases celebrating new science results. The agency has also been encouraging employees to leave their jobs through the government's deferred resignation program. A July 18th letter, sent to Acting NASA Administrator Sean Duffy and signed by 64 members of Congress, asks that no NASA actions be taken in alignment with the President's budget request before the final appropriations bill is passed. Doing so would "stand in direct violation of Congress's role," they write.

More than 300 NASA employees also signed a formal dissent to Duffy titled The Voyager Declaration. The letter lists concerns that the White House would shut down operational spacecraft, shrink the skilled space workforce, and decrease agency safety.

Ultimately, if the U.S. fails to fund science, "it's not going to be that somebody else picks up the slack," says Mike Boylan-Kolchin (University of Texas at Austin). "It's just going to be an overall . . . lack of knowing more about the universe we live in."

■ HANNAH RICHTER



ALMA (ESO / NAOJ / NRAO) / M. MCCLURE ET AL.

Webb Images Infant Solar System

More than 1,300 light-years away in the Orion Nebula, HOPS-315 is a young, Sun-like star that has only recently emerged from its natal cloud of dust and gas. A team led by Melissa McClure (Leiden Observatory, The Netherlands) observed this baby solar system with the James Webb Space Telescope and the Atacama Large Millimeter/submillimeter Array (ALMA), finding warm silicon monoxide (SiO) gas and solid grains rich in silicate minerals. The detections indicate the beginning stages of planet formation — a process that occurred in our own solar system some 4.5 billion years ago. "Our detections were consistent with the theory [of solar system formation] that says that these minerals need to condense close to the protostar, rather than farther out in the disk," McClure says. HOPS-315's young age makes it an excellent laboratory to study planet formation in the earliest stages of a star's life. The image and analysis appear in the July 17th *Nature*.

■ ARIELLE FROMMER

Read more at skyandtelescope.org/HOPS315.

The Elusive Girth of the Zodiacal Band

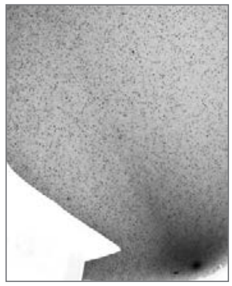
Can you detect this phantom ribbon's diffuse outer edges?

MANY OBSERVERS ARE AWARE of the *zodiacal light* — a dim, very diffuse cone of light sweeping upward from the horizon in the west just after evening twilight and in the east just before morning twilight. But what about its extension, the *zodiacal band?* Under extremely dark skies, this faint ribbon of misty light extends from the tip of the zodiacal light's cone all the way to the antisolar point (opposite the Sun), where it brightens very slightly into an oval patch of light known as the *gegenschein*, or counterglow.

Around nightfall this month is the best time to view the zodiacal band in its sweeping glory, when it crosses the sky largely unimpeded by the Milky Way. More than the zodiacal light or gegenschein, seeing the zodiacal band is a true indicator of a Bortle 1, or extremely dark, sky (*S&T:* Jan. 2024, page 26). But if you'd like to up the ante, see if you can trace the relative extent and definition of its northern and southern edges.

Like the zodiacal light, the zodiacal band is caused by sunlight reflecting off interplanetary dust particles (measuring from 1 nanometer to 100 micrometers in size) in our inner solar system. As seen from Earth, the band is highly concentrated approximately along the ecliptic, which lies centrally within the band of the zodiac — thus, the light's name. The dust particles are primarily derived from comets and asteroids, though their distribution, origin, and evolution remain a mystery.

During December, as seen from mid-northern latitudes at the end of astronomical twilight, the band wraps around the sky from Capricornus in the southwest to Taurus in the northeast, with a maximum altitude of approximately 50° in Pisces. On July 5th to 6th of this year, about 1¼ hours before the start of astronomical twilight, I observed the zodiacal band under Bortle 1 skies from Nxai Pan in Botswana, which is situated at a latitude of 20° south. As it would on December evenings from the Northern Hemisphere, the band stretched from Capricornus to Taurus and culminated at about 80°. The Sagittarius Milky Way (where the gegenschein was located) was nearly setting in the west, and the cone of the zodiacal light was just rising in the east.



◀▲ **DIM AND DIFFUSE** The author captured this view of the zodiacal band from Nxai Pan, Botswana, on July 6, 2025. The tip of the zodiacal light is just rising in the east, where Venus shines near the Pleiades. The glow at upper left is the southern edge of the Milky Way's bulge in Sagittarius. Compare this view with its negative image, shown above. Note how at this time of year, the Milky Way doesn't cross the zodiacal band. This corresponds to the view on December and January evenings in the Northern Hemisphere.

I'd observed the zodiacal band many times before, but on this exceptionally cold, clear winter night in the Southern Hemisphere, the band stood out boldly against the stars. Its bright core was only about 3° wide. But when I swept my head north and south of it, I found its extremely dim outer boundaries spanned from the Circlet of Pisces in the north to near Iota (ι) Ceti in the south — an expanse of about 10° on both sides of the ecliptic. What's more, the southern and northern edges appeared well defined, with the northern side slightly more obvious than the southern.

As reported in a 1999 *Astrophysical Journal* paper, M. Ishiguro (Kobe University, Japan) and colleagues made the first ground-based detection of zodiacal dust bands from the summit of Mauna Kea in Hawai'i. They imaged from October 29 to November 2, 1997, using a 24-mm lens attached to a CCD camera and a blue filter centered at 440 nanometers. Their data of the morning zodiacal light revealed the presence of dust bands up to 10° north and south of the ecliptic, between solar elongations 75° and 90°. The question is, are these zodiacal dust bands related to visual observations made by amateur skywatchers?

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

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THE LOOKBACK MACHINE by N. G. Boeck

Thirty years ago this month, the Hubble Space Telescope spent 10 days looking at an empty patch of sky. What it found changed astronomy — and the people who made it happen.

To understand the origins of one of the most astonishing astronomy images ever taken, consider this question: Who decides what the Hubble Space Telescope looks at?

A committee, of course. If you want to observe with Hubble, you must convince the committee to let you do it. You'll fill out applications, document your request, defend your ideas. The committee — based at the Space Telescope Science Institute in Baltimore — will kick your idea's proverbial tires, deciding whether your proposal is worthy of Hubble's mighty observing prowess. And we do mean "you": anyone — from high school students to senior researchers — can request telescope time (see **stsci.edu/hst/proposing**). You have less than a 20% chance of success.

Unless, that is, you happen to be the institute's director. A slice of Hubble's annual observing time — *director's discretionary time* — belongs to the person populating that chair. The director can approve things like time-sensitive projects or even a program they've designed with their own team. But there's pressure to choose your targets carefully.

Thirty years ago, that director's chair belonged to Robert "Bob" Williams, a marathon-running, Ironman Triathlon–qualifying, Los Angeles Dodgers–loving space cowboy with a PhD in astronomy. He walked away from a tenured teaching post at the University of Arizona in 1983 to pursue more adventure than whiling away his days in an academic safe harbor would provide.

"If you want to be a leader," he says, "you have to be willing to take risks."

Williams eventually landed at the Space Telescope Science Institute in 1993, an astronomy nomad who had bounced from Arizona to positions in Germany, California, and Chile, where he directed the Cerro Tololo Inter-American Observatory for eight years. He arrived in Baltimore the same year the Space Shuttle *Endeavor* flew astronauts up to fix Hubble's flawed mirror — a butt of late-night jokes and newspaper cartoons, much to the chagrin of the project's scientists. But the images from the fixed scope were spectacular. Director's discretionary time was his for the taking.

Williams, ever the risk-taker, didn't want to play small ball. He wanted to hit a home run.

He thus did something no one had done before: He decided to spend 10 days in December 1995 looking not at planets, or known galaxies, or supernovae. Instead, he pointed the telescope at a blank patch of sky.

That blank patch of sky changed the field of astronomy.

The legacy of the image that resulted from those 10 days, the Hubble Deep Field (HDF), is about more than one pretty picture. The HDF turned the science of galaxy formation on its head. There are now two periods in modern-day galactic science: before the HDF, and after. It is one of the grand slams of modern astronomy.

The Team Takes Shape

The project started with postdoctoral researchers — that young, hungry corps of newly coronated PhDs fresh off their dissertation defenses. A great idea can launch a decades-long career. In 1995, postdocs Harry Ferguson and Mark Dickinson shared an office in Baltimore. They and others met with Williams for "science coffee" in the mornings, kicking around new research ideas.

Dickinson, an expert in spectroscopy, had already seen some success with Hubble by the time Williams began trawling for a discretionary project. Dickinson studied a group of small galaxies around the radio galaxy 3C 324. That galaxy has a redshift (z) of 1.2, which means its light left 3C 324 around 8.5 billion years ago, or around 5.3 billion years after the Big Bang. The deep-field image that resulted, a black-and-white image taken with a single filter, also revealed tons of small, compact galaxies hitherto unseen.

Yet nobody really knew whether a deep-field image targeting anything other than a known object would produce scientifically valuable insights. Based on Dickinson's success, Williams decided to find out and look into the void: to target an area that appeared both empty and ordinary. If there was something there, Williams reasoned, then a "typical" patch of empty sky would likely help astronomers infer what they might find in any such patch of the heavens.

▶ **THE ORIGINAL DEEP FIELD** Hubble took 342 exposures using different filters to create this image. Its revelations led to a series of deep-field images, reaching ever farther out toward the horizon of the observable universe.

◀ **THE OUTFIELDERS** From left to right, HDF team members Ray Lucas, Richard Hook, Harry Ferguson (sitting), Marc Postman, and Hans-Martin Adorf examining HDF exposure frames as the data came in.

TEAM: R. LUCAS / STSCI; HDF: R. WILLIAMS (STSCI), HUBBLE DEEP FIELD TEAM, NASA / ESA

Hubble's FIRST Home Run

▲ **CRACK TEAM** *Left:* Harry Ferguson, Mark Dickinson, and Bob Williams stand in the library where they met for science coffee discussions, shortly after the release of the initial deep field image. *Right:* The same trio, gathered together a few years ago for an HDF anniversary.

COURTESY OF R. WILLIAMS (2)

He tasked a team led by Dickinson and Ferguson to plan out the project. The deep-field team would eventually comprise 17 scientists.

They risked more than a single exposure. Ferguson proposed that they observe multiple wavelength ranges, using an ultraviolet filter during the daylight hours of Hubble's orbits (to minimize interference from Earth's reflected light), and a visible-light filter at night. Eventually the team would use four different filters for the project, the better to capture every last photon the sky would offer up. As a result, a substantial fraction of director's discretionary time would be taken up by this one project.

Skeptics recoiled at the prospect. Some theorists thought that objects with exceptionally high redshifts would be undetectable with Hubble. Others wondered how the U.S. Congress that funded Hubble would respond if, after the expense of launching and then fixing their flagship space telescope, those two weeks produced nothing of note.

Williams and the HDF team decided to do it anyway.

The chosen field, tucked inside the constellation Ursa Major, was located in one of Hubble's *continuous viewing zones*, where Hubble can view the sky without being blocked by Earth or bothered by the Sun or Moon. The field was tiny by Earth-bound standards: just 1⁄12 the width of the full Moon.

In December 1995, as Hubble quietly orbited above, sending its missives back to Baltimore, Ferguson, Dickinson, and the rest of Williams's young team churned through the data. They fought one of the largest snowstorms in years in early January ("They shut down New Jersey," Ferguson remembers) to get to their offices — the days of work-from-home arrangements made possible by the internet and video-teleconference software still lay many years in the future. By the time the American Astronomical Society gathered for its annual winter conference in San Antonio in mid-January 1996, Williams and his team had their image ready to present at a morning press conference.

It wasn't, as some had feared, nothing. The image was studded with galaxies — around 3,000 of them, give or take, at previously unheard-of redshifts. Thanks to the decision to use four different filters to take the image, it was bursting with color, revealing stellar populations of various ages, from young, bluish star-forming regions to ancient amber stars.

Because the HDF was a typical "empty" patch of sky, the result meant our universe was likely populated with tens of billions of galaxies.

The image proved that a space-based telescope could find more galaxies, and in earlier stages of their evolution, than ever before. On January 16, 1996, the HDF news made the front page of *The New York Times*.

The HDF was the first truly magnificent deep-field image ever taken. And it would not be the last.

REDSHIFT
Redshift, denoted by *z*, is a measurement of how much the light from a source has been stretched to the redder, longer wavelengths of the spectrum as the photons traveled through expanding space. The *z* value is directly proportional to the distance the light has traveled (*S&T:* Oct. 2024, p. 76).

"Never Going to Be the Same"

The field of galaxy morphology — classifying galaxies by their structure, whether elliptical or spiral or otherwise unique — began in the 1920s with Edwin Hubble. His "tuning fork" illustration visually ordered galaxies by shape: from round ellipticals and oblate ellipticals to both tight and wide spirals. (Hubble himself never meant to imply a literal evolutionary sequence from ellipticals to spirals; the idea that the tuning fork implied an evolution from one shape to another is a common misconception.)

By the 1970s, astronomers had seen that galaxies in distant clusters were bluer than those closer to Earth, and they suspected that galaxies evolved from being bright and blue (due to lots of star formation) to red (as star formation ceased) over

HDF SOUTH Ten days of observations in October 1998 resulted in this deep-field image of a small patch of sky in the constellation Tucana, near the south celestial pole. Galaxies with redder colors may indicate older stars, dust-scattered starlight, or redshifted light. Foreground stars identify themselves with diffraction spikes. The field is 2½ arcminutes wide, less than ⅒ the width of the full Moon.

R. WILLIAMS (STSCI), HDF-S TEAM, NASA

cosmic time. Leading up to the HDF, surveys had turned up faint blue galaxies at such vast distances that images couldn't resolve what they looked like. It was unclear what these objects indicated about galaxy formation and evolution.

In 1996, Roberto Abraham — a self-proclaimed "galaxy guy" — was a postdoctoral researcher at the University of Cambridge in England. Abraham heard about the HDF from colleagues, one of whom had served on the committee that worked with Williams to design the program. Abraham knew when the HDF data drop was likely to happen, and he was ready for it.

"Two seconds after you looked at the Hubble Deep Field, you had the sense that astronomy was never going to be the same," he says.

The HDF revealed many galaxies at high redshifts in unexpected shapes and sizes. Abraham and his fellow researchers devised a quantitative method for analyzing galaxy morphology. They measured and mapped out differences in the intensity of light coming from the center and edges of the galaxies in the HDF. Abraham also figured out a simple algorithm for testing symmetry: Take a picture of an object, rotate it 180°, take another picture of it, and then subtract one picture from the other. If you have anything left over, the object is asymmetrical. He got the idea by watching his wife take a bite out of a fast-food hamburger.

Abraham discovered that the image was full of asymmetrical galaxies with very high redshifts — "train wrecks" of young, dysmorphic galaxies (as Williams describes them), never before seen at the level of resolution that the four-filter approach provided. Many of these objects resembled the faint blue galaxies counted, but not resolved, in earlier surveys. The younger the galaxy, the more likely it was to be asymmetrical, without the discernible central bulge seen in many mature galaxies.

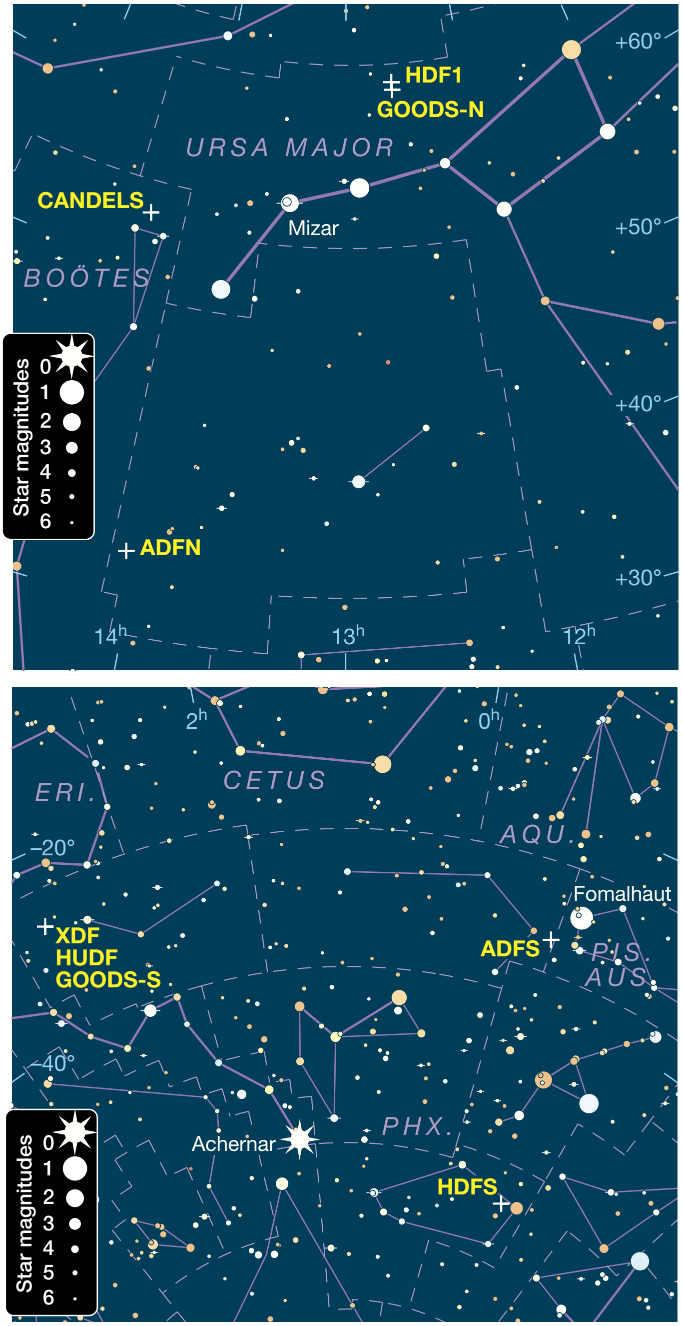
That suggested early galaxies built up from smaller entities that crashed into each other, proving we live in an evolving universe. Astronomers now realize that, contrary to the tuning fork's common misinterpretation, star-forming disk galaxies eventually merge and become red-and-dead ellipticals.

Abraham and his colleagues submitted their HDF paper for publication within a month of the San Antonio meeting, and it was accepted days later — lightning speed in the staid world of academia. It was the first paper published with HDF data, and it remains one of the most-cited of Abraham's career. To this day he's amazed nobody beat him to the punch.

"It was so much fun," he remembers. "I literally slept under my desk for two days. We were all just working like maniacs. Who *wouldn't* be sleeping under their desk for a couple of days? You'd just be nuts. It's just a magical period of time when you get handed this spectacular, historic data set."

Abraham turned 60 this year and just completed a five-year stint as a chair in the University of Toronto's astronomy department. He still talks about the HDF with the same childlike excitement he felt the first time he saw Jupiter and its four largest moons through a backyard telescope.

"Those moons looked like little dots," he recalls. "But then Voyager released its images of Jupiter and its moons, and I realized they were all worlds unto themselves. There was so much more to discover." That, Abraham stresses, is what the HDF did for galaxy studies.



▲ **DEEP FIELDS** Since the first HDF, astronomers have used Hubble to complete several deep fields. They've also conducted the GOODS (north and south), CANDELS, and COSMOS surveys, which are less deep but have wider fields. COSMOS doesn't appear here, since it's near the equator. The Extreme Deep Field (XDF) is a smaller area within the Ultra Deep Field (HUDF). Also shown are the locations of the Amateur Deep Fields (see page 20).

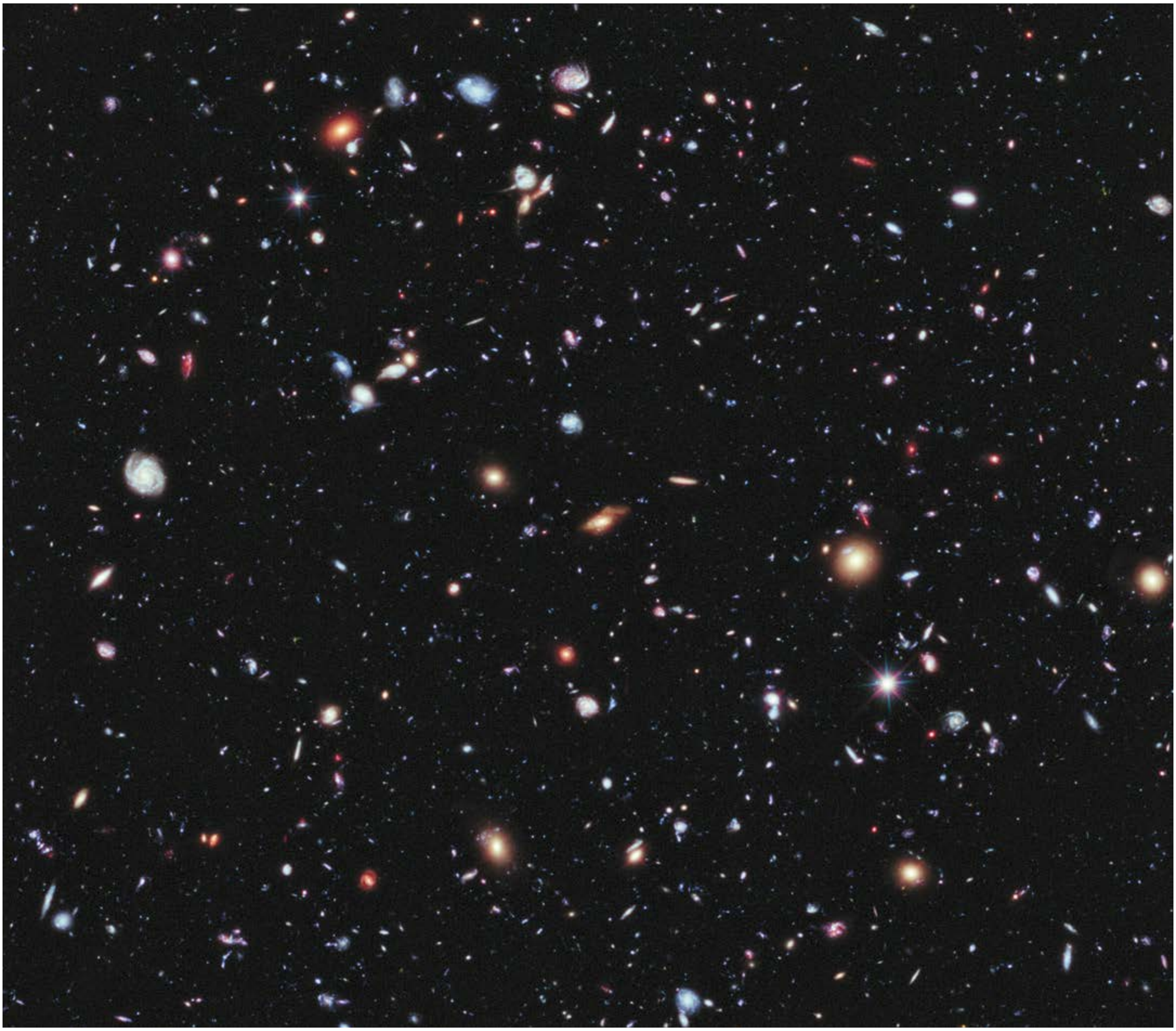
A Mad Dash

Deep-field images are a perfect scientific endeavor: They answer questions and spur new ones at the same time. The HDF North (HDFN), as it was eventually christened, led to a 1998 HDF image in the Southern Hemisphere sky (HDFS), another Williams-led project. After that came the Hubble Ultra-Deep Field (UDF) image, created from data gathered in 2003 and 2004.

Astronomer Chris Evans (European Space Agency) recalls the rush of energy when the UDF image was released in 2004. Everyone scrambled to find the highest-redshift objects, competing for follow-up observations, he says. It was a level of energy and excitement that can be difficult to describe to those outside the profession, not unlike a feeding frenzy among sharks with a prized catch (although, one hopes, a bit more civilized).

In 2012, astronomers created yet another image, known as the Extreme Deep Field, with additional data from Hubble's Ultra-Deep Field Infrared survey. It included galaxies seen as they were 13.2 billion years ago. Telescopes, working as time machines, were nudging closer and closer to the edge of the observable universe.

"We've had these multiple generations of astronomers who've grown up scientifically with this amazing observa-



▲ **GOING TO EXTREMES** Astronomers assembled the Extreme Deep Field, or XDF, by combining more than 2,000 Hubble images taken over a span of 10 years, totaling 2 million seconds of exposure time. The deep field is a patch of sky at the center of the earlier Hubble Ultra Deep Field, in the southern constellation Fornax. The image is 2.3 arcminutes by 2 arcminutes in size and contains more than 5,000 galaxies.

NASA, ESA, G. ILLINGWORTH, D. MAGEE, AND P. OESCH (UC SANTA CRUZ), R. BOUWENS (LEIDEN UNIVERSITY), HUDF09 TEAM

tory," Evans says of Hubble. The HDF itself has generated thousands of academic papers in the last 30 years. When we add the other deep-field images taken by Hubble and other space telescopes, the number of papers citing deep-field projects climbs into many tens of thousands.

These images have informed choices for newer space telescopes. For example, mission planners chose to design the James Webb Space Telescope (JWST) to capture longer wavelengths in the infrared spectrum in part because of what the HDF revealed, according to Marcia Rieke (University of Arizona), principal investigator for the JWST's near-infrared camera, NIRCam.

Hubble deep-field data continue to be re-analyzed, augmented by data collected from other space- and ground-based telescopes, including the Chandra X-Ray Observatory for the X-ray spectrum, the Spitzer Space Telescope (launched in 2003 and retired in 2020) for infrared, and the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile for microwave wavelengths. Mark Dickinson describes the field today as "a very multi-wavelength science," one that has shifted focus from the days when an optical astronomer, an X-ray astronomer, and a radio astronomer would be three different people.

One recent deep-field project, published in August 2024, used data from multiple Hubble deep fields to identify supermassive black holes in the early universe. The team compared

The Amateur Deep Field Images

Big, ambitious research projects can influence the field even more than we imagine at first glance. In the case of the HDF, it led to developments not just in professional astronomy but in the amateur community as well.

Among them is the Amateur Deep Field. Using ground-based telescopes located at remote facilities around the world, a motley crew of serious amateurs decided in 2024 to test the boundaries of their own telescopes with a deep-field project that came with a slightly lower price tag than Hubble's roughly $2 billion — and less professional pressure than Bob Williams experienced as the head of the Space Telescope Science Institute.

The ADF team consists of a group of more than 30 international amateur observers and professional collaborators, led by Steve Mandel (University of California, Santa Cruz). Mandel is a retired science communications expert. With a friend, he co-owns two PlaneWave telescopes ("the Porsche of telescopes," Mandel says), including a 17-inch that retails for more than $25,000, before you add in the cost of the mounts and accessories.

images taken several years apart to detect growing black holes by their flickers — a technique used previously but not with objects at very high redshifts. The study adds to existing evidence that supermassive black holes formed during one of the universe's earliest epochs.

A Cosmic Selfie

In March 2025, Bob Williams told the story of the HDF to a packed audience at a movie theater in Santa Cruz, California. Now in his 80s, Williams still takes long-distance bike rides and looks every bit the athlete he's always been. He admits he's considering purchasing an electric bike, now that friends have told him that the bike doesn't do the hard work for you: It just gives you an assist proportional to the energy you're putting into the pedals. Williams does not strike one as the type of person who would ever willingly take a shortcut.

To honor his impact on astronomy, Williams's colleagues had an asteroid named after him. The plaque they presented him with at the event says the asteroid celebrates Williams's decision "to take the Hubble Deep Field image, which captured infant galaxies 12 billion years back in time and which showed conclusively that the universe is evolving."

Standing beneath the iconic image, displayed on the big

◀▲ **AMATEUR DEEP FIELDS** An international team of amateurs, wielding 12 telescopes in each hemisphere, took the images overlaid to create these deep fields. ADF North combines 295 hours of exposure time and covers 0.52° by 0.35°; ADF South combines 291 hours and covers 0.65° by 0.43°. Most images were taken with a luminance filter, with a bit of RGB for color. Apertures ranged from 12.5 inches to 1 meter.

Together, the ADF team members control about two dozen telescopes in both the Northern and Southern Hemispheres, housed at remote facilities in dark-sky areas around the globe. From the comfort of his living room in Santa Cruz, Mandel can fire up his telescope and start his observing runs every night. An onsite crew at the remote hosting facility is on hand to solve any technical problems. (I asked Mandel where he got the more than $60,000 to invest in his observing hobby. “Some retirees get a sports car, some get a boat,” he mused. “I got telescopes.”)

The team produced two images: the Amateur Deep Field North and the Amateur Deep Field South. Unveiled at Williams’s March 2025 Santa Cruz talk, the images contain objects with redshifts up to 2.77, capturing light that has traveled 11.3 billion years to reach Earth. “I told Bob, ‘You inspired this,’” Mandel says.

movie-theater screen for the assembled crowd, astronomer Sandra Faber (University of California, Santa Cruz) said in her introduction to Williams’s talk, “In my opinion, this is the most important, significant image ever taken by a human telescope.”

Williams attempted to put into words the ultimate goal of the HDF project. He knew the Hubble team needed a big win after a shaky start. He’d spent his whole life watching baseball stars establish their greatness by leaning into the pitch. And he’d bet on himself his whole life and come out winning. Why play it safe when the universe is just begging you to take a big swing?

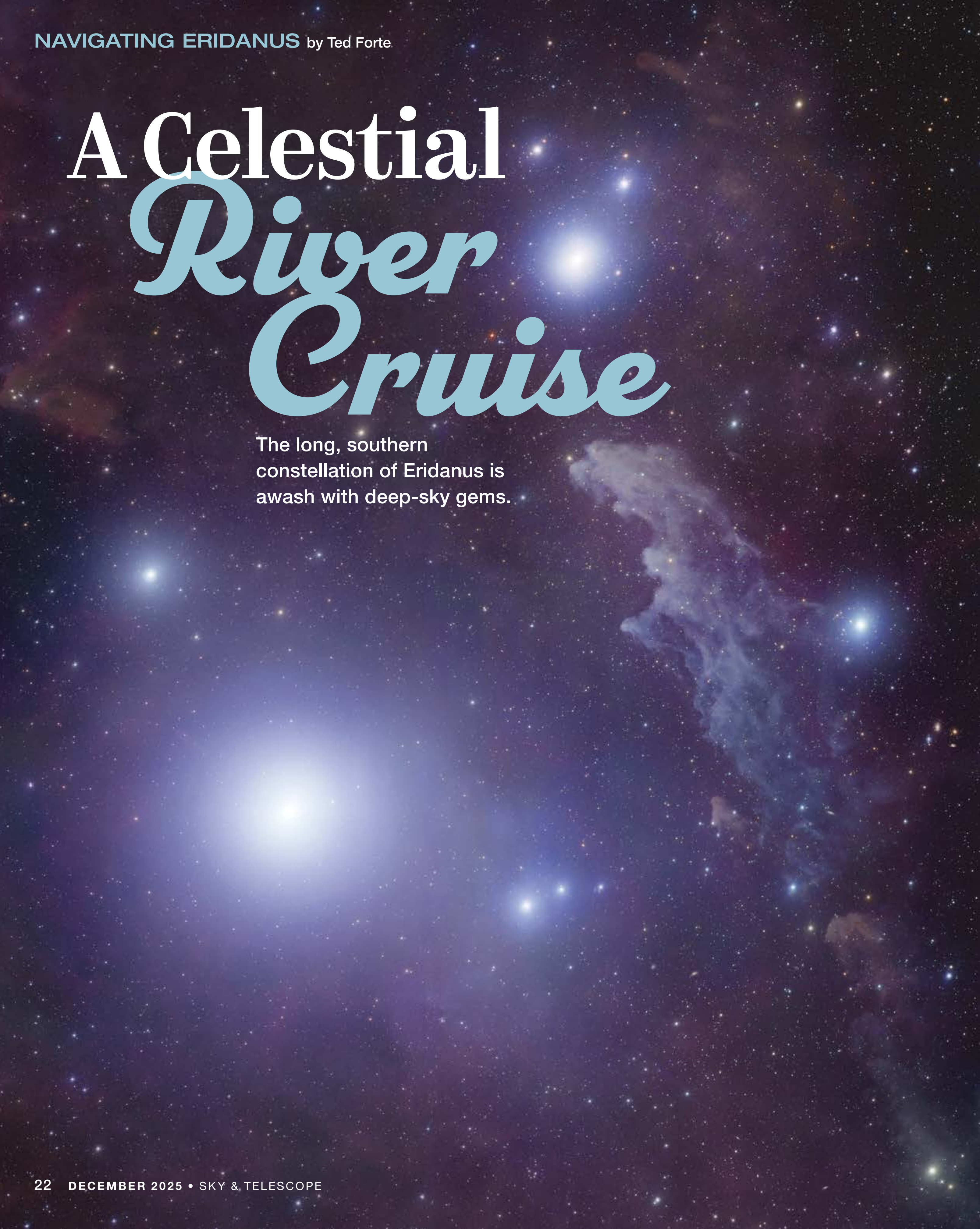
That big swing paid off, giving us what Williams calls “a selfie of humanity.” “All that is out there is what we developed from,” he says. Thirty years after HDF changed our understanding of the cosmos, he told the assembled crowd: “This one image was our attempt to reveal the contents of, and the evolution of, the universe.”

One would argue that it more than accomplished that task.

■ **NICOLE BOECK** (née Nazzaro) is a biochemist and science writer and educator who has written for *Nature*, *The New York Times*, Yale School of Medicine, Fred Hutchinson Cancer Center, and *Runner’s World*.

A Celestial *River Cruise*

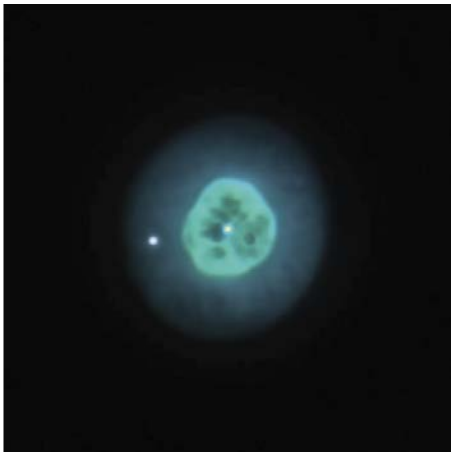
The long, southern constellation of Eridanus is awash with deep-sky gems.



The meandering line of 30 or so stars that delineate the vast constellation of Eridanus represents a river in the star lore of several cultures. Indeed, its sinuous path traced out on star maps evokes the image of a mighty river, winding its way from the foot of Orion and then flowing south to its +0.5-magnitude lucida, Achernar, Alpha (α) Eridani. Along its banks you'll find many interesting denizens of the deep sky, waiting to be encountered.

Arguably, the most famous of these is **IC 2118**, the Witch Head Nebula. Lying near the source of the River and just west of Rigel, Beta (β) Orionis, this large, 13th-magnitude reflection nebula, so attractive in photographs, is devilishly difficult visually due to its ethereal faintness. It can sometimes be detected as a subtle glow that only just exceeds the natural brightness of the background sky. I have only suspected it in my 10×30 binoculars.

There are hundreds of galaxies cataloged in Eridanus. While my hunting here was done mainly with my 18-inch f/4.5 Dobsonian, I've chosen targets visible in a 10-inch reflector from reasonably dark skies.



▲ **CLEOPATRA'S EYE** The planetary nebula NGC 1535 features a faint outer region and a brighter inner center. Its structure is similar to the better-known NGC 2392 in Gemini. A planetary nebula forms when a star approximately the size and mass of our Sun dies, expelling its outer layers into space as the hot core evolves into a white dwarf star.

About 3½° north-northwest of Rigel, the 2.8-magnitude star Cursa, Beta Eridani, serves as a convenient jumping-off point to our first galaxy, **NGC 1700**. To navigate to it, use the wide, 5.5-magnitude double star 62 Eridani situated 2.9° west of Cursa. NGC 1700 is 20′ north-northeast of the double's yellow primary. This 11.2-magnitude elliptical galaxy appears oval with a very bright core in my 18-inch at 197×. It's paired with the smaller, fainter (magnitude 13.9) spiral, **NGC 1699**, which lies 7′ north.

William Herschel discovered NGC 1700 in 1785 but missed NGC 1699. In his *New General Catalogue of Nebulae and Clusters of Stars*, John Louis Emil Dreyer credits the discovery of NGC 1699 to William Parsons, the Third Earl of Rosse, but his assistant, Irish artist Samuel Hunter, actually found the galaxy in 1860. Irish astronomer R. J. Mitchell, using Lord Rosse's famous 72-inch Leviathan reflector at Birr Castle, mistakenly thought he could resolve the core of NGC 1700. As it happens, modern observations indicate that the galaxy is probably the result of a merger event some 5.5 to 8.3 billion years ago.

Continuing west, you'll encounter the 12.1-magnitude barred spiral **NGC 1667**, a short star-hop from 4.4-magnitude Omega (ω) Eridani. It's a Seyfert galaxy — a class of active galaxies with bright, quasarlike nuclei. These objects are named after American astronomer Carl Seyfert, who first described them in 1943. NGC 1667 is also known as NGC 1689. It has two designations in the *New General Catalogue* because American astronomer Lewis A. Swift observed the object on October 22, 1886, but made a 5-minute error in right ascension in recording its position. Dreyer assumed Swift's find was a different object than the one discovered by French astronomer Édouard Stephan three years earlier and gave it its own designation. NGC 1667 has similar-looking NGC 1666 near it, 15′ to the south.

◀ **A HALLOWEEN VISUAL TREAT** Try to catch IC 2118, also known as the Witch Head Nebula, in the northeastern headwaters of Eridanus, the celestial River. It shines by reflected light from brilliant Rigel, Beta (β) Orionis, shown 2° to its left. Astrophotographer Robert Gendler used a Takahashi FSQ106 telescope, an SBIG STL-11000XM camera, and LRGB filters in Western Australia to capture images for this 10-frame mosaic. North is up in all images.

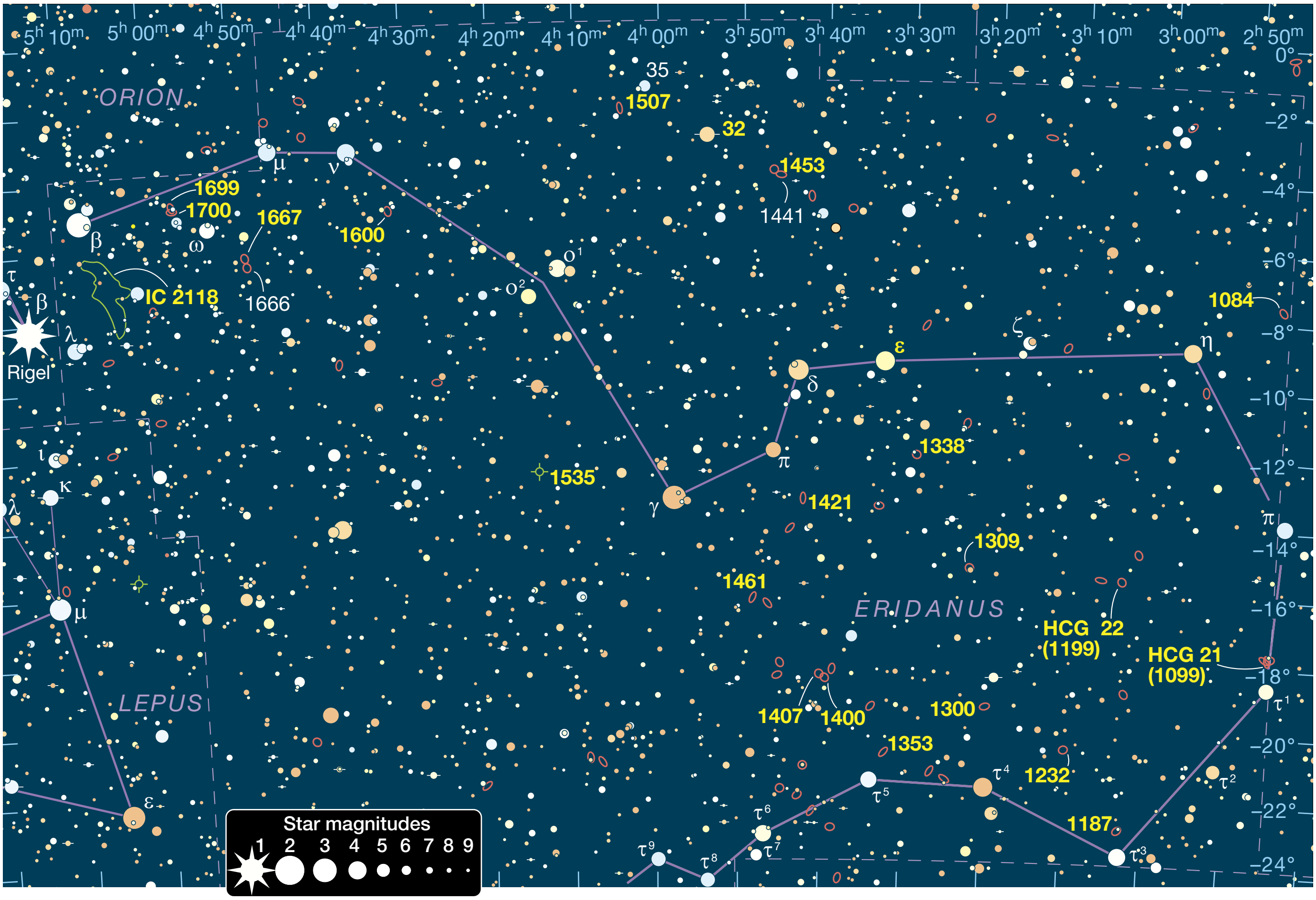
NGC 1600 is the brightest in a group of galaxies about 2° south-southwest of the 4th-magnitude star Nu (ν) Eridani. A 2008 paper in *The Astrophysical Journal* confirms that this 10.9-magnitude elliptical is unassociated with the small, fainter galaxies that pepper the field. In my 18-inch at 140×, NGC 1600 has a very round, bright core that sharpens to a stellar point inside a large, diffuse halo. Herschel discovered NGC 1600 in 1786, while George Johnstone Stoney, an Irish physicist and assistant to Parsons, found several of the surrounding galaxies in 1849, using the 72-inch Leviathan.

Before examining our next galaxy, the nice double star **32 Eridani** is well worth a look. This fine visual double, located 5.9° northwest of the 4th-magnitude star Omicron^1 (o^1) Eridani, is a pretty pair consisting of a 4.8-magnitude yellow-orange primary and a silvery-blue 5.9-magnitude secondary that are separated by 6.9″ and easily split at moderate magnification.

Just 2.7° east-northeast of 32 Eridani you'll encounter **NGC 1507**. Discovered by Herschel in 1785, this 12.3-magnitude barred spiral is seen edge-on, oriented nearly north-south. In my 18-inch at 138×, it appears faint and laden with dust with a slightly bulbous center. The 5.3-magnitude star 35 Eridani lies 58′ northwest.

NGC 1453 is an 11.5-magnitude elliptical situated 2.2° west-southwest of 32 Eridani. In my 10-inch f/4.9 Dobsonian at 197×, it exhibits a bright, circular core within a fainter oval halo. The galaxy and the supermassive black hole at its center were part of a survey called MASSIVE, which examined the structure and dynamics of the about 100 most massive, early-type galaxies within 352 million light-years of Earth.

A trio of dimmer galaxies shares the same field as NGC 1453. Herschel discovered NGC 1453 in 1786 along with one of the smaller-looking galaxies, NGC 1441. German astronomer Heinrich Louis d'Arrest discovered the other two — NGC 1449 and NGC 1451 — in 1864. However, notes from Herschel's



▲ **GALAXY-STUDDED HEADWATERS** The northern end of Eridanus, just west of blazing, +0.1-magnitude Rigel that marks the left foot of Orion, the Hunter, is rich in galaxies and galaxy clusters, along with double stars and nebulae. Use this finder chart to navigate the banks of the celestial River. To read more about the discovery histories of the targets discussed here, go to Contributing Editor Steve Gottlieb's website, **https://is.gd/NGC_IC_Notes**.

second observation of NGC 1441 in 1786 included his impression that there might be two more galaxies trailing it, so he was probably the first to see NGC 1449 and NGC 1451.

My Favorite Things

My favorite Eridanus denizen is certainly the well-known planetary nebula **NGC 1535**. It's popularly known as Cleopatra's Eye, a nickname attributed to *SkyTools* creator, Greg Crinklaw. NGC 1535 lies about 4° east-northeast of 3rd-magnitude Zaurak, Gamma (γ) Eridani. There's an equilateral triangle of 9th-magnitude stars a bit more than ½° to its west-southwest. You can spot this 9.6-magnitude little planetary with as little as 6 inches of aperture. Kent Wallace, author of *Visual Observations of Planetary Nebulae*, reports being able to glimpse this planetary in an 8×50 finderscope fitted with an oxygen III (O III) filter.

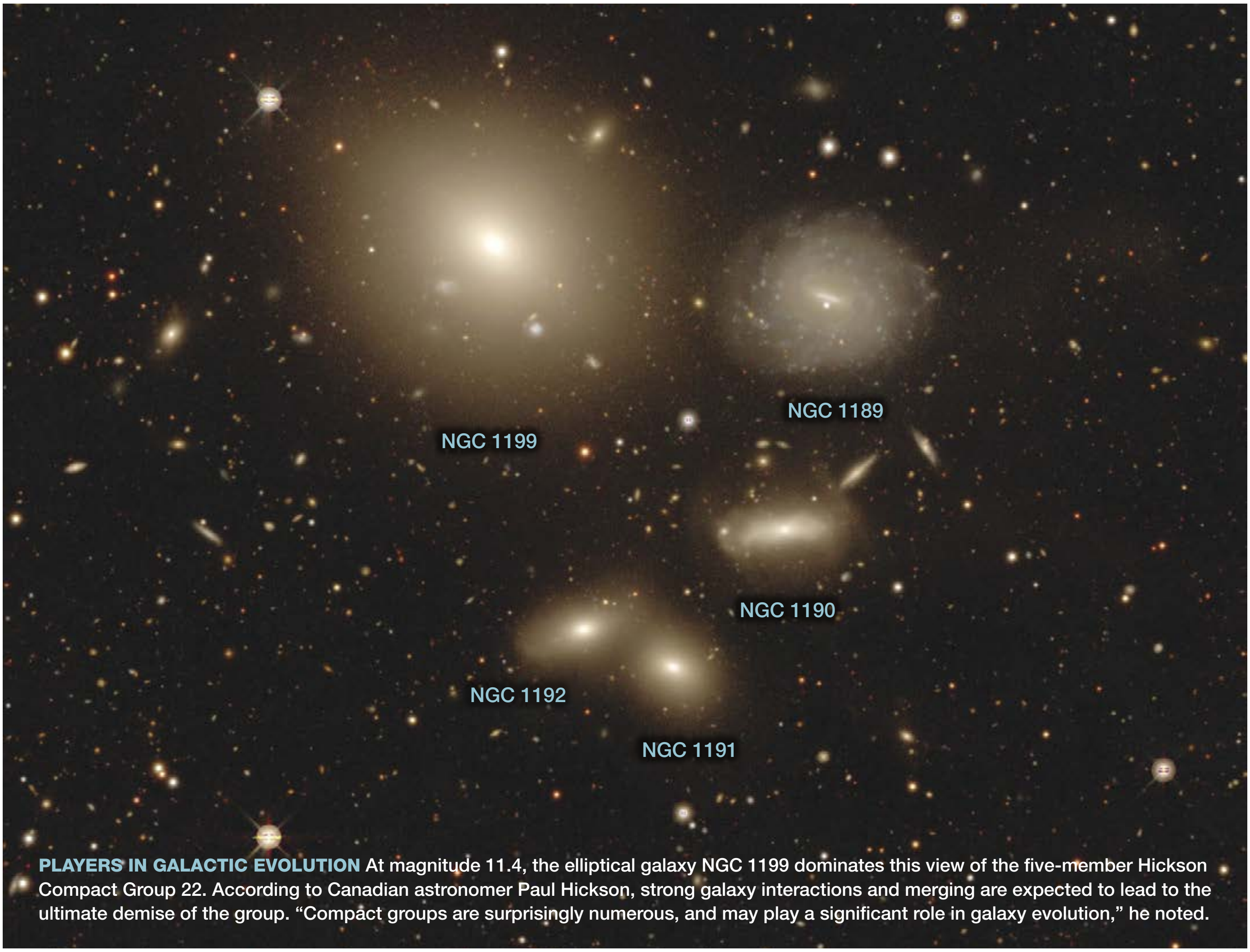
I've examined NGC 1535 many times through different scopes, from an 8-inch Schmidt-Cassegrain to my 30-inch f/4.5 Dob. Herschel, who discovered NGC 1535 in 1785, described it as "a very curious planetary," while English astronomer William Lassell noted it as "the most interesting and extraordinary object of the kind I have ever seen."

As with most planetary nebulae, an O III filter enhances NGC 1535's contrast, its fainter outer halo effectively doubling its size. Its 12th-magnitude central star is typically visible in apertures of 12 inches or greater. The inner 20″ or so of the nebula often displays some intricate structure, and many observers can see its blue color quite easily.

Another of my Eridanus deep-sky favorites is **NGC 1421**. Located 1.6° southwest of 4th-magnitude Pi (π) Eridani, this 11.4-magnitude edge-on barred spiral is an easy target for my 10-inch. At 133×, it appears as a mottled, elongated streak. It really comes alive in my 30-inch Dob at 300× — the blotchy areas seem to resolve into knots, and the main axis appears a bit twisted, with a distinctly curved dust lane.

NGC 1461 is an 11.8-magnitude, lens-shaped galaxy 3.7° southwest of Gamma Eridani. There's a 10th-magnitude star a little more than 3′ to the galaxy's northwest. Discovered by Herschel in 1785, NGC 1461 appears fairly bright in my 18-inch at 197×, with a core elongated north-northwest to south-southeast.

While we're in the area, let's take a break from galaxies



PLAYERS IN GALACTIC EVOLUTION At magnitude 11.4, the elliptical galaxy NGC 1199 dominates this view of the five-member Hickson Compact Group 22. According to Canadian astronomer Paul Hickson, strong galaxy interactions and merging are expected to lead to the ultimate demise of the group. “Compact groups are surprisingly numerous, and may play a significant role in galaxy evolution,” he noted.

and cast a glance toward 3.7-magnitude **Epsilon (ε) Eridani**. At a distance of 10.5 light-years, this orange, *K*-type star is one of the closest Sun-like stars to Earth, and it has fueled the imagination of numerous scientists and novelists alike. Project Ozma, the first search program for extraterrestrial intelligence, targeted Epsilon in 1960. The star has been featured in dozens of science fiction novels and is the proposed target for a number of interstellar probe projects. The Epsilon Eridani system contains one of the closest protoplanetary debris disks to Earth, and it's generally believed to have at least one exoplanet. An observer orbiting Epsilon and looking toward our solar system would see the Sun as a 2nd-magnitude star in the constellation Serpens, the Serpent.

Situated near the Eridanus-Cetus border, **NGC 1084** is a member of the NGC 1052 galaxy group that resides mostly in Cetus. This 10.7-magnitude, nearly face-on spiral lies 2.9° west-northwest of 4th-magnitude Eta (η) Eridani. Stoney called it “a curious object with dark spaces,” and I think that's an excellent description. In my 18-inch Dob at 140×, it appears somewhat round at first, but with study, the shape evolves into two parts with a protruding oval bulge on the northeastern side separated from the main body by a dark void. NGC 1084 is well represented in professional literature, with several researchers studying its spiral structure. I once made a particular effort to trace its spiral arms with my 30-inch at 111× to 433×, but without much success.

Our next target is **NGC 1309**, an 11.5-magnitude spiral located nearly midway between Gamma Eridani and 4.5-magnitude Tau^1 (τ^1) Eridani. Helpfully, it's also 4′ northeast of the 7.5-magnitude star HD 20924. In my 18-inch at 197×, the galaxy appears round and somewhat mottled, with a bright core and a fainter outer halo.

Eridanus contains 10 tight galactic assemblies known as Hickson Compact Groups (HCGs). If you're a fan of these objects — named after Canadian astronomer Paul Hickson, who compiled a list of 100 such groups — you'll want to give at least the two brightest a try. **HCG 21** lies on the border with Cetus, less than 1° north of Tau^1 Eridani. It consists of five members; its brightest, NGC 1099, is of magnitude 13.1 with a surface brightness of 13.0 magnitudes per square arcminute.

HCG 22 is another five-member group found 4.8° east-northeast of HCG 21. Its brightest galaxy, NGC 1199, is magnitude 11.4 with a surface brightness of 13.0. In my 18-inch, both Hickson groups appear to be rather vague smudges of nebulosity, with perhaps one or two members standing out. My 30-inch at 300× distinctly shows all five member galaxies in each group.

Another of Herschel's discoveries, 10.8-magnitude barred spiral **NGC 1187** is located 46′ north of the 4th-magnitude star Tau^3 Eridani. In my 10-inch, it appears mostly round with a bright, nearly stellar core. At 300× in my 30-inch, the outer halo gives just a hint of two spiral arms in a mirror-reversed S shape. A 2018 paper in *The Astrophysical Journal* concludes that NGC 1187 contains a double nucleus, perhaps indicating two supermassive black holes left over from a past merger event. However, there's no evidence of that double nucleus at the eyepiece whatsoever.

Continue 2.8° northeast from NGC 1187 and you'll encounter 14.7-magnitude **NGC 1232**. Lying 7′ west-southwest of a 9th-magnitude star, this face-on, barred spiral shows a bright core with a knotty outer halo in my 10-inch. I strongly suspected spiral arms in the 18-inch, but they're definite in the 30-inch. Several knots, presumed to be ionized hydrogen (H II) regions, are visible in the halo. A 2018 paper in *The Astronomical Journal* identifies 976 H II regions in this grand spiral. NGC 1232 has a small cataloged companion, NGC 1232A, just 4′ to the east, but they're likely 7.8 million light-years apart in space and show no outward signs of physical association. Also known as Arp 41, the pair were assumed by some to have interacted in the past, leading to controversy over the companion's measured redshift. In fact, American astronomer Halton C. Arp used the pair to argue against the validity of redshift-based distances — an argument that is still being debated to this day.

▲ **A MAJESTIC GALAXY** William Herschel discovered 10.8-magnitude NGC 1187 in 1784. The barred spiral, which lies about 60 million light-years away, was home to two supernovae — SN 1982R and SN 2007Y.

William Herschel's son, John, discovered 10.4-magnitude **NGC 1300** in 1835 from his observatory near Cape Town, South Africa (*S&T:* Nov. 2025, page 20). The galaxy lies 2.3° north of Tau^4 Eridani. NGC 1300 is considered by many to be the prototypical barred spiral galaxy. Its bar feature is prominent but can be quite faint in small apertures. In my 30-inch at 300×, two dappled spiral arms wrap around a blocklike core. The brighter northern arm is anchored on the western end of the bar and shows a number of knots; the southern

A CLASSIC BARRED SPIRAL NGC 1300, located approximately 65 million light-years away, was discovered by John Herschel in 1835. The 10.4-magnitude galaxy spans about 130,000 light-years. While you won't see this much detail in your eyepiece as in this close-up taken by the Hubble Space Telescope, your view will give you a general idea of the galaxy's overall shape and structure.

NGC 1187: EUROPEAN SOUTHERN OBSERVATORY; NGC 1300: NASA / ESA / THE HUBBLE HERITAGE TEAM (STSCI / AURA) arm is much less pronounced. In my 18-inch at 197×, the galaxy overall is less defined, appearing rather faint and wispy with the spiral arms just suspected.

NGC 1353 is an 11.5-magnitude barred spiral located 55′ north-northwest of Tau^5 Eridani and 3′ northwest of a 12th-magnitude star. A 6-inch telescope shows this galaxy as a faint, oval patch. In my 18-inch at 197×, the core appears almost circular and much brighter toward the center, with a halo that's elongated northwest-southeast.

Our last stop is a pair of ellipticals that are part of the Eridanus Group, also known as the Eridanus Cloud. **NGC 1407** is situated 3.4° north-northeast of Tau^5 Eridani and about 1° north of a compact triangle of 7th-magnitude stars. At magnitude 9.7, NGC 1407 is the brightest object in a subgroup that includes 11.0-magnitude **NGC 1400** 12′ to the southwest. William Herschel discovered both galaxies almost a year apart — NGC 1407 in October 1785 and NGC 1400 in September 1786. NGC 1407 is moderately large with a bright core while its neighbor is smaller and much fainter. The larger galaxy, and in fact the group that it dominates, has appeared numerous times in professional literature. Researchers have extensively studied NGC 1407's globular clusters to understand its formation history, and they're interested in using the group as an astrophysical laboratory for investigating how early-type galaxies formed.

Eridanus is overshadowed by its flashier neighbor, Orion. The constellation's southern extremity lies beyond the reach of mid-northern latitude observers, making its celestial vistas somewhat unfamiliar to many readers. But even within its northern boundaries are hundreds of NGC and IC objects visible in backyard telescopes. There are also a few dozen double stars as well as many variable stars suitable for small instruments. I hope this tour has whetted your appetite to start exploring them.

■ Contributing Editor **TED FORTE** enjoys hunting deep-sky objects from his home observatory outside of Sierra Vista, Arizona. He can be reached at **tedforte511@gmail.com**.

Eridanus Deep-Sky Denizens

Object	Type	Surface Brightness	Mag	Size/Sep	RA	Dec.
IC 2118	Reflection nebula	—	~13	180.0′ × 60.0′	05h 04.9m	–07° 16′
NGC 1700	Elliptical	13.3	11.2	3.3′ × 2.1′	04h 59.9m	–04° 52′
NGC 1699	Spiral	12.9	13.9	0.9′ × 0.5′	04h 57.0m	–04° 45′
NGC 1667	Barred spiral	12.9	12.1	1.4′ × 1.0′	04h 48.6m	–06° 19′
NGC 1600	Elliptical	12.5	10.9	2.5′ × 1.7′	04h 31.7m	–05° 05′
32 Eridani	Double star	—	4.8, 5.9	6.9″	03h 54.3m	–02° 57′
NGC 1507	Barred spiral	13.4	12.3	3.6′ × 1.0′	04h 27.0m	–02° 11′
NGC 1453	Elliptical	13.2	11.5	2.4′ × 1.9′	03h 46.5m	–03° 59′
NGC 1535	Planetary nebula	—	9.6	0.9′	04h 14.3m	–12° 44′
NGC 1421	Barred spiral	12.5	11.4	3.4′ × 0.8′	03h 42.5m	–13° 29′
NGC 1461	Lenticular	12.8	11.8	3.0′ × 0.9′	03h 48.5m	–16° 24′
Epsilon Eridani	Sun-like star	—	3.7	—	03h 32.9m	–09° 28′
NGC 1084	Spiral	12.5	10.7	2.8′ × 1.4′	02h 46.0m	–07° 35′
NGC 1309	Spiral	13.0	11.5	2.3′ × 2.2′	03h 22.1m	–15° 24′
HCG 21 (NGC 1099)	Barred spiral	13.0	13.1	1.9′ × 0.6′	02h 45.3m	–17° 43′
HCG 22 (NGC 1199)	Elliptical	13.0	11.4	2.3′ × 1.7′	03h 03.6m	–15° 37′
NGC 1187	Barred spiral	14	10.8	4.2′ × 3.2′	02h 37.1m	–22° 52′
NGC 1232	Barred spiral	14	14.7	0.9′ × 0.7′	03h 10.0m	–20° 36′
NGC 1300	Barred spiral	13.8	10.4	6.2′ × 4.1′	03h 19.7m	–19° 25′
NGC 1353	Barred spiral	13.0	11.5	3.4′ × 1.4′	03h 32.1m	–20° 50′
NGC 1407	Elliptical	12.8	9.7	4.6′ × 4.3′	03h 40.2m	–18° 35′
NGC 1400	Elliptical	12.5	11.0	2.5′ × 2.1′	03h 39.5m	–18° 41′

Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0. Magnitudes are visual. For Hickson Compact Group (HCG) 21 and 22, the data for the clusters' brightest galaxy members are given in the table.

Chile's *New Eyes* on the Skies

With three new observatories, Chile maintains its title as the world's astronomy capital.

"It's easy to get lost," says Leonor Opazo as she takes me through a number of hallways and into various elevators to reach the top level of an eye-catching building. I am visiting the Vera C. Rubin Observatory, and I'm happy to have Opazo as my guide. The outreach manager of the Cerro Tololo Inter-American Observatory is a frequent and very welcome guest at nearby Cerro Pachón, which is home to Vera Rubin, as the facility is affectionately known.

However, despite Opazo's mediation, I'm apparently in for a setback. My February visit, at a time when the telescope was still in its final construction phase, had to be planned well in advance. Back then, no one knew exactly what kind of activities would be going on. When we reach the telescope level of the observatory, we're stopped: Workmen prevent us from walking around to get a good view of the impressive new instrument. I have trouble concealing my disappointment.

My Rubin visit was part of a six-week road trip from Punta Arenas, in the very south of Chile, to Arica, in the very north. Driving a small four-wheel-drive camper van, I traversed 35° of latitude and five climate zones. And although this was basically a tourist trip, I was determined to see the three newest astronomical facilities that Chile has to offer.

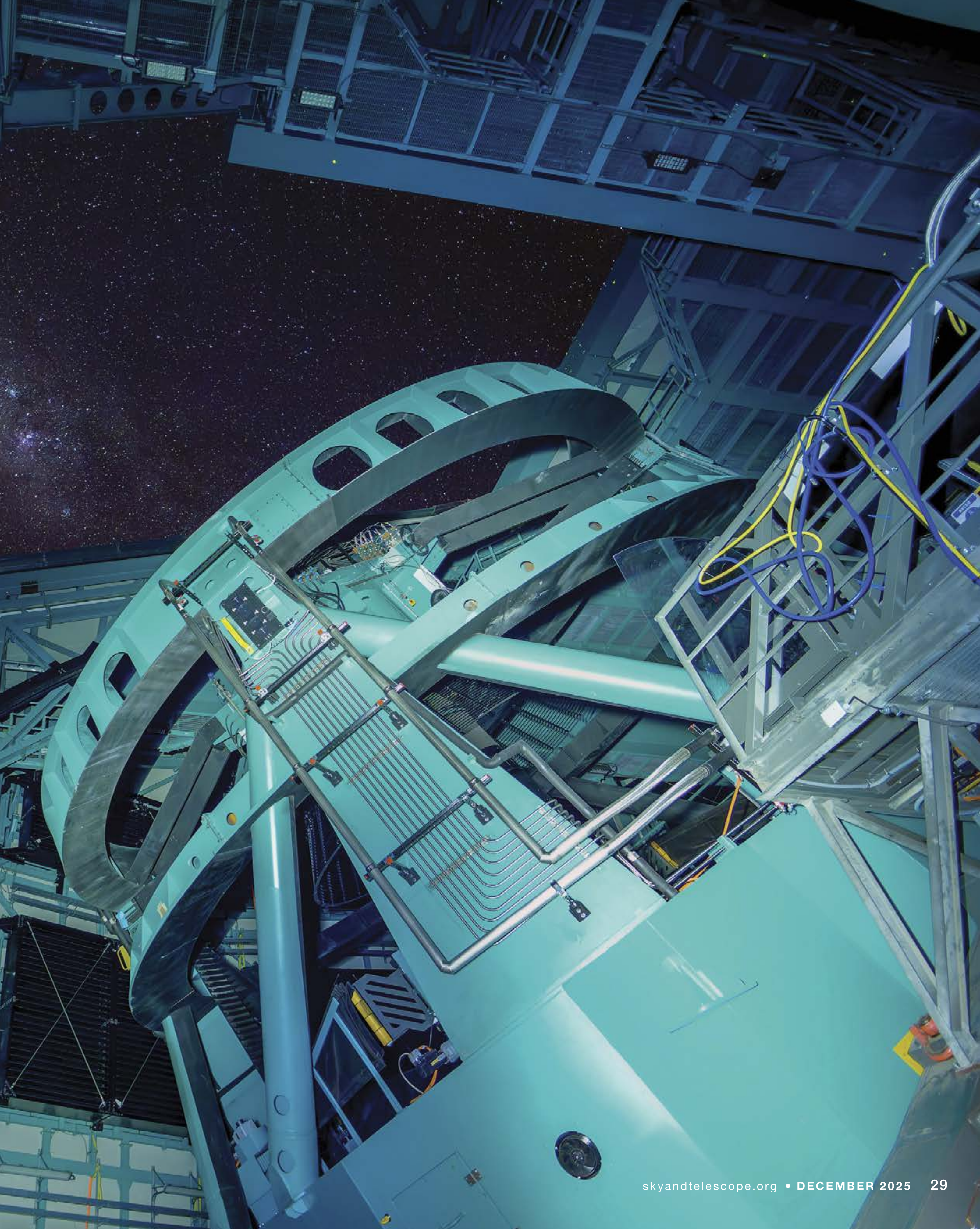
Ever since the 1960s, astronomers have realized that the bone-dry Atacama Desert in northern Chile is an astronomical paradise, with high mountains, clear and steady skies, and little light pollution. Over the decades, many observatories have been built here (see map on page 32), including the European Southern Observatory's Very Large Telescope (VLT) and the international Atacama Large Millimeter/submillimeter Array (ALMA; *S&T:* Sept. 2025, p. 34). But since I've had the good fortune to visit these facilities several times before, I decided this time to focus on the three newest ones: Vera Rubin; the Simons Observatory; and the Extremely Large Telescope (ELT).

Rubin's Revolution

Perched on Cerro Pachón, a 2,700-meter (8,900-foot) mountain south of Chile's Elqui Valley, Vera Rubin — named after the American dark matter pioneer — is visible from many miles away. The unusual but elegant design of the 10-story observatory building minimizes air turbulence that might affect the observations. When we arrive, I don't see an official entrance or reception; instead, Opazo takes me through a

RUBIN OBS. / NSF / DOE / NOIRLAB / SLAC / AURA / W. O'MULLANE

OPEN FOR BUSINESS The Simonyi Survey Telescope stares through the Rubin Observatory's open dome.



metal door, next to a small plaque commemorating the *primera piedra* — the laying of the first stone in April 2015. Before long, we're entering a huge area that looks like a factory hall.

Actually, it *is* a factory hall: This is the coating plant, where the giant, 8.4-meter primary mirror of Rubin's Simonyi Survey Telescope will receive a new layer of reflecting silver every two years or so. (To do so, the mirror will first have to be lifted out of the telescope and lowered to the building's ground level in a 10-meter-wide elevator.) The same coating facility is used for the instrument's secondary mirror, which has a diameter of 3.4 meters — the largest convex mirror ever made.

During my visit, the large coating chamber sits idle, but elsewhere in the hall, the telescope's 3.2-billion-pixel camera is being prepared for its final installation just four weeks later, on March 12th. Funded by the Department of Energy and built at the SLAC National Accelerator Laboratory, it is the biggest digital camera ever built, as large as a small car and weighing more than three tons. Seen from a meters-high walkway, the black camera and its teal-colored support structure remind me of NASA's historic Gemini spacecraft; the technicians with their hard hats resemble space-walking astronauts.

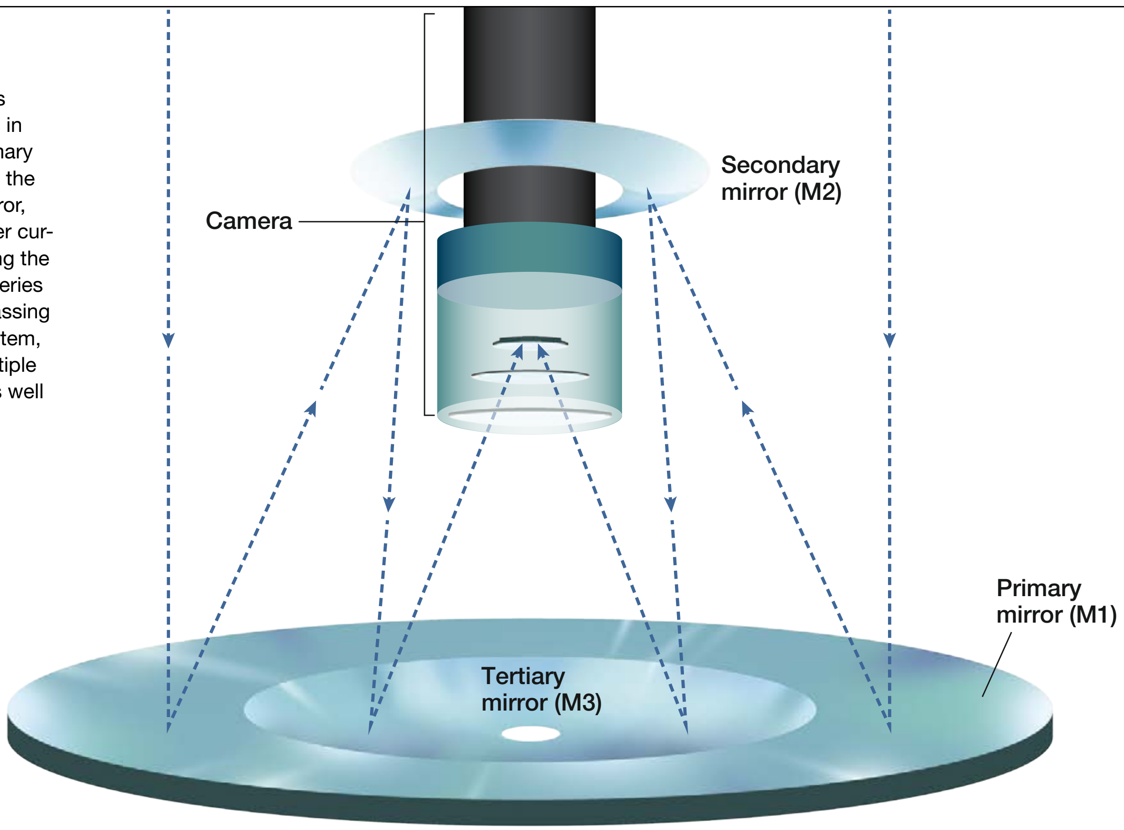
In a sense, the camera will indeed embark on a cosmic voyage, going much farther than any spacecraft has ever flown, by taking an extremely deep, 9.6-square-degree image of the sky every 30 seconds. Over 10 years, astronomers will use these far-reaching images to survey the sky, hunting for transient phenomena and producing a 3D map of the universe (*S&T:* June 2024, p. 34).

At two separate intermediate levels, I can actually enter the hollow telescope pier — a 16-meter-wide concrete structure with 1.25-meter-thick walls that supports Rubin's 350 tons. However, looking at the intricate power, coolant, and electronics cables beneath the instrument is no substitute for a close-up view of the giant telescope itself. Stupid construction schedule, I think to myself, as we head out of the building to visit the 8.1-meter Gemini South Telescope and the 4.1-meter Southern Astrophysical Research Telescope (SOAR), both of which are also located on Cerro Pachón.

But later that afternoon, Opazo has good news. She's been in touch with French-born optical engineer Jacques Sebag, who has been with the project since the very beginning and who came up with Rubin's unusual design. "We're allowed to go in after all," she says, "and Jacques will give us a quick tour." I'm as happy as a child on Christmas morning.

Sebag takes us through the hallways and up the elevators all over again, rapidly answering my numerous questions about "his" telescope in a heavy French accent. The instrument has a revolutionary and very compact optical design, with a 5-meter-wide tertiary mirror embedded in the 8.4-meter primary, meaning that the mirror's central area has a much stronger concave curvature than its 1.7-meter-wide outer rim. "My original design was more conventional," Sebag explains, "but because the telescope needs to slew very rapidly from one sky position to the next, it had to be extremely compact and stiff, so I came up with this solution." The mirror was cast and ground by the University of

▶ **RUBIN OPTICS** The observatory's 8.4-meter primary is actually two mirrors in one: The larger primary forms a ring around the 5-meter tertiary mirror, which has a stronger curvature. Light entering the telescope hits the series of mirrors before passing into the camera system, which contains multiple lenses and filters as well as a cryostat.



Not to scale

LEAH TISCIONE / *S&T*, MIRRORS: RUBIN OBSERVATORY / NSF / AURA / J. PINTO

Arizona's Mirror Lab in Tucson, then shipped to Chile.

Eventually, we arrive at the observing floor again, and now I'm allowed to walk around the impressive instrument, which is still partly surrounded by scaffolding. It is so huge that it almost completely fills its 30-meter-diameter dome (actually more of a cylinder); even with a wide-angle lens it's hard to take decent pictures. Since Rubin is in its horizontal resting position, I can actually look through its top end to see the curved reflections of the telescope in the combined primary/tertiary mirror. Just a few months from now, I think, this piece of silver-coated high-tech optics will start observing the distant universe. In fact, by the time you read this story, Vera Rubin will be up and running: Astronomers unveiled its first images on June 23rd, and the Legacy Survey of Space and Time was set to begin a few months later.

That night, before going to sleep in one of the dormitories at nearby Cerro Tololo, I step outside to marvel at the ink-black sky, adorned by thousands of glittering stars and the majestic band of the Milky Way. I can only imagine what spectacular images and unexpected discoveries the Vera C. Rubin Observatory will soon start to deliver.

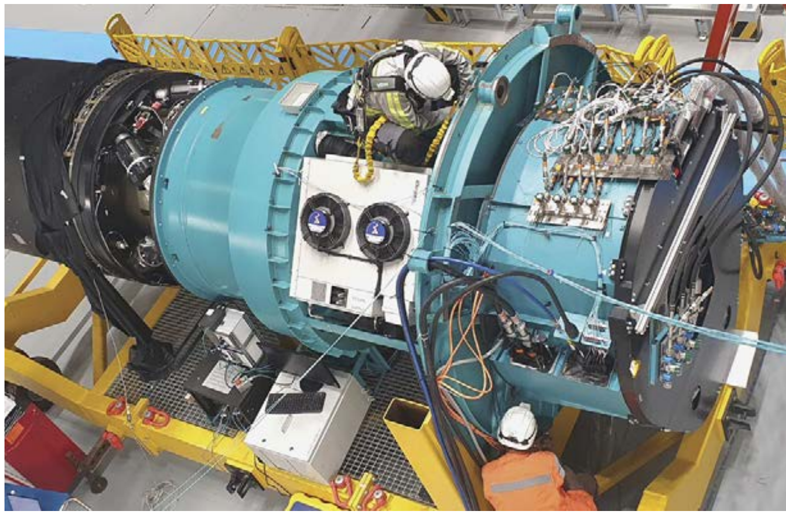
Afterglow Explorer

One week later, and some 800 kilometers farther north as the crow flies, David Boettger takes a sharp right from Ruta 27 (the highway to Argentina) and up an unmarked gravel road. He stops his four-wheel-drive pickup truck and hands me a small backpack with an oxygen bottle and a plastic tube that goes into my nose. We're at an altitude of some 4,200 meters (14,000 feet) in the Andes mountain range, and we've got another 1,000-meter climb ahead of us. "From here, everyone is obliged to take extra oxygen," Boettger says, before he continues along the rocky, winding road, with a grand view of nearby Volcán Licancabur.

Boettger is the soft-spoken scientific systems engineer of the Simons Observatory — a new facility that will study the *cosmic microwave background* (CMB), the afterglow of the Big Bang (*S&T:* June 2023, p. 34). Since water vapor in Earth's atmosphere absorbs microwaves from space, the observatory has been constructed at an extremely high and dry location, at an altitude of 5,200 meters on the Chajnantor plain, close to where the borders of Chile, Argentina, and Bolivia meet. Chajnantor is also home to the ALMA array, which has its own broad access road from the south, but Simons Observatory staff members usually take the steep, bumpy track from the north. "We only use the ALMA road for heavy transports," says Boettger.

Chajnantor is really the next best thing to being in space. The sky is deep blue, and the Sun is blindingly bright. It's freezing cold, and the wind is so strong that I hardly manage to open the door of the truck when we arrive at the Simons Observatory site, at the foot of the Cerro Toco volcano. In a makeshift office — basically a converted freight container — Boettger provides me with a hard hat and a pair of large sunglasses before taking me on a tour.

THE AUTHOR



▲ **SNAP-HAPPY** Seen from above before its installation, this is the Rubin Observatory's 3.2-gigapixel Legacy Survey of Space and Time (LSST) camera and its lens system.

The Simons Observatory, named after its main benefactors, the late hedge fund manager Jim Simons and his wife, Marilyn, consists of one large and three small telescopes. Each instrument is outfitted with tens of thousands of small, ultra-sensitive bolometers that precisely measure the microwave radiation from the Big Bang. The small telescopes have 42-centimeter lenses (to focus the incoming microwaves) with a very large field of view. Their goal: to discover the curl-like polarization patterns in the CMB that would shed light on the *inflationary epoch*, the hypothesized period of exponential expansion in the first split second after the birth of the universe.

Each Small-Aperture Telescope (SAT) sits in the open air, encircled by a large metal "collar" that shields the instrument from microwaves reflected by the surrounding landscape. As I am walking around taking pictures, one telescope suddenly starts to move. "They are operated remotely from Princeton University," explains Boettger.

"We plan to build more SATs in the future," he adds. "The more bolometers we have, the higher our signal-to-noise ratio will be."

While the SATs are already operational, the Large-Aperture Telescope (LAT) is still in the final construction phase during my visit. A huge crane has just installed two giant 6-meter mirrors, each one consisting of dozens of rectangular aluminum panels; workmen are removing the large wooden crates in which they arrived from Germany. As I am climbing the four flights of metal stairs at the outside of the rectangular, multistory telescope building, I am happy I have my oxygen bottle — at this altitude, atmospheric pressure is just 60% of its sea-level value, and without extra oxygen, every physical act is exhausting.

"For me, this is also the first time I see the mirrors in place," says Boettger, as he shows me the large cylinder-shaped enclosure of the LAT's cryogenically cooled camera,

▶ **ROAD TRIP** The author journeyed across the full length of Chile, visiting three (red) professional observatories in the country's northern reaches. The inset zooms in on the locations of Cerro Paranal, Cerro Armazones, and the location of a future telescope array, CTAO South (center and extension marked). The yellow boxes mark the approximate locations and extents of a proposed industrial megaproject (large box) and its port (small box). The megaproject would include hydrogen and ammonia production, solar and wind farms, and other facilities. Its port would lie almost due west of the VLT. An estimated 1,176 lamps would be installed for the project.

▲ **TREKKING** The author poses with the camper van he drove.

MAP: LEAH TISCIONE / S&T; PLANT FACILITY LOCATIONS: ESO; VAN AND AUTHOR: THE AUTHOR which is already installed. "It won't be long before first light." (In fact, the telescope captured its first celestial photons on February 22nd, just one day after my visit.)

Because of its much higher resolution, the large telescope will be able to measure the gravitational-lensing effect that cosmic matter — both visible and dark — has on the CMB. These observations yield information on cosmic structure, and they are also necessary to correctly interpret the measurements of the three small telescopes.

Scientists from dozens of universities and institutions around the world are participating in the Simons Observatory's five-year survey, a collaboration founded by Brian Keating (University of California, San Diego) and his team. According to cosmologist and team member Jo Dunkley (Princeton University), it will probably take a few years before the first results are published.

Meanwhile, competing teams, both on the Chajnantor plain and at the South Pole, also hope to find inflation's telltale polarization patterns in the CMB. Despite the competition, they must proceed carefully: Scientists from the BICEP project in Antarctica announced the discovery of the inflationary signal back in 2014, but they had to retract their claim less than a year later, when further analysis concluded galactic dust was the signals' likely source (*S&T:* May 2015, p. 12).

"For certain types of observations, Antarctica is an even better location than Chajnantor," says Boettger. "But in terms of logistics, it's even more challenging, and from the South Pole you can only see half of the sky. Right now, ours is the most sensitive and promising CMB observatory."

As we drive back — and down — to Ruta 27 and to the small oasis town of San Pedro de Atacama, I try to visualize the low-energy CMB photons from the Big Bang that are constantly raining down on the surreal landscape, as they have been doing for billions of years. I feel fortunate to live at a time when scientists are starting to study them in detail, hopefully elucidating the very beginning of the universe.

Monster Scope

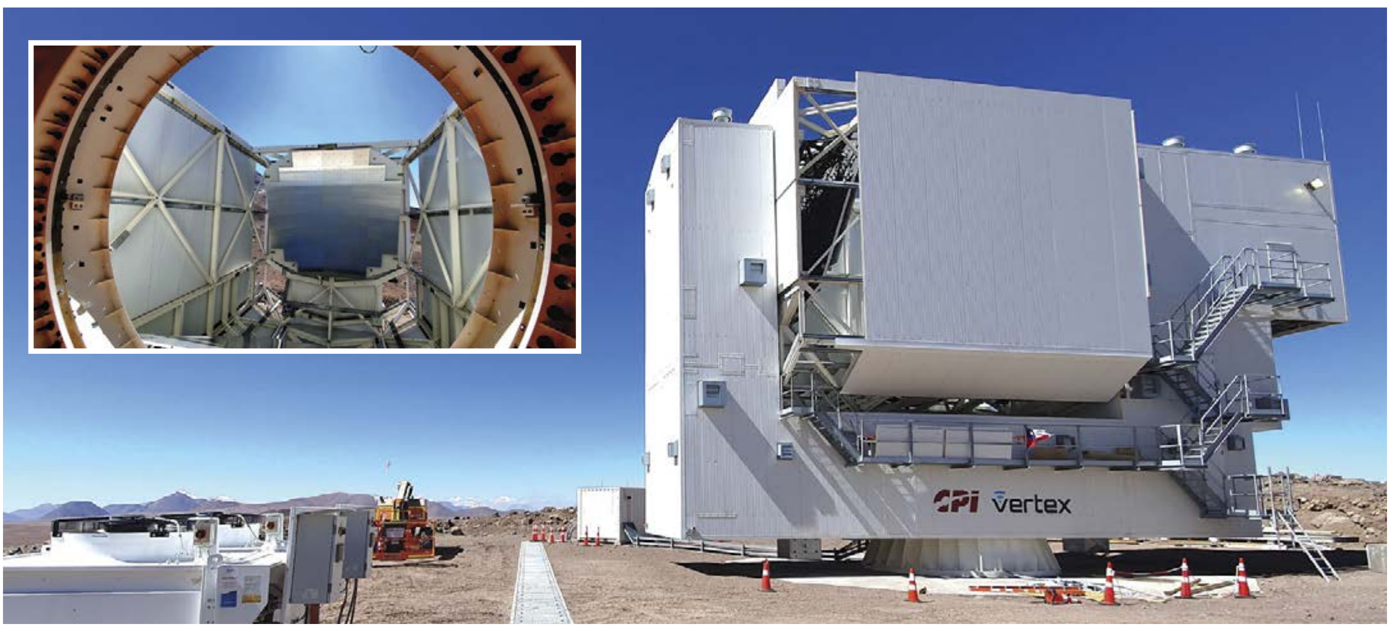
At the end of my six-week road trip, after touring the beautiful Lauca National Park in the very north of Chile, I have to drive hundreds of kilometers south again for my third and last observatory visit. But I don't complain: It's a huge privilege to come face-to-face with what will become the largest optical telescope in the history of mankind.

Under construction on 3,046-meter-high (9,993 feet) Cerro Armazones by the European Southern Observatory (ESO), the Extremely Large Telescope's 39.2 meters (129 feet) primary mirror will have more light-collecting power than all previous professional telescopes in history put together. (Yes, it sounds incredible, but I checked the math, and it's really true.)

I'm joining a Chilean TV crew on a two-hour visit of the ELT. Cerro Armazones lies just 20 kilometers (12 miles) east of ESO's Paranal Observatory, home to the 25-year-old Very Large Telescope. In an administration building a few hundred meters below the summit, we are provided with hard hats, safety shoes, and reflective vests. Next, our host, ESO's Sofía Otero, takes us to the observatory site, which is buzzing with building activity.

Safety coordinator Luigi Pinto, of the Italian consortium that is building the telescope, takes us on a tour around the 93-meter-wide dome, which is about half-finished. Huge cranes

▼ **SIMONS OBSERVATORY** *Main photo:* This oddly shaped observatory houses the 6-meter Large-Aperture Telescope (LAT). *Inset:* The newly installed secondary mirror of the LAT, consisting of dozens of aluminum panels, is seen through the circular aperture of the telescope's huge camera (not visible in this picture).



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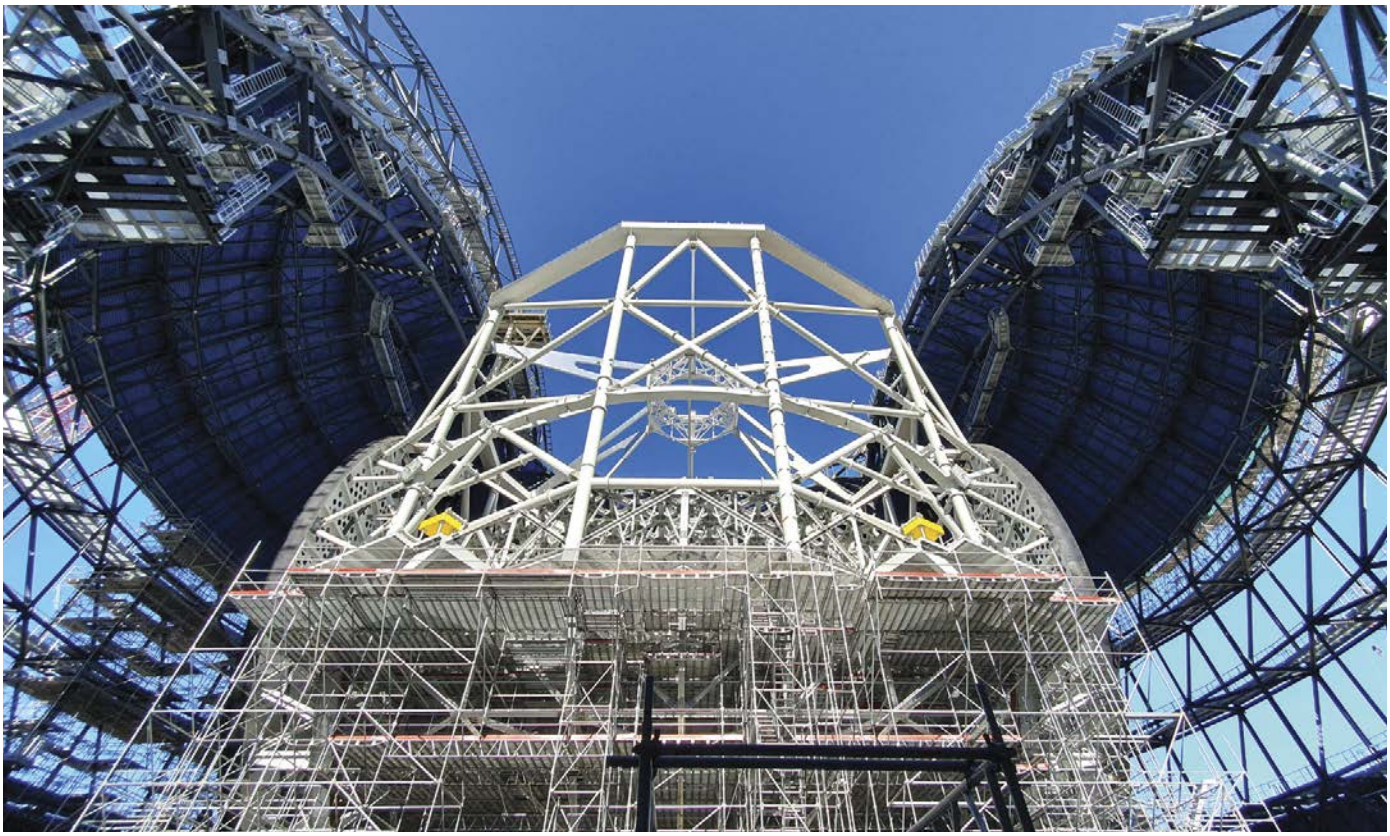


THE AUTHOR (2)

▲ **EXTREMELY LARGE TELESCOPE** *Top:* The 93-meter-wide dome of ESO's ELT nears completion. *Bottom:* The telescope structure of the ELT (white) within the dome skeleton. The ring on the telescope's top will hold the 4.2-meter secondary mirror; the bottom of the picture is the level where the segmented 39.2-meter primary mirror will be installed.

have put the first elements of the dome's two giant doors in place. "Here's part of the second door," Pinto says, while walking around a complicated curved steel structure as large as a bridge. "In fact, one of the previous jobs that I worked on was a large bridge. To me, there's not that much difference."

After entering the building, we climb a number of stairways to a high gallery, which runs all the way around the inside of the dome. From here, the view is even more impressive. The white telescope structure, consisting of dozens of interconnected steel tubes, and still surrounded by scaffolding, is nearing completion. It is so large that I have difficulty perceiving the right scale. Trucks and forklifts that drive around on the concrete floor down below look as small as toy cars.

Pinto points to a technician in orange coveralls, who is working inside the telescope, almost too small to discern. "He sits at the level where the primary mirror will be," he says. "But of course, the mirror segments will only be installed when everything else is ready." The giant primary will consist of a staggering 798 hexagonal segments, manufactured in Germany. Some 200 of them have already been delivered.

That evening, at neighboring Paranal Observatory, I meet Guillaume Blanchard, the head of ESO's optical group. "If you want, I can take you into the ELT Technical Facility tonight," he says. "That's where the mirror segments are tested, coated, and stored." In fact, there will be 931 segments in the end — 133 spares of various curvatures are needed to keep the mirror complete during the continuous recoating process. "If we want to re-aluminize the whole mirror once every two years, we need to take out and recoat two segments per day," explains Blanchard.

After dinner, we walk toward a large, rectangular building. Inside is the testing and coating facility, which is relatively small, since the mirror segments are just some 1.5 meters wide. The whole lab is a clean room, so I'm not allowed to enter, but through a large window, I can see one shiny hexagon on a test bench, ready to have its quality checked.

Next, Blanchard takes me into another, much larger room. When he turns on the light, I'm flabbergasted. I'm in a giant warehouse, with meters-high storage racks. Large, flat metal crates fill about one-fifth of the total storage capacity. Every crate, uniquely identified by a QR code, contains a single mirror segment. Around me is the largest telescope mirror in the world, in pieces. About once per month, a new truckload arrives.

When we walk back to Paranal's Residencia, it's utterly dark outside. Blanchard looks up to the night sky, with an upside-down Orion high above the northern horizon. Even after working with the largest telescopes in the world for many years, the naked-eye view never ceases to amaze and inspire him, he says. "This is really one of the best places on the planet to do astronomy."

Unfortunately, that discerning quality is soon to be challenged. Earlier that day, Ortego told me about the plans of AES Andes — a subsidiary of an American energy company — to build a "green hydrogen plant" as large as a small city,

THE AUTHOR

▲ **LARGEST MIRROR EVER** The ELT's primary mirror has a six-fold symmetry, comprising six identical sectors of 133 segments each, for a total of 798. Each of the 133 segments differs in shape and optical prescription. There will also be 133 spares, one for each segment type, bringing the total to 931. The crates in the Paranal warehouse shown here contain the hexagonal segments that had arrived as of early 2025.

just 11 kilometers south of the VLT and a mere 5 kilometers southwest of the planned southern site of the Cherenkov Telescope Array Observatory (CTAO-South; *S&T:* May 2025, p. 8). According to a recent ESO study, the facility, with huge numbers of wind turbines and solar panels, would produce air turbulence, vibrations, and dust contamination, and lead to a 35% increase in light pollution at the VLT. Even Cerro Armazones, some 30 kilometers away, would be impacted.

"Nothing is definitive yet," says Ortego (the proposed site still has to be approved by the Chilean government), "but we really need to have our voice heard. I just don't understand why they couldn't choose another location."

Three weeks after my visit, an ESO press release stated that the impact of the facility would be "devastating and irreversible." And in June, ESO teamed up with institutes running other large observatories in northern Chile to create the Dark Skies Council — an alliance to protect Chile's dark skies, in close cooperation with the Office for the Protection of the Quality of the Northern Chilean Sky (OPCC) and the Skies of Chile Foundation, which focuses on the conservation of the country's night sky heritage.

When I drive away from Cerro Armazones, eventually heading back north to Arica, I keep seeing the huge dome of the Extremely Large Telescope in my rearview mirror, surrounded by tower cranes. Within a few years, humankind's biggest eye on the sky will start observing the universe, hopefully unhindered by industrial activity.

I'm looking forward to returning to this astronomical paradise, if only to attend the ELT's inauguration, probably in 2029. This was not my first trip to this spectacular country, and it certainly won't be my last.

■ *S&T* Contributing Editor **GOVERT SCHILLING** first visited Chile in May 1987, when Supernova 1987A was still visible with the naked eye and when Cerro Tololo's 4-meter Blanco Telescope was the largest astronomical instrument in the Southern Hemisphere.

Aryabhata Deciphers the Heavens

Centuries ago, an Indian astronomer set in motion the wheels of a scientific revolution.

In the 5th century, humanity struggled to understand its place in the cosmos. Many believed Earth was flat. The world remained largely uncharted, and knowledge of natural phenomena intertwined with religion and philosophy. As Western civilization plunged into chaos with the fall of the Roman Empire, far away by the shores of the Ganges River in India, a 23-year-old thinker began challenging the predominant views of the ancient world. His name was Aryabhata. With a clarity of reasoning well ahead of his time, he laid the groundwork for a scientific understanding that would take centuries to gain recognition.

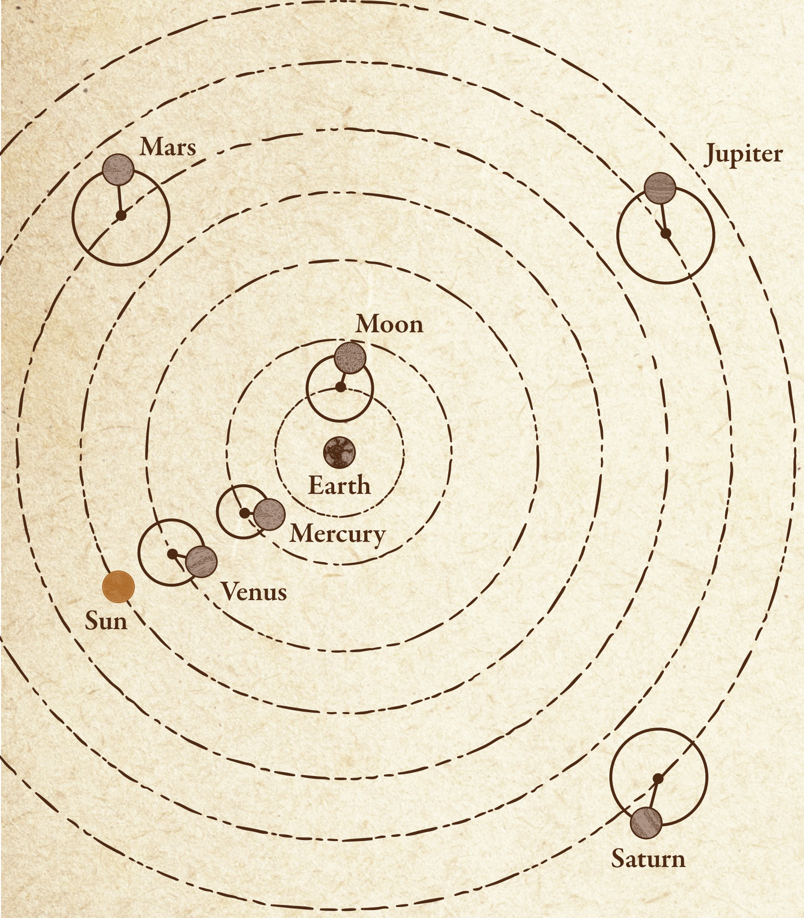
A Tale as Old as Time

In AD 476, Aryabhata was born into a society that regarded knowledge as the key to salvation and the pursuit of truth as the highest calling. The intellectual climate of India at that time was a blend of religious and philosophical traditions. Ancient Hindus didn't separate disciplines of science from their divine literature. Scientific disciplines were considered sacred and necessary to obtain the highest truth. In particular, the Hindus marveled at the night sky. Because their rituals were governed by the positions of the Sun, Moon, and planets, Khagola-sastris — a special class of ancient Hindu priests — observed the skies with great care. Their devoutness fueled their curiosity as they tracked the motions of planets, meteors, and comets against the background of fixed stars. In time, they were able to infer Earth's spherical shape, understand the phases of the Moon, and design a lunisolar calendar.

Ancient Hindu scholars were also uncommonly comfortable with long time spans. To them, the universe underwent an infinite number of deaths and rebirths in eternal cycles. A single cycle was the duration of one day of *Brahma*, the God of Creation, and was 4.32 billion years long. This makes Hinduism one of the few religions (if not the only

ARYABHATA'S ALMA MATER This 2013 photo shows the excavated ruins of Nalanda Mahavihara, or the university of Nalanda, the world's first residential university. Headed by its most prominent scholar, Aryabhata, in the 6th century AD, the university attracted pupils from Korea, Japan, China, Tibet, and many other regions, in what was an ancient cultural hub of knowledge.

LEONID PLOTKIN



COSMIC CLOCKWORKS Aryabhata developed a sophisticated planetary model using a concentric equant system. Unlike Ptolemy's fixed-size single epicycle model shown here, Aryabhata's model used two epicycles — *manda* (slow) and *sighra* (fast) — that varied depending on a planet's position within the zodiac. This allowed for more accurate corrections and helped account for non-uniform planetary speeds, retrograde motions, and orbital eccentricities.

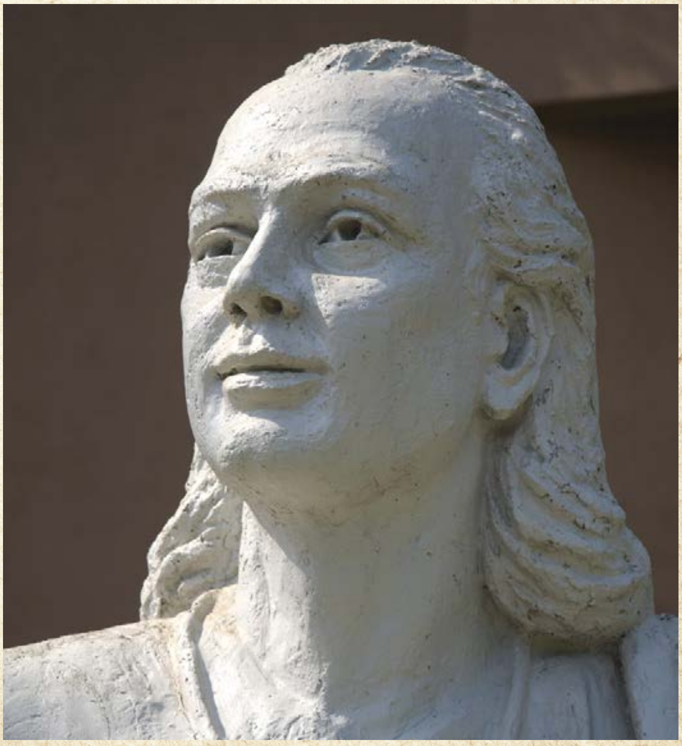
one) that utilizes a time scale that approaches the physical reality we understand today.

Aryabhata grew up surrounded by the knowledge of his ancestors and the sacred texts of Hinduism. The religion offers four paths to enlightenment, but it was *Jnana-yoga* — the path of knowledge and ultimate truth — that likely appealed to him the most. This path of knowledge took Aryabhata to Kusumapura (now Patna) in northeastern India, one of the world's oldest continuously inhabited cities. Kusumapura was a major learning center and home to the prestigious university of Nalanda, where Aryabhata studied astronomy, physics, and mathematics, and immersed himself in intellectual debates.

Transcending the Gods

The Hindus documented painstaking observations about the night sky in stories and poetic verses that formed the basis of various religious texts. The most extensive compendium, the *Vedas*, composed between 1500 BC and 500 BC, describes a complex cosmology that merged the spiritual and physical worlds. The scriptures spoke of Earth being spherical and included beautiful prose about the glory of the Moon's luminous appearance. They described how aerial cords secured the planets, constellations, and stars in their proper orbits to Dhruva, the pole star, and were kept in their places by bands of air called *Pravaha*. The texts weave a beautiful tapestry of stories describing an eternal and unchanging cosmos governed by divine forces, celestial beings, gods, and creatures alike.

Aryabhata sought explanations that went beyond mythology, perhaps because he found rationality offered an inherently deeper, more enduring form of beauty. He sought to break the veil of illusion drawn over the cosmos. During the early hours of the day, when the world was shrouded in the cool morning mist, Aryabhata gazed at the stars and pondered their motion. Why did they traverse the sky the way they did? Why did the Sun rise in the east and set in the west? At the time, most assumed Earth was stationary and the center of the universe. Two observations supported this view: First, the Sun appeared to revolve around Earth once daily, and second, the Moon and planets had their own motions but also made the same daily trip. The stars seemed



OF NUMBERS AND STARS Aryabhata (AD 476–550) was the first of the major Indian mathematician-astronomers. Also referred to as Aryabhata I or Aryabhata the Elder to distinguish him from a 10th-century namesake, Aryabhata composed at least two works: the *Aryabhatiya* and the lost *Arya-Siddhanta*. Known for his astronomical treatises, Aryabhata also introduced the concept of the decimal system and the use of zero as a number, provided methods for extracting square and cube roots, and developed solutions for quadratic and indeterminate equations. Aryabhata's work not only shaped Indian science for centuries but also profoundly influenced major developments in the Islamic world and medieval Europe.

PTOLEMAIC MODEL DIAGRAM: TERRI DUBÉ; PLANETS IN DIAGRAM: TARTILA / SHUTTERSTOCK.COM; STATUE OF ARYABHATA: DINODIA PHOTOS; PAPER TEXTURE: DMITR1CH / SHUTTERSTOCK.COM fixed on a celestial sphere that rotated once daily. By contrast, the ground and Earth felt stable and stationary. However, Aryabhata described a vastly different and audacious vision.

Using the analogy of a boat floating down a river, he wrote, “A man in a boat going forward sees a stationary object moving backward just so at [Sri] Lanka a man sees the stationary asterisms [stars] moving backward (westward) in a straight line.” To the boatman, a tree on the riverbank would appear to move backward, though of course it simply appears to do so because the boat is floating forward down the river. Similarly, Aryabhata realized the stars didn’t revolve around Earth. Like the tree by the riverbank, the stars are stationary, and it’s the rotating Earth that carries the stars and the Sun across the sky, creating the repeated occurrence of night and day. Aryabhata verified this for various, specific locations on Earth, correctly stating that sunrise at one place corresponded to sunset at another, and midday at one location occurred when it was midnight at another.

But this insight didn’t completely satisfy Aryabhata — he wanted to quantify his understanding of Earth’s rotation. He noted Earth made a complete rotation of 360° in a *nakshatra dina* — a sidereal day. This is the time it takes a fixed star to return to the same altitude and azimuth position in the sky. From this, Aryabhata calculated that for Earth to rotate an angle of 1 arcminute (1/60th of a degree), it would take 1/(60 × 360), or 1/21,600 of a sidereal day — an interval called *prana* in Hindu astronomy. He used the metric of the prana to measure the exact duration of a sidereal day. To achieve this, he turned toward the brightest light in the sky, the Sun.

The ancient Hindus performed rites at sunrise and sunset and at other defined intervals when the Moon or the Sun entered specific constellations. As a result, Aryabhata’s predecessors left behind centuries of regular and meticulous records of the Sun’s position on the celestial sphere. Utilizing this vast storehouse of knowledge and observations, he calculated a sidereal day to be 23 hours, 56 minutes, and 4.1 seconds long. Modern measurements produce a value of 23 hours, 56 minutes, and 4.0905 seconds. This tiny difference speaks volumes. Not only did Aryabhata conclude Earth rotated, but he was also able to accurately quantify its rate.

Planets in Motion

Having unraveled the mystery behind the daily motions of the Sun and stars, Aryabhata shifted his attention to the planets. The academic and cultural knowledge exchanged between India, Central Asia, and the West all influenced Hindu science. The geocentric model of the cosmos, popularized by scholars such as Ptolemy in the 2nd century AD, dominated the ancient world. The Ptolemaic model assumed that planets move in a small circle, called an *epicycle*, which in turn revolves along a larger circle, known as a *deferent*. Neither of these circles is centered on Earth. Instead, each planet circles a point slightly away from Earth called the *eccentric*.

The Hindus were aware of Greek astronomy and even translated their works into Sanskrit. Like the Greeks, Aryabhata maintained that the planets and the Sun orbited a stationary Earth — except for one significant difference.

In place of Ptolemy’s fixed-size epicycles, Aryabhata developed a two-epicycle model that built upon and refined older Hindu traditions. His version involved the use of epicycles that varied in size from place to place. One could call it an *eccentric-epicycle model*.

Ancient Hindu scriptures attributed the unequal motions of the planets to demons who pulled the planets with chords of wind. Aryabhata formalized this interpretation using mathematics. In his model, the Sun and Moon are carried by single epicycles, while the planets are supported by a complex of two epicycles — a small, slow *manda*, and a larger, fast *sighra*. The planet is always situated on its deferent, while the two epicycles revolve about it. As the planet progresses about this deferent, at each instant it is pulled by the two epicycles away from its mean position to its true, observed location. The orbits of the planets are also concentric with Earth’s center as a *concentric-equant system*.

In essence, Aryabhata’s model blended varying epicycles with an eccentricity-capturing equant and introduced the dynamic *manda* and *sighra* anomalies to account for variations in the planets’ speed, retrograde motion, and interactions with the Sun. His model significantly improved on the prevailing methods of his time for calculating planetary positions, while reducing the number of corrections required

Unlocking Planetary Motion

Aryabhata calculated the rotations and sidereal periods of the naked-eye planets. Reputed Indian historians of science K. V. Sarma and K. S. Shukla analyzed these numbers, calculating them in terms of days (middle column) and compared them to modern values (right column).

Aryabhata’s Precision

Object	Sidereal Period Aryabhata	Sidereal Period Modern Value
Moon	27.32167	27.32166
Mercury	87.96988	87.9693
Mars	686.99974	686.9797
Venus	224.69814	224.7008
Sun	365.25868	365.25636
Jupiter	4,332.27217	4,332.5887
Saturn	10,766.06465	10,759.201

for precise results. The specifics of Aryabhata's methods have both puzzled and intrigued scholars. Esteemed Dutch mathematician and historian Bartel Leendert van der Waerden (1903–1996) even suggested the presence of an underlying heliocentric architecture in Aryabhata's model. Whether or not Aryabhata ever considered a Sun-centered model isn't known, but if he did, he stopped short of explicitly stating it. His preference could have stemmed from a widespread tendency among ancient astronomers to avoid the idea of attributing motion to Earth.

Chasing Shadows

Aryabhata remained captivated by the Sun and was naturally inclined to investigate its disappearance during total eclipses. The Hindus considered these events inauspicious. Scriptures described eclipses as the Sun or Moon being swallowed by the demons Rahu and Ketu. According to legend, the gods churned the cosmic ocean in search of the elixir of immortality. During this process, a demon named Svarbhanu, disguised as a god, secretly drank the elixir. The Sun and the Moon saw through the demon's deception and warned the god Vishnu of his transgression. Vishnu promptly slit the demon's throat, beheading him in the process. However, the demon had already consumed the elixir and couldn't be killed. His head became Rahu, and his body became Ketu. Vowing revenge against the Sun and the Moon, the two demons eternally chased them across the sky in an attempt to swallow them. A solar or lunar eclipse symbolized the occasions when Rahu and Ketu triumphed in their vendetta.

Ancient Hindus called Rahu and Ketu shadow planets or *nodal points*. These are the two locations where the Moon's orbit intersects the plane of the ecliptic. Rahu was considered the *ascending node* — where the Moon crosses the apparent path of the Sun in the sky while moving south to north. Ketu was the *descending node*, where the Moon crosses the ecliptic while moving north to south. When the Sun and Moon meet at either of these nodal points, the alignment results in a solar or lunar eclipse.

Unlike his contemporaries, who viewed eclipses as a momentary victory of evil over good, Aryabhata worked out a scientific explanation for eclipses. The ancient Hindus understood the changing geometry of Earth, the Moon, and the Sun. They believed Earth to be a sphere and that the Sun neither rose nor set. This understanding, along with Aryabhata's own observations of the night sky — including

▶ **SOLAR TIME-OUT** *Top:* In Hinduism, Rahu, the malefic planet and the king of meteors, is said to cause a solar eclipse by swallowing the Sun. Considered an inauspicious influence, the event denotes a period as unfavorable to start any good deed.

▶ **SCIENCE IN THE SHADOWS** *Bottom:* Eclipses were a moment of cosmic transition to ancient Hindus. Hindu astronomers understood that a lunar eclipse, like the one pictured here, was caused by the Moon falling into Earth's shadow. Still, they practiced specific rites to mitigate the eclipse's negative influence while also integrating their empirical knowledge of the phenomenon into their spiritual worldview.

▲ **A LEGACY OF NOTE** A pioneering mathematician and astronomer, Aryabhata's legacy continues to inspire generations and symbolizes India's rich scientific heritage. In honor of his monumental contributions, India named its first artificial satellite Aryabhata in 1975, marking the nation's entry into space exploration. Aryabhata's legacy was also commemorated on the Indian two-rupee bill between 1976 and 1997, which featured the satellite.

the changing lunar phases — enabled him to recognize that the Earth, Moon, and planets were illuminated by the Sun. He correctly explained that solar eclipses occur when the Moon passes between Earth and the Sun, casting its shadow on Earth. Similarly, lunar eclipses take place when Earth passes between the Sun and the Moon, casting its shadow on the Moon. By using geometry and orbital mechanics, Aryabhata was even able to go one step further and quantitatively calculate the area of the Moon or the Sun that's covered during an eclipse.

A Timeless Legacy

Aryabhata's observational prowess, analytical mind, and meticulous methodology unlocked a new vision of the cosmos. In an era when the boundaries between science and religion were blurred, Aryabhata formalized and systematized the knowledge of his predecessors. He achieved this through mathematical rigor and by utilizing the simple tools at his disposal. At the age of 23, in AD 499 he compiled his insights into his magnum opus, the *Aryabhatiya*. His work departed from the classical Vedic worldview, presenting the cosmos with a rationality that paved the way for future generations of scholars seeking to understand the universe empirically. However, he was also emphatic about not taking credit for the book, labeling its contents as *Svayambhu* or "self-existing" and "old knowledge." His actions reflected the intellectual tradition of his culture, where the possession of knowledge — and the specifics of when and where it emerged — were regarded as unimportant. The Hindus rejected the obsession surrounding authorship of innovation, instead prioritizing personal fulfillment in their pursuit of truth and sharing the resulting knowledge. Ironically, it's for this reason that no chronological records of the vast literature of this ancient culture exist.

The earliest records of astronomy in India date back to approximately 2000 BC. Then, the world was largely viewed through the lens of religion and scripture, such as the *Rig Veda*, one of the primary and foremost texts of Hinduism. Aryabhata emerged in the Siddhantic Era, when thinkers began to diverge from the Vedas and an intellectual revolution started to brew. Following Aryabhata, the scope of astronomy continued to widen. Outgrowing its original purpose of providing a calendar and governing religious practices, astronomy expanded beyond the study of the Sun and Moon to that of the planets, stars, and the universe.

Aryabhata's ability to explain these phenomena as observable, natural processes significantly advanced astronomy, but his contributions weren't limited to this field alone. The *Aryabhatiya* included discussions on topics as diverse as mensuration, geometric progressions, algebra, trigonometry, timekeeping methods, and celestial mechanics. It's the only one among the several treatises Aryabhata authored that has survived. A second but lost work on astronomical computations, the *Arya-siddhanta*, is known to have existed thanks to the writings of Aryabhata's contemporaries.

Disagreements with the *Aryabhatiya* ran rampant among India's scholarly and religious communities. Nonetheless, the work also encouraged discourse beyond India's borders, spreading Aryabhata's global influence. Most prominently, Aryabhata's ideas were transmitted to the Islamic community. Muslim scholars such as al-Biruni, al-Khwarizmi, and al-Battani continued building on Aryabhata's work, which was known to the Islamic world as *Zij al-arjabhar* (the *Astronomy of Aryabhata*). In his study of the Hindu faith in India, al-Biruni would even mention a third text authored by Aryabhata that may have survived in an Arabic translation.

Translations of the *Aryabhatiya* and similar books from the Middle East based on Hindu astronomy eventually reached European shores, where they indirectly influenced the rapid development of Western astronomy, mathematics, and science. In the 16th century, Nicolaus Copernicus utilized a similar analogy to Aryabhata's for assigning axial rotation to Earth. In his seminal 1543 work, *On the Revolutions of the Celestial Spheres*, the Polish polymath wrote, "For when a ship is floating calmly along, the sailors see its motion mirrored in everything outside, while on the other hand, they suppose that they are stationary, together with everything on board. In the same way, the motion of the earth can unquestionably produce the impression that the entire universe is rotating."

In recognition of Aryabhata's contributions, India's first artificial satellite, launched in 1975, was named after him. The satellite was an important symbol of the country's expanding space capabilities and pays tribute to this visionary astronomer. But perhaps Aryabhata's greatest achievement is best summarized in his own words near the end of the *Aryabhatiya*: "I dived deep in the ocean of theories, true and false, and rescued the precious sunken jewel of true knowledge by the means of the boat of my own intellect."

■ **AJAY P. MANUEL** is a freelance science writer and astronomy enthusiast based in Calgary, Alberta, who enjoys uncovering forgotten stories and enduring mysteries of the past.

SKY AT A GLANCE
December 2025

3 DUSK: Face east to see the almost-full Moon rise with the Pleiades. As the evening wears on, the Moon covers more cluster stars. However, it will be challenging to snag Pleiads, even with binoculars. Turn to page 46 for more on this and other events listed here.

7 MORNING: Early risers will be greeted by the delightful sight of the waning gibbous Moon, Jupiter, and Gemini's brightest light, Pollux, forming a triangle high in the southwest. The Moon is around 4½° below Pollux and about 5° right of Jupiter.

9 EVENING: The waning Moon, two days shy of last quarter, rises in the east-northeast a mere ½° above Leo's lucida Regulus. As they climb higher, the gap between the pair narrows until shortly after midnight when it starts to widen. The Moon occults the star for many locations, including most of Canada.

13–14 ALL NIGHT: The Geminid meteor shower peaks tonight. The waning crescent Moon rises in the wee hours of the morning and shouldn't interfere with viewing. See page 48 for details.

14 MORNING: Turn to the southeast to see the waning crescent Moon hanging about 2° right of Spica in Virgo.

14 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:39 p.m. PST (go to page 50).

17 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:28 p.m. EST (7:28 p.m. PST).

20 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:17 p.m. EST.

21 THE LONGEST NIGHT OF THE YEAR in the Northern Hemisphere. Winter begins at the solstice at 10:03 a.m. EST (7:03 a.m. PST).

26 DUSK: Look high in the south to see the waxing crescent Moon a bit less than 3° upper right of Saturn.

31 DUSK: The waxing gibbous Moon, the Pleiades, and Aldebaran are arranged in a pretty tableau above the eastern horizon. The Moon is almost 6½° lower left of the cluster.

—DIANA HANNIKAINEN

▲ The Moon visits the Pleiades a couple of times this month — on the 3rd it will pass through the cluster. MASIL IMAGING TEAM

DECEMBER 2025 OBSERVING

Lunar Almanac
Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

FULL MOON
December 4
23:14 UT

LAST QUARTER
December 11
20:52 UT

NEW MOON
December 20
01:43 UT

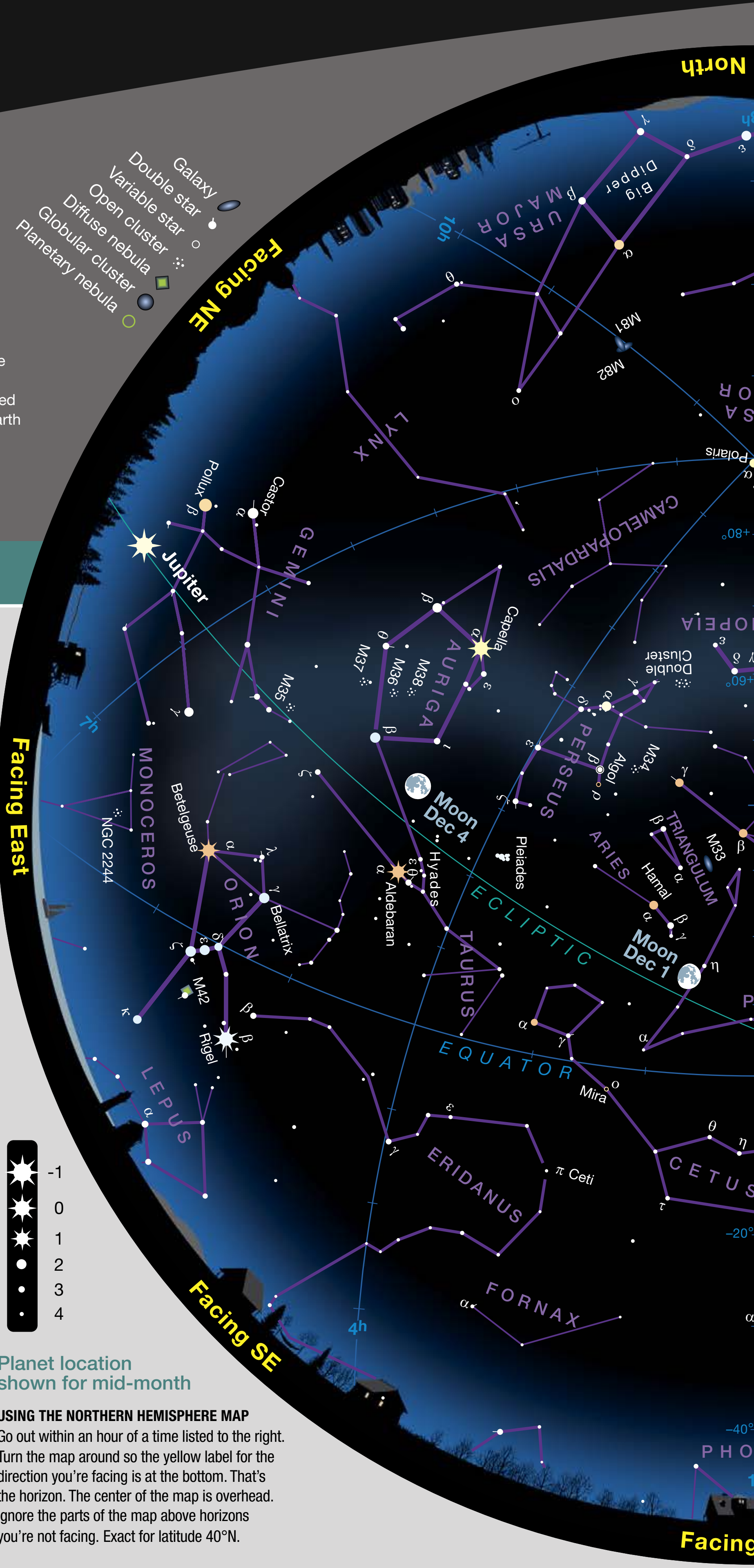
FIRST QUARTER
December 27
19:10 UT

DISTANCES

Perigee	December 4, 11^{h} UT
356,963 km	Diameter 33′ 29″
Apogee	December 17, 6^{h} UT
406,322 km	Diameter 29′ 25″

FAVORABLE LIBRATIONS

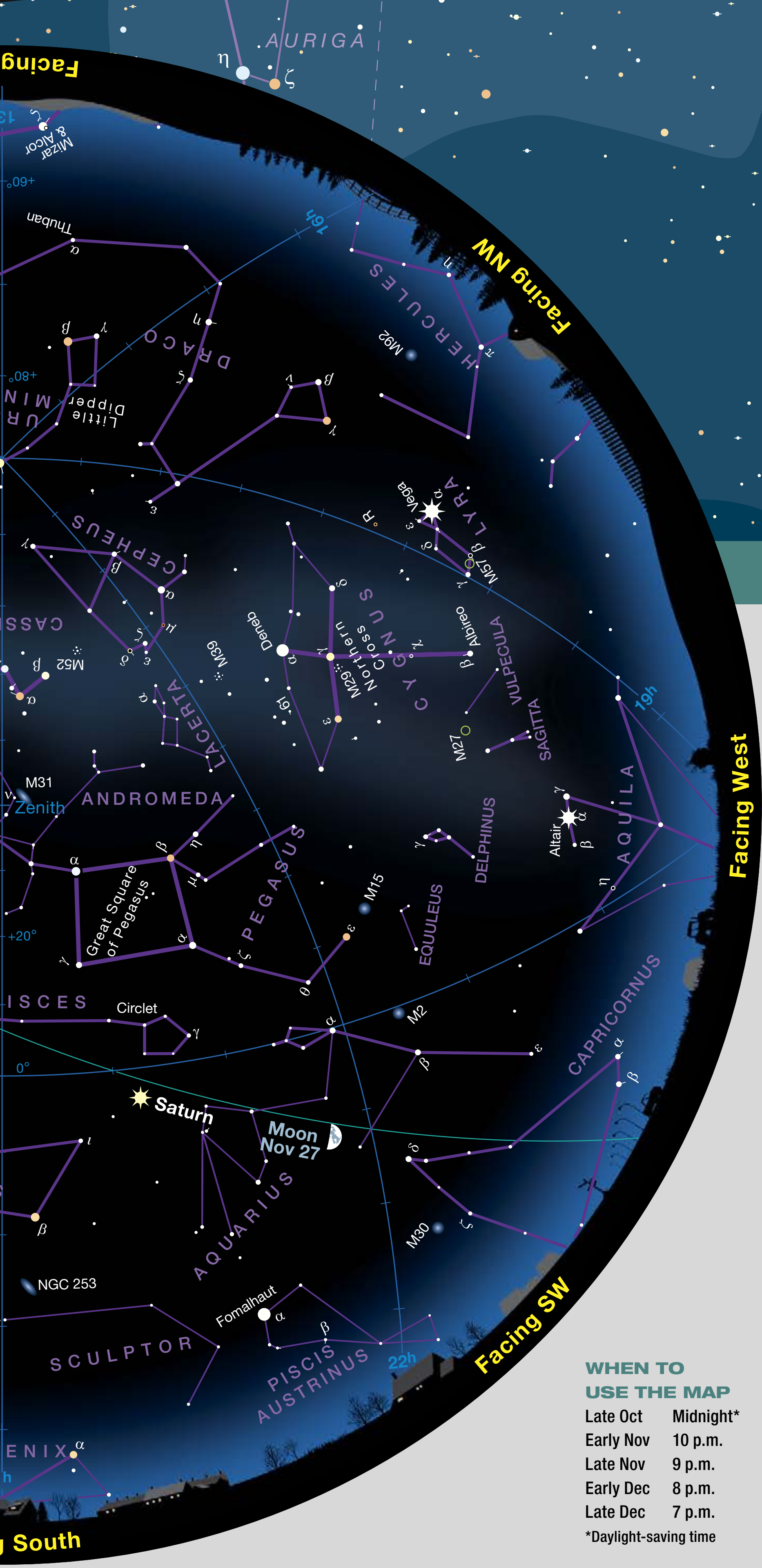
• Bailly Crater	December 3
• Casatus Crater	December 4
• Demonax Crater	December 5
• Gill Crater	December 6

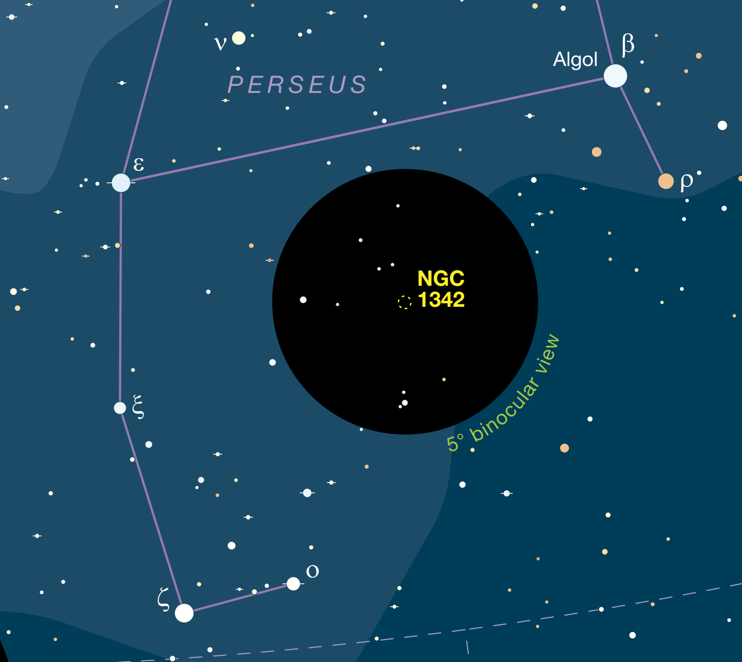


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

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





WHEN TO USE THE MAP

Late 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

Binocular Highlight by Mathew Wedel

Pulled into Perseus

The constellation Perseus, named for one of the great heroes of Greek mythology, has an unusual effect on me. Its bright stars are so charmingly laid out, and it's so rich with deep-sky objects, that I hardly ever visit without giving the entire constellation a slow and thorough sweep with binoculars. Usually I'm more of a run-and-gun type of observer, bouncing around the night sky at will, but Perseus exerts a powerful pull.

The constellation is loaded with open clusters, and one of my personal favorites is **NGC 1342**. It's easy to find since it's one point in a squat isosceles triangle that also includes Algol, or Beta (β) Persei, and Epsilon (ε) Persei. The little cluster lies almost exactly 5° from both stars. At magnitude 6.7 and with no particularly bright distractors or visual clutter nearby, it jumps right out even in 7×50 binoculars. As usual, more magnification brings more detail. For me, NGC 1342 starts to resolve into interesting shapes in 10×50s, and in 15×70s I see a bright, triangular core inside a rough box of bright boundary stars. My eyesight isn't aces, though, so you may see more than I did at the lower magnifications.

One of the reasons I'm so drawn to NGC 1342 is its location in the southern reaches of Perseus. Algol, Epsilon, and Zeta (ζ) Perseі make an incomplete rectangle (like a box that's had one corner torn off), with Xi (ξ) and Rho (ρ) Persei helping to fill out the shape. As the chart above shows, NGC 1342 sits roughly in the middle of this array. I can't help envisioning the cluster as an insect caught in an invisible web slung from the stars that form the not-quite-rectangle — possibly a subconscious metaphor for how Perseus ensnares my attention. Maybe it will capture yours, too.

■ It's a good thing the sky changes with the seasons, or **MATT WEDEL** might never leave Perseus. Or is it Cygnus? Or maybe Sagittarius, or . . .

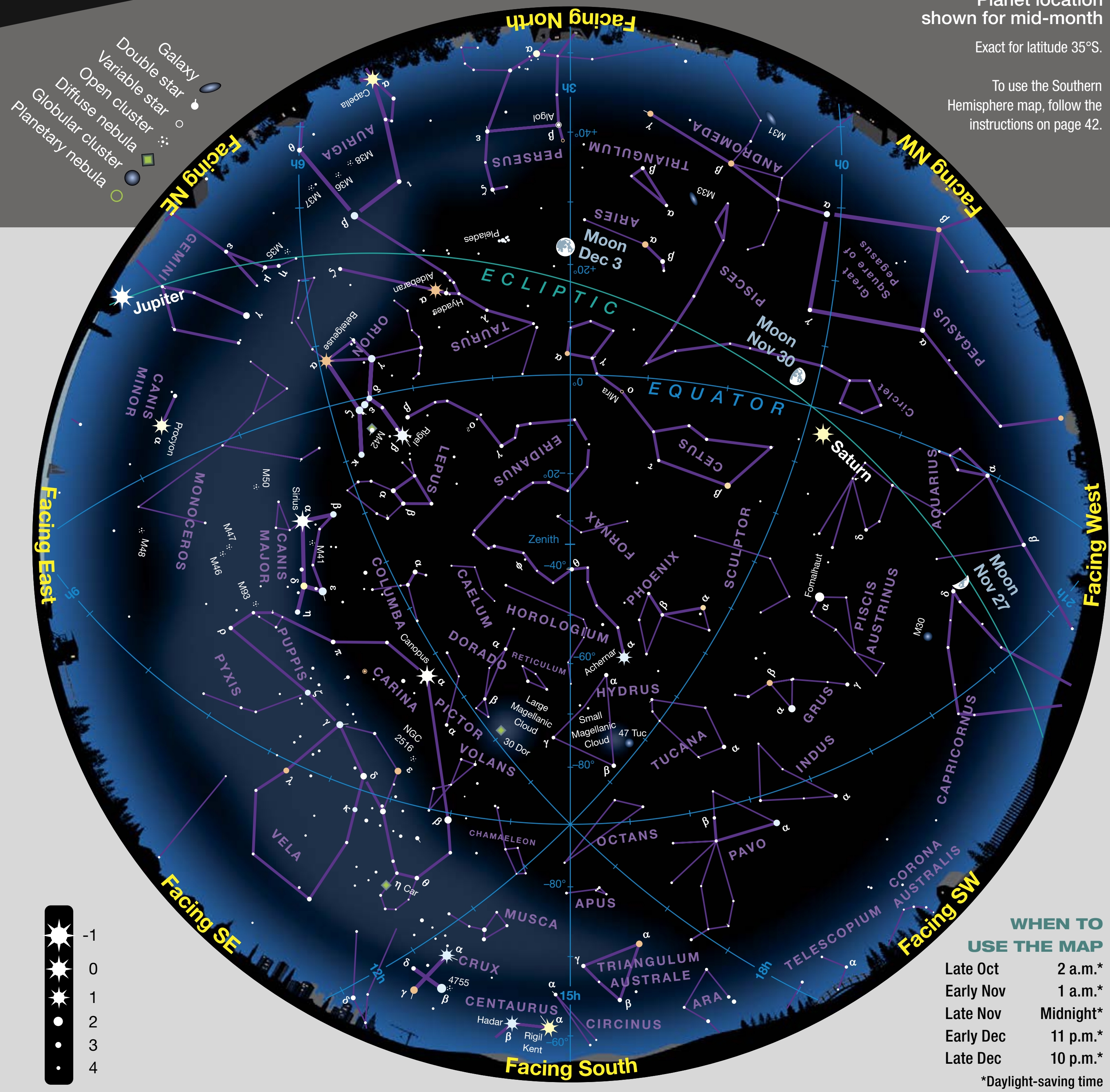
Southern Hemisphere Sky Chart

by Jonathan Nally

Planet location shown for mid-month

Exact for latitude 35°S.

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



WHEN TO USE THE MAP

Late 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

DEEP IN THE SOUTHERN SKY is the small constellation **Hydrus**, the Water Snake — the *male* water snake to be precise. That's what makes it different from its far larger cousin, Hydra, the female Water Snake. Hydrus was originally much bigger, but it has shrunk over time as some of its stars were transferred to neighboring constellations.

Marked on the chart above are Alpha (α), Beta (β), and Gamma (γ) Hydri. At magnitude 2.79, Beta is a whisker brighter than 2.84-magnitude Alpha. Beta is very similar to our Sun but has expanded in its late middle age to become almost twice the Sun's diameter. Alpha is much younger — less than a billion years old — and about three times larger than the Sun. Finally, Gamma shines at magnitude 3.3 and is an evolved red giant, more than 60 times bigger than the Sun. ■

A Naked-Eye, Deep-Sky Trapezoid

Put your skies to the test with this celestial quadrilateral.

This month, we'll explore what I call the Deep-Sky Trapezoid. It's an asterism composed of clusters and galaxies. Two are relatively easy to see under a dark sky; the others are not, though they are visible to keen-eyed observers under clear, dark skies. You'll find the four objects labeled on this month's Northern Hemisphere Star Chart on pages 42–43.

We'll start just northeast of the *zenith*, the point overhead, by looking for the famous **Double Cluster** (NGC 869 and NGC 884) in Perseus, the Hero — one of the few deep-sky objects recorded by skywatchers before the invention of the telescope. Look halfway between Delta (δ) Cassiopeiae and Gamma (γ) Persei for a 4th-magnitude knot in the ruffled folds of the Milky Way. That "knot" is actually two clusters separated by about ½°, or the apparent diameter of the full Moon. Early observers saw them as a single misty "cloud" occupying 1° of the sky. That shouldn't stop you, however, from trying to resolve them into two objects. Deep twilight will give you an advantage by lessening the contrast between the clusters and the sky. The Double Cluster lies 7,400 light-years away in the Perseus Arm of our galaxy (*S&T:* Nov. 2019, p. 16).

Shift your gaze now to the zenith to find **M31**, the great Andromeda Galaxy. It appears as a faint 3°-long cocoon of nebulous vapor 1° west of 4.5-magnitude Nu (ν) Andromedae. M31 belongs to the Local Group of galaxies, which includes the Milky Way. If you spot it, you will be looking beyond our galaxy, across a great gulf of space 2.5 million light-years wide, to another island universe. If we lived on a planet in the Andromeda Galaxy, the Milky Way would look much the way as M31 does to us today. Note that although this spiral shines at magnitude 3.4, which is slightly brighter than the combined light of the Double Cluster, M31's light is spread over an area three times greater, making it less apparent.

Dim Realities

Next up are the more challenging targets. First we have the 5.5-magnitude open star cluster **M34** in Perseus. This cluster is visible in a reasonably dark sky and serves as a good test object when determining the darkness of your observing site. To find it, look just north-northeast of the midpoint between the variable star Algol and golden Gamma Andromedae. It's probable that Italian astronomer Giovanni Battista Hodierna (1597–1660) first spied M34 before 1654. Can you? Look for a fuzzy kernel of light, like an out-of-focus star.

M33, the Triangulum Galaxy, is the fourth object that makes up our naked-eye vista. The late *Sky & Telescope* Deep-Sky Wonders columnist Walter Scott Houston often stated that seeing it is a barometer for the clarity of one's observing site. Its dim glow is completely washed out in urban areas. Even under dark skies, some will find it easily, while others won't see it at all. The problem likely lies in the galaxy's low surface brightness. Although the total magnitude of M33 is the same as a 6th-magnitude star, this spiral's light is spread over an area larger than two full Moon diameters. You'll need a dark sky, a steady atmosphere, and good vision to see M33 without optical aid. At 3 million light-years distant, M33 lies farther from us than M31, making it the farthest object in the naked-eye Deep-Sky Trapezoid. You'll find it 4° west-northwest of 3.4-magnitude Alpha (α) Trianguli.

By the way, if you see them all, you'll be a visual champion with a story to tell. Good luck!

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

▲ This nightscape by Alan Dyer displays the naked-eye Deep-Sky Trapezoid above a gathering of amateur astronomers. The Perseus Double Cluster is at center with, going clockwise, the Andromeda Galaxy to the upper right, followed by M33 below, and finishing with M34 at left.

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

Hello Mercury!

The innermost planet saves its best for last.

WEDNESDAY, DECEMBER 3

This evening, the full **Moon** drives right through the heart of the **Pleiades** cluster in Taurus. Wow! Wow? At first blush, it sounds like a "can't miss it" type of event. But if you think about it a little longer, you'll quickly see the problem. The full Moon is bright. Really bright. And the very brightest star in the Pleiades is 2.9-magnitude Alcyone, also known as Eta (η) Tauri.

If you've ever tried to view a 3rd-magnitude star next to the Moon before, you know how difficult it can be. And the majority of the main Pleiades come in at 4th-, 5th-, and 6th-magnitude. In short, this isn't something you're going to see very well without optics. Even binoculars are going to be only modestly helpful. Still, it's worth a try at least.

The action begins at around 8:42 p.m. EST, when the 99%-illuminated Moon covers 3.7-magnitude Electra (the third-brightest cluster star) and effectively concludes about an hour later. The specifics of which stars get occulted and when very much depend on your location. For example, in North America, only observers in the western U.S. (including Alaska) and Canada get to see the Moon cover Alcyone. Fire up your favorite planetarium software to investigate your specific viewing opportunities.

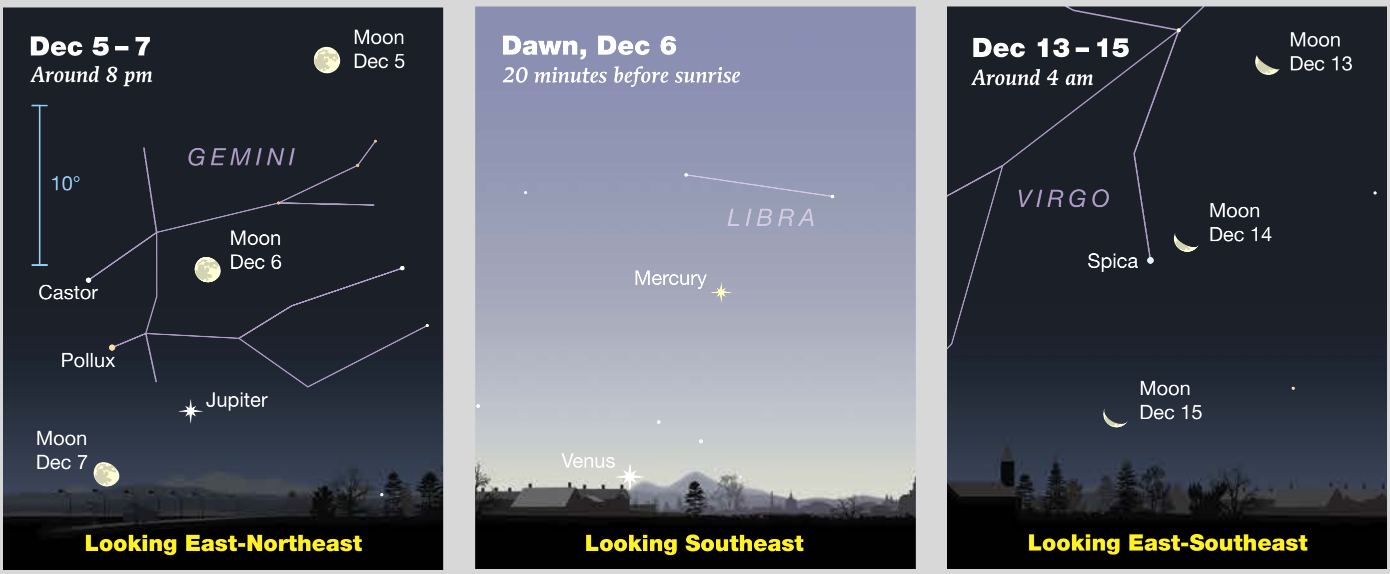
SATURDAY, DECEMBER 6

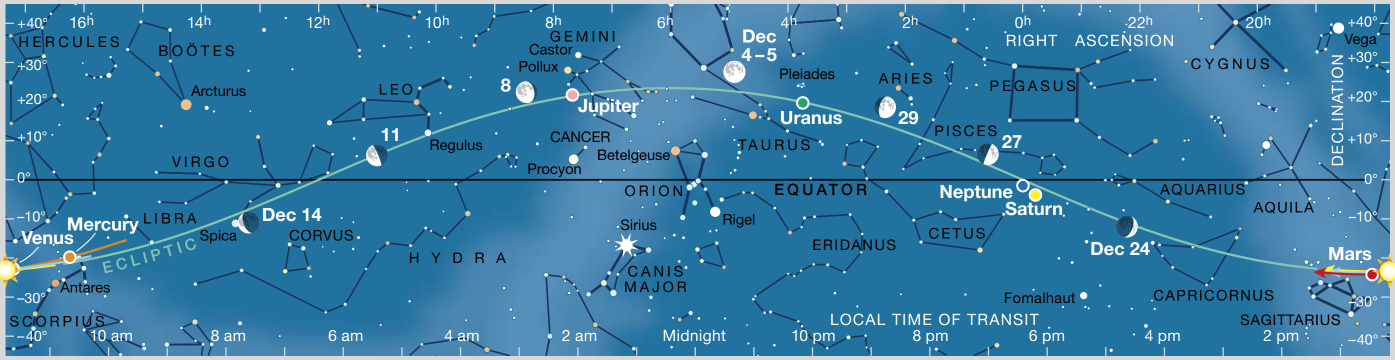
Mercury is in the midst of its final and best apparition for 2025. This morning, it achieves its greatest altitude for observers at mid-northern latitudes, standing 10° above the east-southeastern horizon roughly 45 minutes before sunrise. The little planet is also bright, gleaming away from the barrens of central Libra at magnitude −0.5. If you've never spotted the swift-moving innermost planet before, this is a golden opportunity. Generally, we get a half dozen chances to see Mercury each year, usually three at dawn and three at dusk. But not all apparitions are created equal — favorable showings happen only once or twice a year. Fortunately, if you miss out this time, you won't have to wait long for another chance. The next good Mercury apparition takes place at dusk in February.

SUNDAY, DECEMBER 7

Here's a fun two-for-one event for fans of celestial geometry. Or of triangles, at least. We begin at dawn, when you

▼ 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.

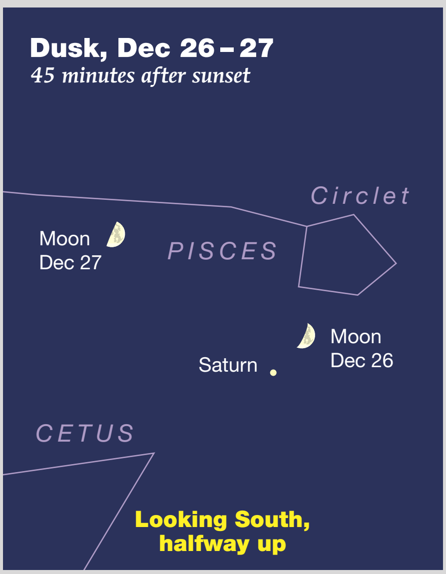




▲ The Sun and planets are positioned for mid-December; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

can sight a tidy triangle built with the waning gibbous **Moon**, **Jupiter**, and **Pollux**, the brightest star in Gemini. Jupiter beams handsomely at magnitude –2.6, which is 30 times brighter than 1.1-magnitude Pollux.

The trio hangs high in the west as the first blush of twilight begins to color the sky. The scene is enhanced by a nearby quartet of stars shining brighter than 1st magnitude: Sirius, Procyon, Betelgeuse, and Capella. Fortunately, at this time of year, you don't have to rise terribly early to catch a dawn scene like this. But if you're not a morning person, don't worry. Cast your gaze towards the eastern horizon at around 8 p.m. local time in the evening to see that same threesome on the rise. This time, however, the Moon is positioned east of Jupiter, though the triangle they form with Pollux retains the same appealing symmetry it had at dawn.



TUESDAY, DECEMBER 9

The closest meeting between the **Moon** and a bright star happens late tonight and into the early hours of the 10th. That's when the 66%-illuminated waning gibbous Moon slips by 1.4-magnitude **Regulus**, the brightest star in Leo, the Lion. The two will be at their closest just after midnight, at around 12:15 a.m. local time on the 10th. How close is *close?* As with such things involving the Moon, it depends on where you're located. The farther north you are, the closer they get. Observers in the contiguous U.S. will see the bright lunar disk just north of the star, but as described on page 49, some get to see the Moon's southern limb eclipse Regulus.

No matter where you are, the best views are with binoculars or a small telescope, which will allow you to more readily see the star awash in lunar glare. This event is part of a sequence of Regulus/Moon encounters that began in July and runs until the end of 2026. Most U.S. observers only have to wait until next February for a chance to see a Regulus occultation. More on that in that month's issue.

SUNDAY, DECEMBER 14

One week after its dusk and dawn meeting with Jupiter and Pollux, the **Moon** is parked near **Spica**, the brightest light in Virgo. The Moon won't approach Spica as closely as it did Regulus earlier in the month, but this morning's show is arguably more appealing for two reasons: a brighter star and a fainter Moon. At 1st magnitude, Spica is roughly 1½ times brighter than Leo's luminary. And this time the Moon is a 25%-illuminated waning crescent instead of the 66% gibbous it was on the 9th. As the first trace of morning twilight starts to light the sky, the lunar crescent is less than 2° right of Spica. Binoculars easily contain both objects in the same field and should nicely enhance the view.

FRIDAY, DECEMBER 26

The closest pairing between the **Moon** and a naked-eye planet in December happens this evening. The lucky planet is **Saturn**, which is in a prime location for viewing at a convenient time. It sits at the *meridian* (the imaginary line in the sky that connects north to south and passes directly overhead) around 5:30 p.m. local time, as evening light starts to fade and darkness falls. The Ringed Planet shines at magnitude 1.2, which is the same as the star Fomalhaut, twinkling away some 28° to the south. That brightness means Saturn is easy to see next to the 41%-illuminated lunar crescent. At 5:27 p.m. EST, the two are at their closest, with a gap of less than 3° separating them.

■ Consulting Editor **GARY SERONIK** likes to keep tabs on Mercury even if that means getting up early.

KPNO / NOIRLAB / NSF / AURA / R. SPARKS (NSF'S NOIRLAB)

▲ Dozens of bright and faint Geminids streak across the sky above the Mayall 4-meter telescope at Kitt Peak National Observatory, in Arizona, during the shower's peak on December 14, 2023. This composite photo was captured over a two-hour period.

Icy Meteors Streak

Favorable conditions promise fine showings from two December showers.

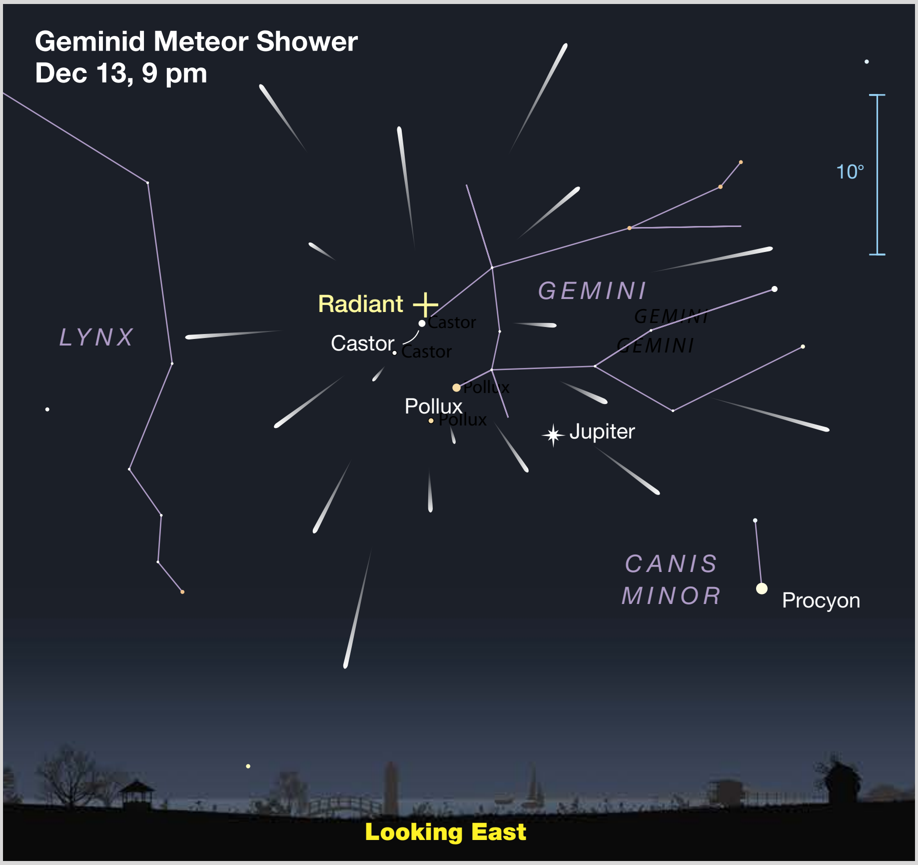
A nearly full Moon compromised our view of the annual Perseid meteor shower last August. However, we'll do much better with the year's other major display, the Geminids, which reach maximum on the night of December 13–14. A 26%-illuminated waning crescent Moon is present but rises in Virgo around 2:30 a.m. local time. Its modest glare has little impact on the year's richest meteor event.

North America could hardly be teed up much better for the Geminids, which are expected to peak around 3 a.m. EST (8:00 UT) on December 14th. The shower's *zenithal hourly rate* (ZHR), an idealized number based on pristine skies with the radiant overhead, is 150 meteors per hour. If you live near a city and contend with light pollution, divide that number by three for a more realistic estimate. The International Meteor Organization notes that the broad Geminid maximum — when the ZHR is 100 or higher — lasts for 10 to 12 hours, guaranteeing that a large swath of the globe gets a taste of the shower's power.

One of the things I've always loved about the Geminids is that you can start meteor gazing as early as 9 p.m. local time. That's when the streaming point (called the *radiant*), located near the star Castor, Alpha (α) Geminorum, begins its climb above the northeastern horizon. A few years back, I listened to the local kids slap a hockey puck around at a nearby outdoor rink as the Geminids ripped across the sky, caught in the net of Earth's atmosphere.

While some observers avoid cold December nights, a little preparation makes Geminid-watching a piece of cake even in subzero temperatures. A reclining chair is essential for comfort and to avoid a stiff neck. Since you won't be moving around much, insulated boots, long underwear, a wool sweater, heavy down coat, lined gloves, and a scarf are essential. Chemical hand-warmers placed inside your gloves (and boots) give much-needed extra warmth. And don't forget a warm, wool hat. Pull a blanket or sleeping bag over yourself, and you'll be as cozy as a cat on a sunny windowsill. I usually work a split shift during the Geminids — watching for an hour in the evening to take the shower's pulse, then get up at 2 or 3 a.m. to enjoy the peak.

In addition to being rich in fireballs, many meteor watchers describe Geminids as colorful, with hues of green, yellow, and red. These tints are caused by both the excitation of atoms in



Earth's atmosphere along the meteor's path as well as from the composition of the particles themselves. Blue-green is associated with magnesium emission, yellow derives from sodium and iron, and red from the interaction between atmospheric oxygen and nitrogen with material ablated from meteorite fragments as they fall. Excitation of oxygen at the start of the particle's plunge makes meteor trails glow green.

Geminids originate from the asteroid 3200 Phaethon, a hybrid object dubbed a "rock comet." At perihelion, it passes just 21 million kilometers (13 million miles) from the Sun — much closer than the planet Mercury. Astronomers theorize that the intense heat from the Sun bakes and cracks the asteroid's surface, releasing dust and fragments into space along its orbital track. Every December, Earth crosses the object's orbit and sweeps up particles that incandesce as Geminid meteors.

While most everyone looks forward to the Geminids, December features a second meteor shower that I'll wager few have seen. The Ursids peak around 5 a.m. EST (10:00 UT) the morning of the 22nd. This may be one of the best years to try your luck as the Moon is just a very thin, 3%-illuminated waxing crescent that sets in the early evening. The timing is rarely so good.

From a dark, rural location about 10 Ursids per hour hasten from a radiant 1½° northwest of Kochab, Beta (β) Ursae Minoris, the brightest star in the Little Dipper's bowl. That means that for many readers, the shower's radiant is circumpolar.

Ursid meteoroids originate with Comet 8P/Tuttle, which has an orbital period of only 13.6 years. It most recently passed our way in 2021 and reaches perihelion again in April 2035. When Earth crosses the comet's path this month, we'll encounter a denser filament of material that may enhance the shower's typical ZHR. Astronomer Peter Jenniskens, an expert on meteor showers, predicts that run-in occurs at 5:39 UT (12:39 a.m. EST) on December 22nd. Keep your eyes peeled!

A Waning Moon Occults Regulus

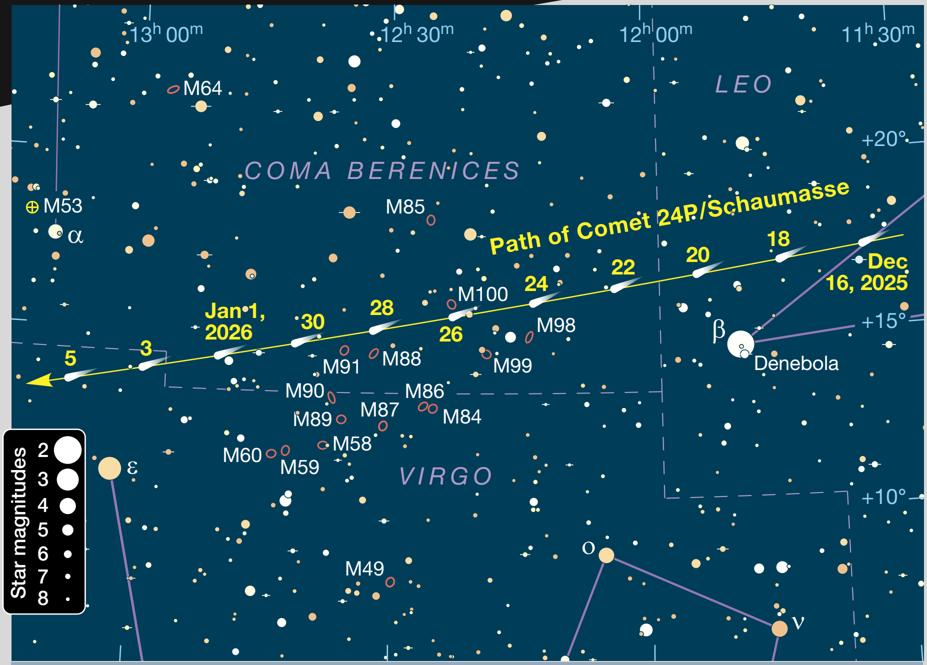
AS THE MOON WEAVES above and below the ecliptic during its 27.3-day orbit, it occasionally eclipses one of the zone's quartet of 1st-magnitude stars: Antares, Aldebaran, Regulus, and Spica. Occultations occur in bunches, where the Moon covers the star nearly every month from some location on Earth for up to several years. As noted on page 47, Regulus started its current series, which recurs about every nine years, last July. After 20 occultations, it finishes the series on December 27, 2026.

On the night of December 10–11, the waning gibbous Moon occults Regulus for observers in much of Canada and Greenland. In Saskatoon, Saskatchewan, for example, the bright southern limb of the Moon covers the star at 12:08 a.m. CST on the 11th. Just 13 minutes later, it flashes back in view on the dark limb. Observers in the rest of southern Canada and the U.S. instead witness a striking, close conjunction of the pair.

For a visibility map and occultation times for a host of cities, go to the International Occultation Timing Association's website, **https://is.gd/Regulus2025.**

This simulated view shows the star Regulus reappearing from behind the Moon's dark limb on the night of December 11–12, as seen from Saskatoon, Saskatchewan. For most of the U.S., the lunar disk will pass just north of the 1st-magnitude star.

MOON AND REGULUS: STELLARIUM



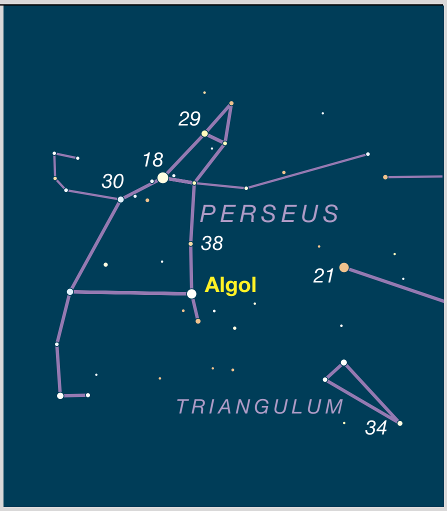
▲ **FREQUENT VISITOR** Every 8.3 years, Comet 24P/Schaumasse passes through the inner solar system to the delight of comet watchers waiting to see an old friend. When it last reached perihelion in November 2017, Schaumasse brightened to a modest 10th magnitude. The current apparition is more favorable, with the comet expected to peak at around 8th magnitude in late December and early January.

It saunters from the Sickle of Leo on December 1st and ends the month drifting through the blizzard of galaxies in Coma Berenices. In the chart above, the comet's positions are plotted for 0^h UT on the dates indicated. The best viewing is between about 2 a.m. local time and the start of dawn, when the comet is high in the south-southeastern sky. By the morning of the 13th, the Moon is largely out of the way. Look for a small, fuzzy blob with a brighter core and short tail pointing west.

Minima of Algol

Nov.	UT	Dec.	UT
2	6:23	3	19:22
5	3:12	6	16:11
8	0:01	9	13:00
10	20:50	12	9:50
13	17:39	15	6:39
16	14:28	18	3:28
19	11:17	21	0:17
22	8:06	23	21:06
25	4:55	26	17:56
28	1:44	29	14:45
30	22:33		

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



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

Action at Jupiter

JUPITER IS FAST approaching its January 10, 2026, opposition date, which means December offers plenty of opportunities to inspect the giant planet telescopically at a convenient time. As the month opens, Jupiter rises three hours after sunset and transits the meridian at around 3 a.m. local time. However, from mid-northern latitudes the planet achieves an altitude of 30° by 10:30 p.m. — high enough for good, high-magnification views of the planet's various belts and its Great Red Spot. At mid-month the planet shines at magnitude –2.6 and its disk spans a generous 45.6″.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The moons orbit Jupiter at different rates, changing positions along an almost straight line. Use the diagram on the facing page to identify them by their relative positions. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

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

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

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

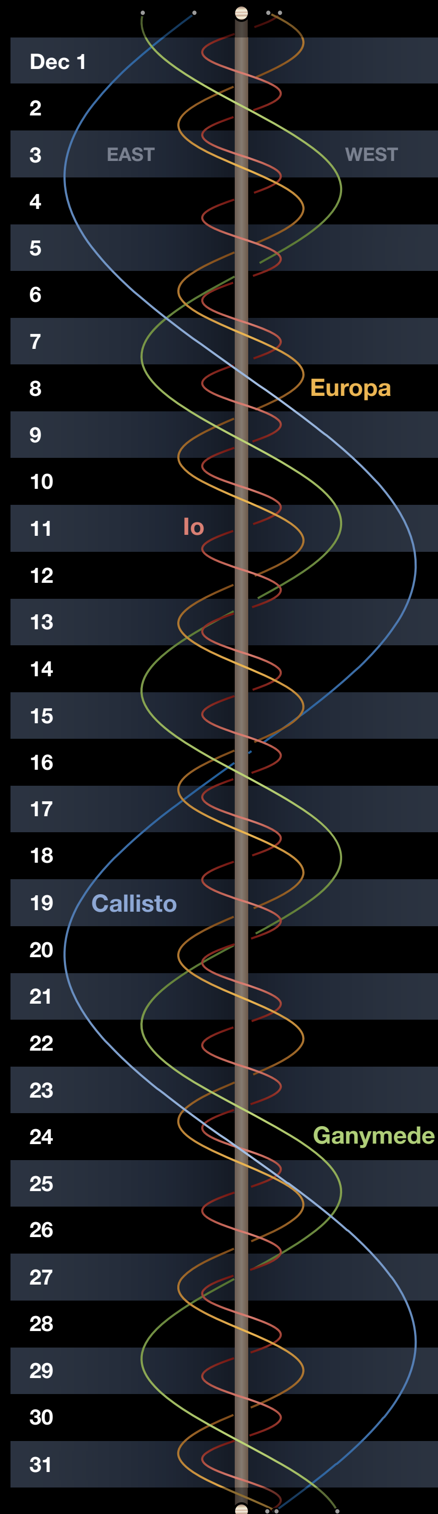
These times assume that the spot will be centered at System II longitude 87° on December 1st. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 87° and 1⅔ minutes later for each degree more than 87°.

Phenomena of Jupiter's Moons, December 2025

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

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

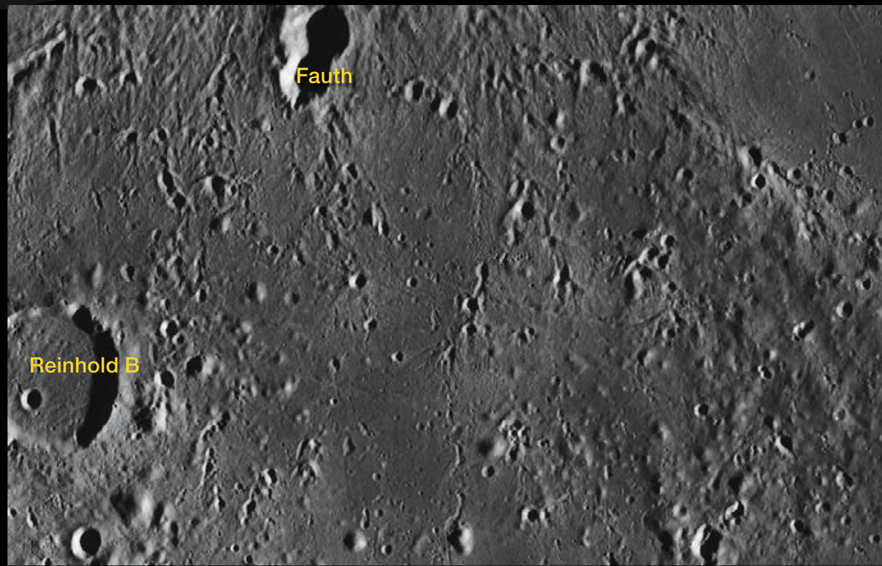
Jupiter's Moons

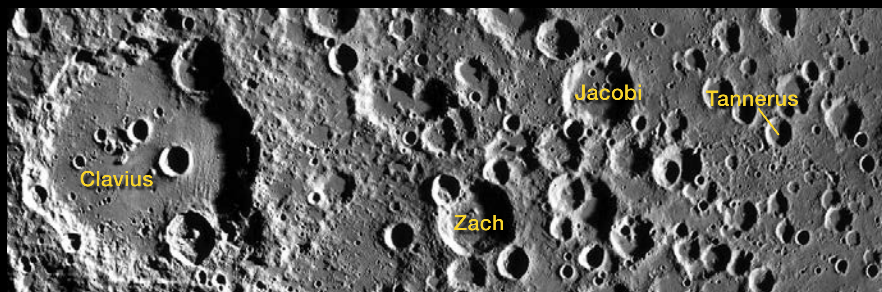


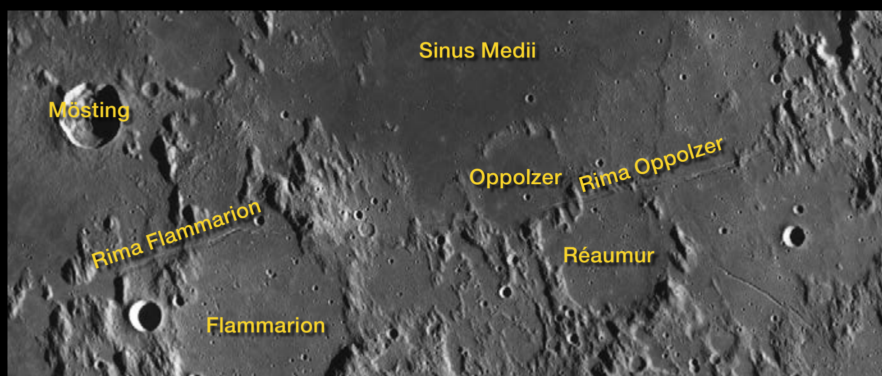
The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites'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

Hidden in Plain Sight

A radical change in lighting reveals little-known lunar features.







For more than four centuries, telescopic observers have carefully studied the Moon, and for more than 60 years, spacecraft have provided us close-up views in unprecedented detail. All this intense scrutiny has culminated in high-resolution imaging of the *entire* lunar surface at 100 meters per pixel or better. You'd think that with all this resolving power available, every surface feature larger than a few hundred meters would have been identified by now. But that isn't the case.

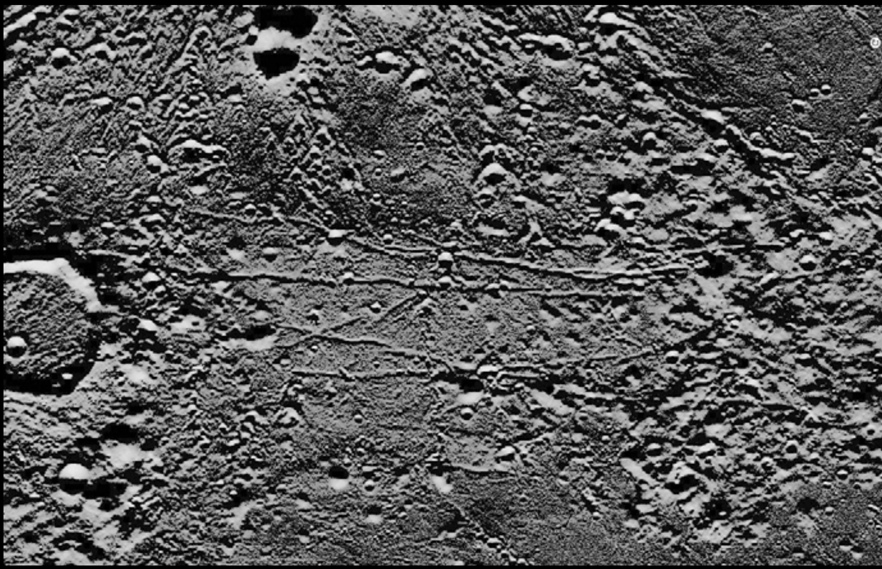
The reason isn't that the observations are flawed, nor that the images are somehow deceptive. The limitation is that nearly all lunar observations are biased by the Sun's illumination. The Sun rises in the east and sets in the west on the Moon, just as it does here on Earth. As such, we can never see nor photograph the Moon illuminated from the north or south. This means that subtle linear features such as rilles, crater chains, and mare ridges spanning east-west would rarely cast shadows and are therefore difficult to see, whereas similar north-south-trending landforms like the rilles circling the east side of Mare Humorum and the Serpentine Ridge, known today as Dorsa Smirnov and Dorsa Lister in eastern Mare Serenitatis stand out in stark relief under low-Sun illumination.

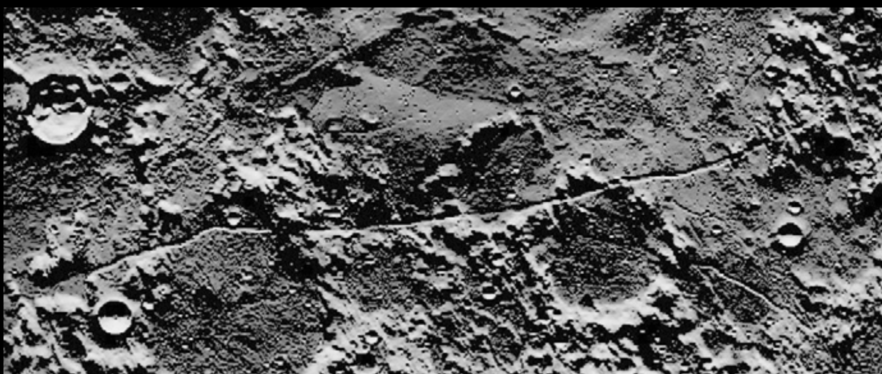
If the Moon were in a chaotic, tumbling orbit as it circled Earth, then all portions of the lunar surface would gradually be illuminated from every direction, providing Earth-based observers with a clearer understanding of the topography of our only natural satellite. Of course this isn't the case, but thanks to billions of measurements produced by the Lunar Orbiter Laser Altimeter (LOLA) instrument aboard NASA's Lunar Reconnaissance Orbiter and other spacecraft, we now have the tools to visualize this unorthodox perspective. To correct for nature's pesky astronomical oversight, New Zealand amateur astronomer Maurice J. S. Collins and I recently published the *Extreme Illumination Atlas of the Moon*. Our book uses LOLA data to depict the lunar surface as if it were illuminated from the north or south, and we include comparisons with east-west lighting.

While we were compiling the atlas, many unknown or rarely noticed landforms dramatically came to light. Here are three of these surprises that may be within reach of amateur telescopes.

The first is a family of rilles just south of the well-studied crater

NASA / GSFC / ARIZONA STATE UNIVERSITY; C. WOOD / M. COLLINS (6)





◀ *Top:* A series of rilles oriented east-west just south of crater Fauth is only hinted at in this Lunar Reconnaissance Orbiter mosaic (*facing page*). The same rilles stand out in stark relief when illuminated from the south (*top right*) shown here using data from the Lunar Orbiter Laser Altimeter instrument.

◀ *Middle:* A chain of small craters spans some 425 km to the east of Clavius. The craters are practically invisible under grazing sunlight (*facing page*), though they jump out when illuminated from the south (*middle right*).

◀ *Bottom:* Rima Flammarion appears to be a separate feature from Rima Oppolzer in the southern extent of Sinus Medii when viewed under normal solar illumination (*facing page)*. However, the two rilles are connected as seen in the *Extreme Illumination Atlas of the Moon* map *(bottom right)*.

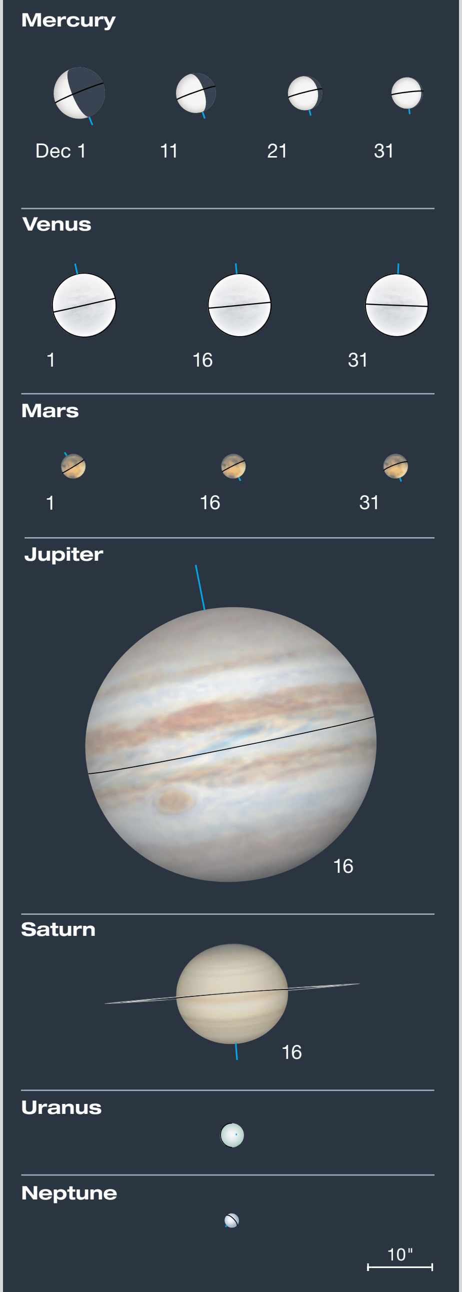
Copernicus. Our south-illuminated image above (top row) clearly reveals the bright walls and shadowed floors of the 2-km-wide (1¼-mile-wide), roughly 150-km-long series of rilles, whose east-west orientation positions them perpendicular to our virtual illumination from the south. The rilles are nearly invisible in Lunar Reconnaissance Orbiter Camera (LROC) images with lighting from the east or west, explaining why they are virtually unknown. I say "virtually" since I'm only aware of one report of their existence by lunar photographer K. C. Pau of Hong Kong, who called attention to them in his images.

A second well-studied area with a surprisingly overlooked feature is near the prominent, 230-km-wide crater **Clavius**. Starting at its east rim, a mostly battered linear crater chain extends some 425 km to the east-southeast and then bends toward the south-southeast, passing south of the crater **Tannerus**. Here, it changes into a broad, scraggly zone of overlapping smaller craters. Why it changes direction and terrain is unknown, as is its origin — the 2,200-km-distant Orientale Basin to the west and adjacent Clavius are possible suspects. British observer Barry Fitzgerald is the only person to have noticed this previously.

The third surprising feature that's revealed under our north-south illumination is a distinct connection between **Rima Flammarion** and **Rima Oppolzer** along the southern border of Sinus Medii, strongly suggesting the two rilles are opposite ends of a single, continuous tectonic feature. Once seen, the connecting segment is partially visible in an LROC image. Has it been detected before?

Each of these features were barely known prior to our work on the *Extreme Illumination Atlas of the Moon*. But now that they're well shown, I wonder if more telescopic observers might be able to detect them. The fact that the features are revealed in stark contrast when the Sun is artificially positioned at the poles suggests there's a chance to see them when the Moon's latitudinal libration is at its maximum of 6.7°. While this doesn't put the Sun at the poles, it's not on the equator either.

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



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

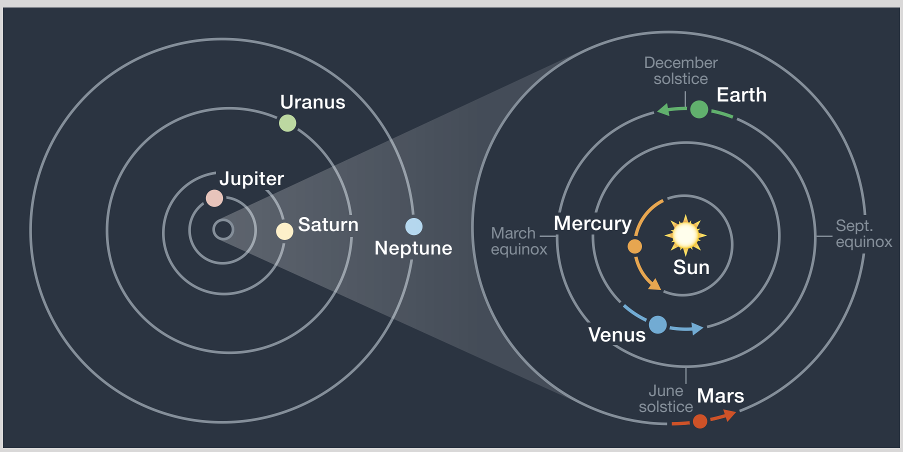
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during December. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn to the 27th • **Venus** visible at dawn to the 11th • **Mars** lost in the Sun's glare all month • **Jupiter** rises in the early evening and visible to dawn • **Saturn** transits in the early evening and sets around midnight.

December Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	16^h 27.8^m	–21° 45′	—	–26.8	32′ 26″	—	0.986
	31	18^h 40.0^m	–23° 07′	—	–26.8	32′ 32″	—	0.983
Mercury	1	15^h 15.1^m	–15° 22′	18° Mo	0.0	8.0″	36%	0.843
	11	15^h 46.9^m	–17° 51′	20° Mo	–0.5	6.2″	71%	1.080
	21	16^h 42.1^m	–21° 27′	17° Mo	–0.5	5.3″	87%	1.259
	31	17^h 45.9^m	–23° 51′	12° Mo	–0.5	4.9″	94%	1.370
Venus	1	15^h 51.2^m	–19° 25′	9° Mo	–3.9	9.9″	99%	1.682
	11	16^h 44.0^m	–21° 58′	6° Mo	–3.9	9.8″	99%	1.695
	21	17^h 38.2^m	–23° 25′	4° Mo	–3.9	9.8″	100%	1.705
	31	18^h 33.2^m	–23° 41′	2° Mo	–4.0	9.8″	100%	1.710
Mars	1	17^h 11.6^m	–23° 38′	10° Ev	+1.3	3.9″	100%	2.424
	16	18^h 00.7^m	–24° 13′	6° Ev	+1.3	3.9″	100%	2.420
	31	18^h 50.6^m	–23° 49′	3° Ev	+1.2	3.9″	100%	2.411
Jupiter	1	7^h 44.4^m	+21° 26′	135° Mo	–2.5	44.2″	100%	4.462
	31	7^h 31.5^m	+22° 01′	168° Mo	–2.7	46.4″	100%	4.245
Saturn	1	23^h 44.7^m	–4° 14′	106° Ev	+1.1	18.1″	100%	9.207
	31	23^h 48.0^m	–3° 46′	77° Ev	+1.2	17.1″	100%	9.699
Uranus	16	3^h 43.6^m	+19° 32′	154° Ev	+5.6	3.8″	100%	18.602
Neptune	16	23^h 58.5^m	–1° 37′	95° Ev	+7.9	2.3″	100%	29.782

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**.



Capture Your First Orion Nebula Photo

Shooting M42 with your camera gear is easy if you follow these simple tips.

In 1880, medical doctor and amateur astronomer Henry Draper aimed his 11-inch Clark refractor in Hastings-on-Hudson, New York, toward a bright knot of light in Orion's Sword. For 50 minutes he guided the telescope by hand, keeping the nebula centered while its light slowly burned onto the photographic emulsion coating a glass plate. When he developed the plate, it revealed the first successful photograph of M42, the Orion Nebula, a breakthrough that proved such feats were possible, even for extremely faint objects.

Fortunately, modern tools have made capturing M42 far more accessible, allowing us to build on Draper's achievement in ways he could only dream of. The Orion Nebula remains one of the most rewarding targets for beginners and experienced astroimagers alike — it's easy to locate, bright enough to pierce urban skyglow, and spectacular at any image scale. M42 delivers. On a clear night, the nebula is sufficiently bright that even modest camera equipment will record it, and a thoughtful approach will show the nebula's brilliant Trapezium asterism at its center as well as its sweeping expanse of colorful gas clouds.

Your Basic Equipment

The gear list for shooting Orion is refreshingly short compared to other astrophotography projects. A modern DSLR or mirrorless camera with manual controls works beautifully, and even entry-level models offer all the settings you'll need. What matters most is stability — a solid tripod and head will keep the camera steady, avoiding the subtle shifts that can blur fine details.

Pick a spot to set up your gear that has a clear view toward Orion and, if possible, away from nearby lights. A light-pollution filter can help tame skyglow in bright, urban locations. Using a shutter-release cable or even your camera's built-in self-timer will also allow you to avoid shaking the camera when you start an exposure.

Different lenses reveal different personalities of Orion. Your lens focal length determines whether you zero in on the Trapezium's sparkling stars or frame it amid the rich star fields and glowing clouds surrounding the asterism. A "fast" lens (one with a low focal ratio, or f/number) can bring out the nebula's delicate outer filaments in just a short exposure. Since we're working without a tracking mount for this go, faster optics such as f/4 or less are an advantage.

On cameras with an APS-C-size sensor, a 50-mm lens offers a wide field, while a 300-mm provides a close-up of the nebula itself. Many astrophotogra-

▲ **MAJESTIC NEBULA** The author captured this view of M42, the Orion Nebula, with a single 0.5-second untracked exposure with a Canon EOS Rebel T7 DSLR camera (with APS-C-size sensor) and a 300-mm f/4 telephoto lens. M42's central Trapezium region is well-defined and not overexposed, though its outer nebulosity is less visible.

▲ **AN EXPOSURE BALANCING ACT** This single 2-second untracked exposure was taken with the same camera at ISO 1600 and a 75-mm lens at f/4. M42's bright core, which dominates the field, is overexposed, but the surrounding faint nebulosity is revealed in detail. North is up in both images, and the fields shown are about 1.3° and 2.5° wide, respectively.

▲ **A SIMPLE SETUP** The author's Canon EOS Rebel T7 camera paired with a 135-mm lens and mounted on a fixed tripod with a ball head. Without motorized tracking, exposures would have to be kept short to prevent star images from becoming elongated or trailed.

▲ **VIBRATION-FREE EXPOSURES** You can use a simple shutter-release cable or the camera's built-in timer to prevent camera shake when operating the shutter. An intervalometer (above), a programmable device for timing shot intervals, can also be used.

▲ **GO MANUAL** Set your lens and camera control settings to manual (M) mode before photographing M42, so you'll have full control on the lens focus as well as the camera's shutter speed, lens aperture, and ISO, which refers to the camera sensor's sensitivity to light.

phers find the 135-mm focal length to be a pleasing balance between nebula detail and image scale. A camera with a larger, full-frame sensor covers a wider swath of the sky, so you'll need longer focal lengths to achieve the same framing. For example, depending on your system you'll need roughly a 75-mm lens instead of a 50-mm, or a 200-mm instead of a 300-mm, to achieve the same sky coverage with the full-frame sensor compared to the APS-C.

Camera Settings

With your gear in place, switch the camera to full manual (M) mode so you have complete control over the "exposure trinity" — that is, your camera's shutter speed, lens aperture, and ISO, or the sensor's sensitivity. Shooting in RAW format is ideal, as it preserves the Orion Nebula's broad dynamic range and gives you flexibility to adjust the white balance during post-processing. This is especially useful if you're using a light-pollution filter, which can shift the image's color balance.

Set the white balance to daylight if your camera is unmodified (conventional) and you're not using a filter. If you have a camera that's been modified for astrophotography or are using a filter, you may need to set a custom white balance to yield more accurate colors.

Be sure to turn off the image stabilization (IS) feature on the lens or in the camera body. While invaluable for handheld shooting, IS can actually cause blur when the camera is mounted on a tripod by searching for movement that isn't there.

Disable high ISO noise reduction as well; it can soften fine detail in nebulosity, and noise can be removed more effectively during post-processing.

Finally, switch both your camera and lens to manual focus (MF). Autofocus will struggle in low light; careful manual adjustment will help ensure crisp stars.

Focusing and Framing

Even a well-composed, properly exposed image won't shine if the focus is soft. Fortunately, manual focusing at night is easier to accomplish than it sounds. Switch the lens to MF, then activate the Live View feature in your camera. This switches the camera into a type of video mode. On the LCD screen on the back of the camera, center a bright star in the frame. Brilliant Rigel, Beta (β) Orionis, is an ideal choice when photographing M42. If nothing appears on the screen, raise the display brightness or temporarily increase the exposure time and ISO setting until the star becomes visible. Then, magnify the view as high as it can go (typically 5× or 10×). Slowly rotate the lens's focus ring while watching the star. It will contract into a fine point, then expand again as you overshoot focus. Gently rock back and forth until the star looks as small and crisp as possible, then you're done. (As an alternative, preset your focus in daytime on a distant object and secure the ring with tape.)

With focus set, go ahead and compose your M42 shot, but be careful not to touch the focus ring. Take a few test exposures to confirm the nebula's placement in the frame. The Trapezium should stand out clearly. Whether you'd want to center it or compose the shot more creatively with the surrounding nebulosity and star fields is totally up to you.

Exposure Settings

Earth's rotation waits for no one, and even wide-angle lenses will show trailing sooner than you might expect. A useful guideline is the "300 Rule" for APS-C-size sensors. Divide 300 by your lens focal length to estimate the longest exposure you can take before stars begin to elongate. For example, a 200-mm lens on an APS-C camera gives roughly 1.5 seconds (300 divided by 200). This is just a starting point, not absolute. Many astrophotographers prefer slightly shorter exposures to get sharp, pinpoint stars. The surest method is to take a test image, zoom in at 100%, and adjust until the stars are tack sharp.

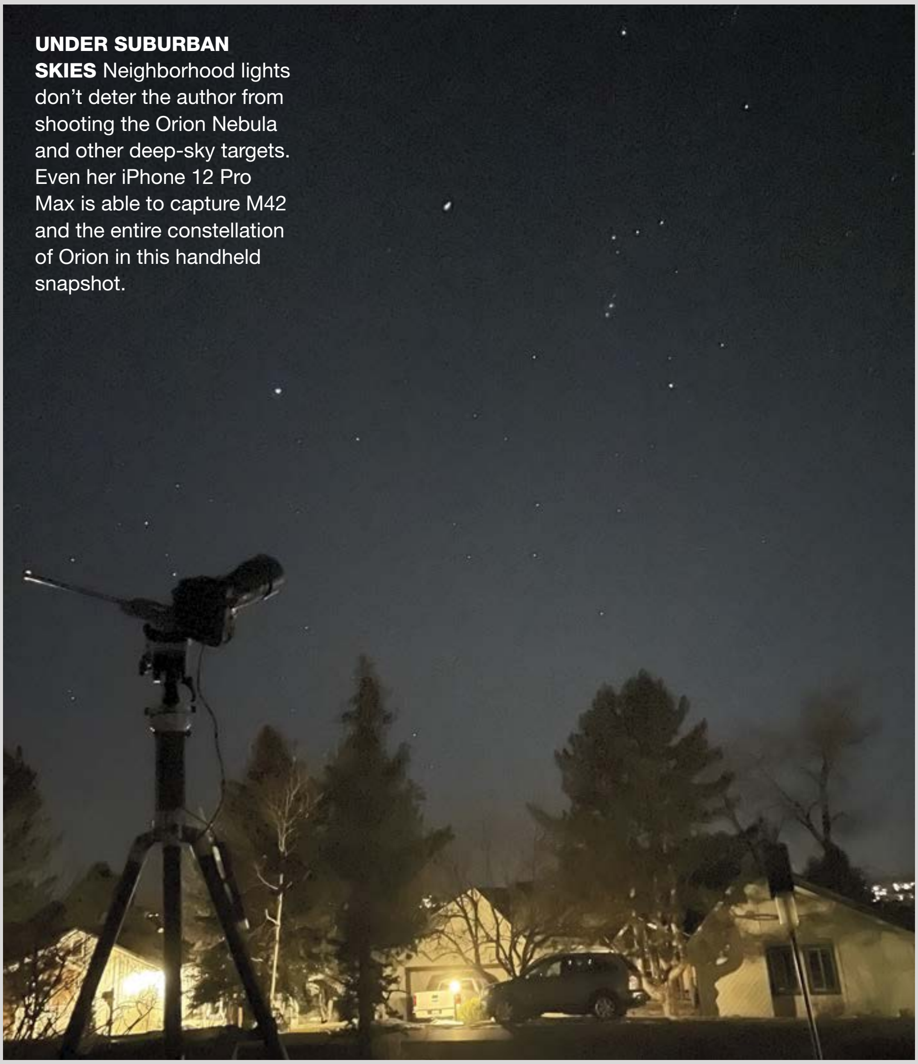
Now that you've established a ballpark exposure time, your lens focal ratio, controlled by the aperture setting, plays an equally important role. Opening the lens aperture fully to, say, f/2 gathers more light and shortens your exposure compared to f/2.8, but stopping down slightly can sharpen the frame edges by reducing the lens's apparent optical aberrations.

ISO is the last of the trio of variables to balance alongside shutter speed and aperture. Many entry-level DSLRs deliver the cleanest results around ISO 800 to 1600, while newer cameras with ISO-invariant sensors handle ISO 3200 to 6400 with minimal electronic noise. Some sensors have a "sweet spot," where dynamic range and noise performance are at their best, making it worth testing your own camera. And under light-polluted skies, it's best to avoid pushing ISO too high. Doing so will only brighten the skyglow and wash out the nebula's fainter details.

The goal is to balance all three settings so they work together. If you shorten the exposure to avoid trailing, you may need to open the aperture or boost the ISO. If you stop down the lens to sharpen the stars, you can compensate with a slower shutter speed (within trailing limit) or a moderately high ISO.

Orion's brightness is both a gift and a challenge. The Trapezium's core can saturate (overexpose) easily while the nebula's delicate outer regions remain dim. Keep an eye on your image's histogram to avoid clipping in either the highlights or shadows, and remember that RAW files contain more recoverable detail than you'll see on the back LCD screen of your camera.

▲ **MOTOR-DRIVEN MOUNT** To get longer exposures and better resolution with telephoto lenses, use a polar-aligned, motorized equatorial tracking mount. In this photo, the author's Canon camera and 135-mm lens are set on a portable Sky-Watcher Star Adventurer tracker.



UNDER SUBURBAN SKIES Neighborhood lights don't deter the author from shooting the Orion Nebula and other deep-sky targets. Even her iPhone 12 Pro Max is able to capture M42 and the entire constellation of Orion in this handheld snapshot.

Once your exposure settings are dialed in, use the shutter-release cable or the camera's self-timer to fire off some exposures. Take several frames so you have backups; sometimes a sudden gust of wind or an unnoticed bump can ruin a single exposure. If Orion has drifted out of your frame while you've been fine-tuning your settings, reposition, recompose, and refocus before continuing.

In summary, it's possible to obtain decent shots of the Orion Nebula using simple gear, something that you may already own and use for daytime activities like bird or wildlife photography. For best results, consider using a polar-aligned, motorized tracking mount so you can record long exposures at high resolution. But regardless of the equipment used, your first photo of M42 is an important personal accomplishment, one that could lead to a desire to capture even better, richer portraits of Orion's glorious nebula. Good luck!

■ **SARAH MATHEWS** is an astrophotographer and science communicator with a background in the space industry. She shares her passion for space and astro imaging through writing, YouTube videos, workshops, and public talks.

Chasing Winter IC Objects

Go beyond the Messier and NGC catalogs for more deep-sky delights.

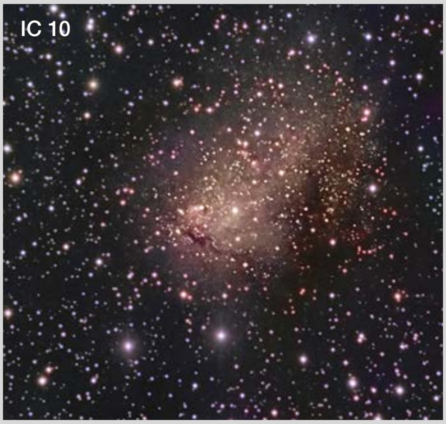
When first embarking on a deep-sky hunt, we usually start with the brighter Messiers and then graduate to the easiest NGC objects, perhaps using the Astronomical League's Herschel lists as a guide. There are enough rewarding targets in the NGC list to keep one busy for many observing sessions.

And so, you might be hesitant about chasing objects with IC designations. John Louis Emil Dreyer compiled the *New General Catalogue of Nebulae and Clusters of Stars* and published a further two tomes in 1895 and 1908 titled the *Index Catalogues* containing more than 5,000 objects. Years ago, I showed an IC galaxy to my observing buddy, Joe McCormick, who looked through the eyepiece and quipped: "IC, No-See."

Here are some of the brighter ICs that I observed during the icy (pun intended) winter season with my club buddies, Frank Colosimo and Gary Trapuzzano, who imaged while I peered through the eyepiece. Let's get going.

The Starting Gate

We begin our winter tour in Cassiopeia with **IC 10**, a 10th-magnitude dwarf irregular galaxy discovered by prolific comet hunter Lewis Swift in 1887. Point your telescope at 2.3-magnitude Beta (β) Cassiopeiae (Caph) and you'll find your dim quarry less than 1½° east in the same eyepiece field as 9th-magnitude HD 236376 and the 7th-magnitude variable star TV Cassiopeiae. My 22-inch Dobsonian at 177× shows these two stars forming the base of a right triangle with IC 10, which has a surface brightness of 14.0 magnitudes per square arcminute, appearing very spread out.



▲ **MEMORABLE IC TARGETS** Nebulae IC 410 (left) and IC 405 (right) are two of the brighter objects in the *Index Catalogue*. The author describes several other great objects on this oft-neglected list of deep-sky objects. All images are north up.

Try looking for warmth in the southeastern corner of Cassiopeia — just across the border of northern Perseus and about 5° northeast of the famed Double Cluster. That's where you'll find **IC 1805** and **IC 1848**, two open clusters embedded in nebulosity fondly called the Heart and Soul nebulae, respectively. My 22-inch at 77× showcased the emission nebulae best, and a broadband or O III filter enhanced the view. The open clusters comprise the relatively young stars that energize the surrounding gas and dust.

IC 405 AND IC 410: GARY TRAPUZZANO; IC 10: FRANK COLOSIMO

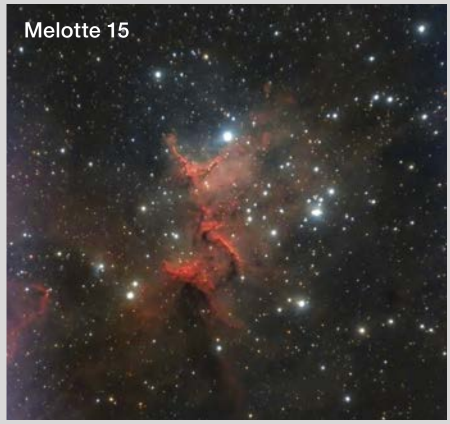
Melotte 15, the large cluster that acts as the Heart Nebula's "pacemaker," is visible in a 10×50 finder, 11×80 binoculars, and with my 10-inch Dobsonian at 47×. Through my 20-inch reflector at 73×, I had difficulty identifying where the northern edge ended, but the southern part of the nebula stood out well. The Soul Nebula's energy source, Collinder 32, is about 2½° southeast of IC 1805 and has noticeably fewer stars than its neighbor. Can you detect these subtle differences?

While you're in the area, scoot to the northwestern edge of IC 1805, about 1° from the cluster, to arrive at the emission nebula **IC 1795**. Scout around for it ¼° west of the 8th-magnitude star HD 15069. IC 1795 forms part of a larger complex along with another emission nebula, NGC 896. Both my 20-inch and 22-inch reflectors at 73× to 77× with an O III filter showed it quite well. I saw it as a faint, hazy area, with a brighter patch surrounding a 10th-magnitude star. I also noted an obvious dark area.

Now slew across to orangey 2.4-magnitude Gamma (γ) Cassiopeiae and from there shift your gaze 25′ north and east to land at **IC 59** and **IC 63**, the latter of which is also known as the Ghost of Cassiopeia. Both objects are a combination of reflection and emission nebulae. The emission nebulae respond well to a broadband filter — but they're fairly challenging to snag, even with my 22-inch at 90×, as they're small (each is only about 10′ at its greatest extent) and dim. Try observing them both with and without a filter.

Next, we'll head some 20° east to 4.6-magnitude Gamma Camelopardalis. From there drop roughly 3¼° south to land on **IC 342**, an 8.4-magnitude spiral galaxy. It's relatively close, which gives it a large apparent size, but it's also located along the plane of the Milky Way rendering it rather faint (its surface brightness is 14.9). With my 22-inch at 77× and paired with a Galaxy Contrast Enhancement filter, I detected some milkiness in this faint, face-on galaxy.


IC 1805


Melotte 15

The Last Lap

Slide a slippery slope through the heart of Auriga by steering 12½° due south of +0.1-magnitude Alpha (α) Aurigae, or Capella. There you'll find the open cluster Melotte 31, sometimes called the Flying Minnow. Just east of 4th-magnitude 16 Aurigae (not a cluster member, the star just happens to be in the line-of-sight), you'll find **IC 410**, the Tadpole Nebula, surrounding the open cluster NGC 1893. Immediately north is **IC 405**, the Flaming Star Nebula. I found the emission portions of both nebulae difficult with Ultra-High Contrast (UHC) and O III filters, but using my 22-inch at 77× and 208×, I could easily see the reflection patch around 6th-magnitude AE Aurigae in IC 405. Some 2½° due east of IC 405 is **IC 417**, the Spider Nebula — I detected it even in less-than-ideal skies with my 15-inch reflector at 55× equipped with a UHC filter. It's energized by Stock 8, an embedded open cluster that's rich in both bright (magnitude 8.5) and faint (magnitude 15) stars. You'll see 5.1-magnitude Phi (φ) Aurigae in the same field.

Continuing onwards into Gemini, try for the small open cluster **IC 2157**, which is around 1° west-southwest of naked-eye (under dark conditions) cluster M35. The IC cluster is quite


IC 63 and IC 59

IC 1805: FRANK COLOSIMO; IC 1805: GARY TRAPUZZANO; IC 63 AND IC 59: FRANK COLOSIMO

faint (its brightest star is 11th magnitude) even with my 22-inch reflector at 48×. Moving 2¼° southeast of M35 you'll come to 3.3-magnitude Eta (η) Geminorum. Immediately east of Eta you have **IC 443**, the Jellyfish Nebula. This supernova remnant is quite large (about 50′ across), but with my 22-inch at 77× and a UHC filter, I could only snag a small part of it. However, I obtained a better view with my 13-inch reflector at 61× and an O III filter. About halfway along an imaginary line connecting Eta and Mu (μ) Geminorum scan about ¾° north and you should be able to locate **IC 444**, a faint reflection nebula that I saw well in my 13-inch reflector at 113×.

IC Targets for Icy Nights

Object	Type	Mag	Size	RA	Dec.
IC 10	Dwarf irregular galaxy	10.4	6.4′ × 5.3′	$00^h\ 20.4^m$	+59° 18′
IC 1805	Open cluster	6.5	20′	$02^h\ 32.8^m$	+61° 28′
IC 1848	Open cluster	6.5	18′	$02^h\ 51.3^m$	+60° 24′
IC 1795	Emission nebula	—	10′ × 10′	$02^h\ 25.5^m$	+62° 01′
IC 59	Emission/reflection nebula	—	10′ × 5′	$00^h\ 57.5^m$	+61° 09′
IC 63	Emission/reflection nebula	—	10′ × 3′	$00^h\ 59.5^m$	+60° 55′
IC 342	Spiral galaxy	8.4	21.4′ × 20.9′	$03^h\ 46.8^m$	+68° 06′
IC 410	Emission nebula	—	55′ × 45′	$05^h\ 22.7^m$	+33° 25′
IC 405	Emission/reflection nebula	—	30′ × 20′	$05^h\ 16.5^m$	+34° 21′
IC 417	Emission nebula	—	13′ × 10′	$05^h\ 28.1^m$	+34° 25′
IC 2157	Open cluster	8.4	5′	$06^h\ 04.8^m$	+24° 03′
IC 443	Supernova remnant	—	50′ × 40′	$06^h\ 16.6^m$	+22° 31′
IC 444	Reflection nebula	—	48′ × 38′	$06^h\ 22.5^m$	+22° 52′
IC 434	Emission nebula	—	60′ × 10′	$05^h\ 41.0^m$	−02° 27′

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

The Finish Line

Skipping down to Orion, imagers can't resist capturing the emission nebula **IC 434** and the dark Horsehead Nebula (B33) embedded within it. They're found about ½° south of Alnitak, Zeta (ζ) Orionis. I was able to detect the emission nebula with my 10-inch reflector at 47× and 117× and a hydrogen-beta filter. But observing conditions, position in the sky (close to the meridian is best), and large apertures are crucial for visually snagging the dark notch that is the Horsehead Nebula. From my locations and observing conditions, I needed at least an 18-inch or larger telescope at magnifications ranging from 73× to 97× and a hydrogen-beta filter to see it. What has your experience been with this visually challenging object?

Astronomy teaches us many things, including patience. With careful attention, planning, persistence, and determination, there's no such thing as "IC, No-See." By pushing the envelope, you can expand your horizons and add more deep-sky trophies to your collection!

AL LAMPERTI is a member of the Delaware Valley Astronomers along with his imaging buddies, Frank Colosimo and Gary Trapuzzano. The trio relishes the night sky no matter the season.

FRANK COLOSIMO (2)

▲ POWERFUL PLANETARY IMAGER

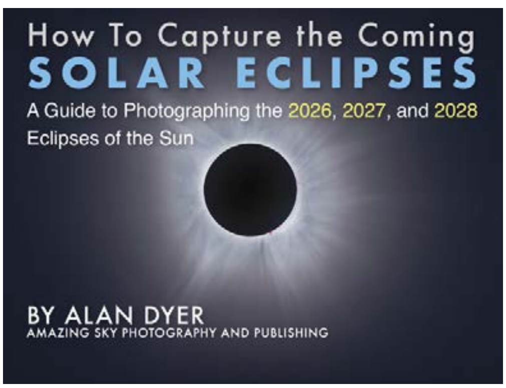
Celestron recently announced its latest planetary imaging camera, the NexImage 20 Solar System Color Imager ($449.95). This 20-megapixel color video camera uses a Sony AR2020 Back-Side-Illuminated CMOS detector that boasts a generous 5,240 × 3,840 array of 1.4-micron-square pixels measuring 7.3 × 5.4 millimeters. Its extremely compact housing is smaller than a typical eyepiece. The camera features a rolling shutter capable of recording up to nine full-resolution frames per second, or up to 430 frames per second with region-of-interest cropping. The NexImage 20 is compatible with both Windows and macOS operating systems, and users can download drivers and Celestron's *iCap 2.5* control software for Windows platforms from its website. Each camera comes complete with a C-to-1¼-inch nosepiece adapter and USB 3.0 cable.

Celestron
2835 Columbia St., Torrance, CA 90503
310-328-9560; celestron.com

▲ OBSERVATORY MOUNT

Astro-Physics adds new additions to its line of observatory-class mounts. The 1150GTO German Equatorial Mount is rated to handle a payload of up to 57 kilograms (125 lbs). It features 183-mm (7.2-inch), 225-tooth aluminum gears and brushless Micro-step drive system on both axes for precise slewing and tracking and auto-adjusting gear mesh that virtually eliminates backlash. The mount head weighs 24 kg, and its axes can be separated for easy transport and setup. Optional Standard Temperature and Extended Temperature Absolute Encoders on the 1150GTO-AE and 1150GTO-AEL models reduce periodic error to 0.19 arcseconds or less. The mount requires 12V DC and includes a 47.6-mm-wide by 419-mm-long counterweight shaft, a thumb drive containing its manuals, *APCC Pro* and *PEMPro* software, and a power cable. Prices yet to be determined.

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



◀ ECLIPSE PHOTOGRAPHY HOW-TO

Sky & Telescope Contributing Editor Alan Dyer expands and updates his downloadable ebook aimed at photographing eclipses with an eye on those happening in 2026 though 2028, including the annular eclipse in January 2028. *How to Capture the Coming Solar Eclipses* ($10.99) provides detailed advice and instruction for capturing solar eclipses using a variety of techniques. Dyer covers a wide range of options, from grabbing wide-field images with smartphones to shooting HDR composites through a telescope. The ebook also provides tips for choosing cameras, lenses, and other equipment necessary for eclipse photography, as well as extensive step-by-step tutorials on how to process the results. It's available from the Apple Books store, or as a downloadable PDF file readable on any operating system. 400 pages, ISBN 978-0-9939589-5-3.

Amazing Sky
www.amazingsky.com/EclipseBook

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

Caring for Your Cat

Here's how to keep your SCT at peak performance.

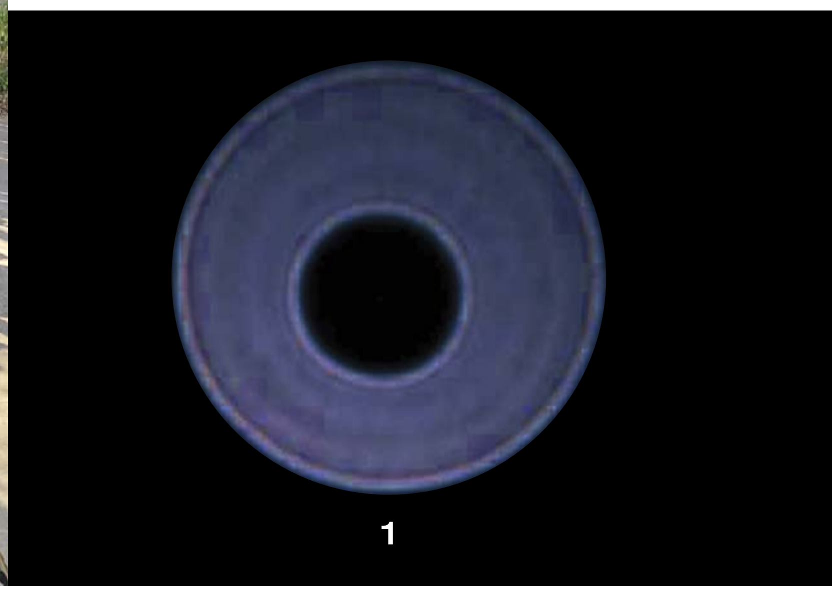
A certain mystique has surrounded the Schmidt-Cassegrain telescope (SCT) since its introduction to the amateur astronomy community some 60 years ago. This compact, exotic optical system folds a long focal length into a short tube that's very robust and seldom needs repair. Its corrector plate removes spherical aberration in star images produced by its spherical primary and secondary mirrors and also protects those optics from dust and moisture, ensuring the reflective coatings rarely need attention. But periodic collimation and routine cleaning of the outer surface of the corrector plate are important tasks that often intimidate new users. Here's how I keep my SCTs performing like new.

Optical Alignment

The secret about SCTs is they are easier to keep in peak working order than Newtonian reflectors. Collimating a Newtonian often requires adjusting both the secondary and primary mirrors. The SCT, on the other hand, only needs adjustments to its secondary mirror.

A typical SCT optical tube assembly (OTA) uses a 5× magnifying secondary mirror to increase the focal length of its f/2 primary mirror to achieve an f/10 focal ratio. The result is a short telescope with a lot of focal length. These scopes maintain their collimation quite well — short moves in and out of the house for backyard observing generally don't cause the optics to misalign. However, prolonged jiggling from a road trip to a star party or remote dark site can shake things loose. Likewise, scopes that reside in a backyard observatory

▼ **DISTORTED DISK 1:** Out-of-focus stars display an offset central shadow when an SCT isn't in proper collimation. **2:** Using a low-power eyepiece, center the central shadow by adjusting the three collimation screws on the secondary assembly. **3:** Switch to a higher magnification eyepiece and repeat the process. **4:** Focus the star until the donut is small but the secondary shadow is still visible, then tweak the collimation to center the star pinpoint within the diffraction pattern.

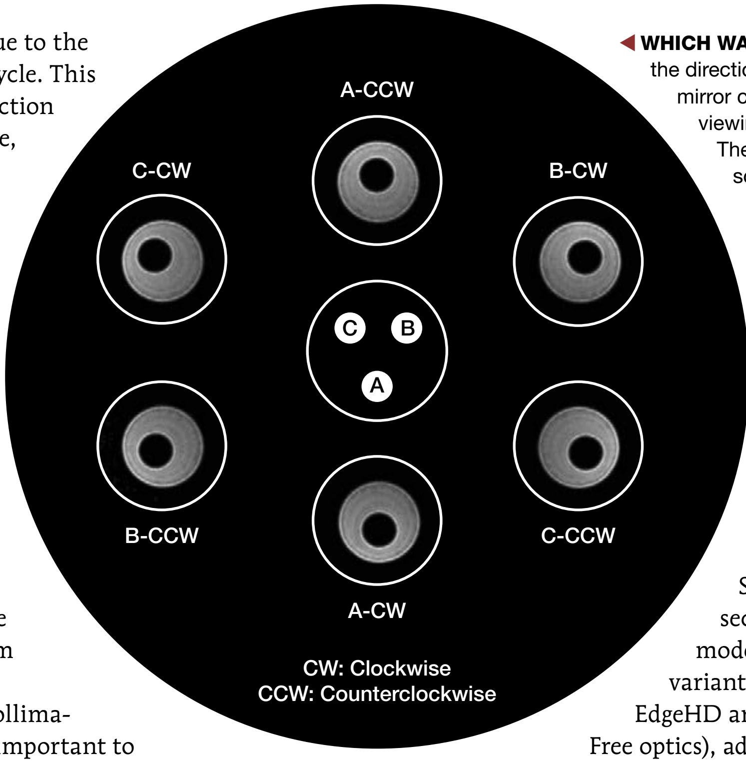


UNLESS OTHERWISE NOTED, ALL IMAGES ARE COURTESY OF THE AUTHOR can fall out of collimation due to the daily warming and cooling cycle. This causes expansion and contraction in the mechanics of the scope, loosening the collimation screws over time. Regardless, every SCT eventually needs a collimation tweak.

When it's time, there are several methods you can use to get your scope back into optical alignment. SCT collimation can be performed using a star, an artificial star, or a specialized laser collimator designed specifically for Cassegrain telescopes. All work quite well, though some methods are easier to perform than others.

If you use a star as your collimation target, for example, it's important to first ensure the telescope is close to the ambient air temperature, so that the image isn't a churning mass that prevents careful adjustments. I typically wait about an hour after setting up my scope before checking collimation. Aftermarket cooling fans that circulate air inside the tube assembly can help to speed the process. Even in poor seeing, an SCT's concentric out-of-focus doughnut star image is seen well enough to get you close to alignment.

Although it's best to perform collimation straight through the scope, you can use a star diagonal to put the eyepiece at a comfortable position. Be sure to verify the diagonal doesn't shift the field of view by rotating it in the visual back while observing a distant terrestrial object. If the view moves away from the center as you turn, then it isn't perfectly aligned to the optical axis of the scope and shouldn't be used.

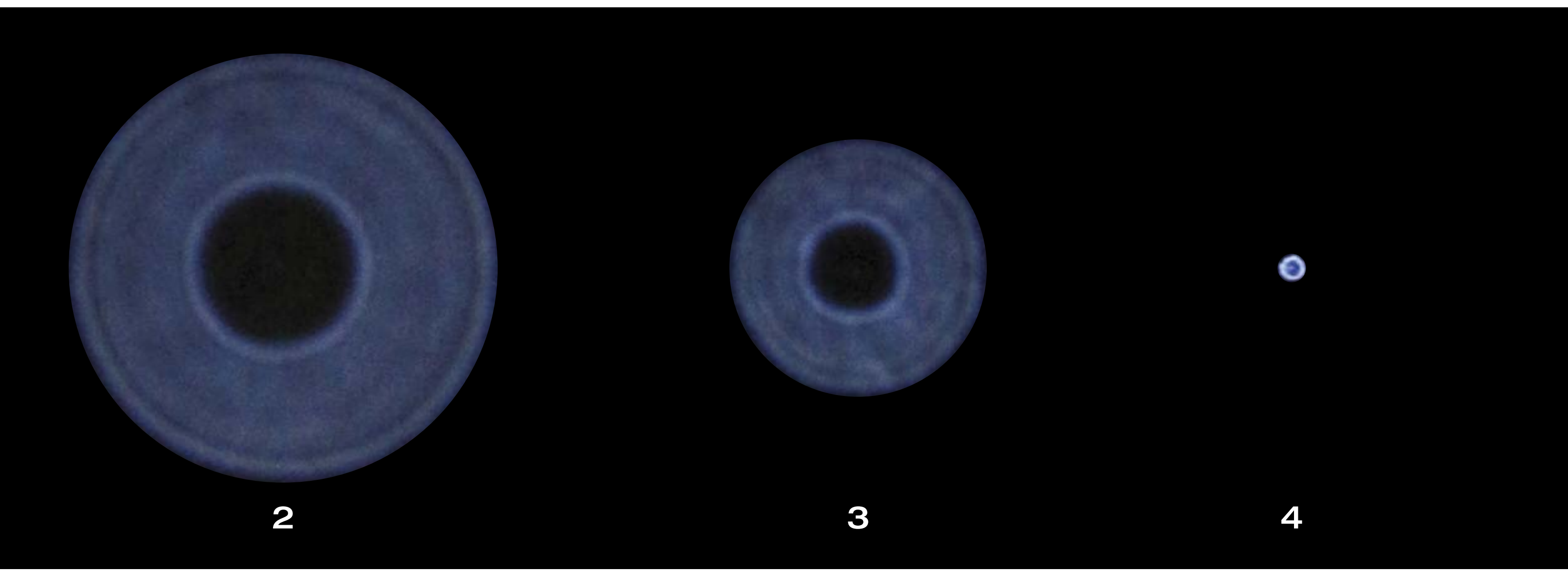


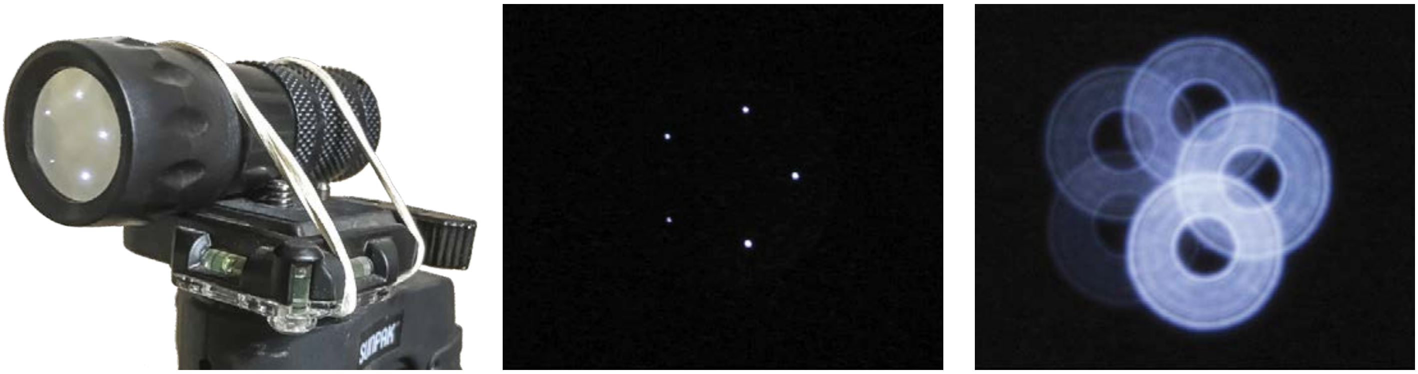
◀ **WHICH WAY TO TURN** This chart shows the direction to turn each of the secondary mirror cell's three collimation screws when viewing straight through the instrument. The center illustration shows how the screws are labelled, with A being the one closest to the ground. For example, if the secondary shadow is offset upwards in the eyepiece, turn knob A counter-clockwise to center it.

Fine Adjustments

So how do you adjust the SCT's secondary mirror? On most modern SCTs and their newer variants (including Celestron's EdgeHD and Meade's Advanced Coma-Free optics), adjust the optical alignment via three hex-head (Allen-head) or Phillips-head screws located on the secondary mount in the center of the corrector plate. (Some older scopes have a snap-on cover over the screws, while more recent models use a three-bladed cover that rotates to expose the collimation screws.) The screws are spaced 120° apart and threaded into the metal backing plate that the secondary mirror is affixed to. This backing plate has a central pivot so that tightening or loosening a screw changes the mirror's tilt slightly. If your SCT has a screw in the middle of the three collimation screws, this is the secondary support pivot and it's very important that you don't loosen it.

To identify which collimation screw to adjust, aim the telescope so that one screw is closest to the ground when





▲ **STARS ON DEMAND** The Hubble Optics 5-Star Artificial Star is as small as a pocket flashlight and is easily affixed to a tripod with a rubber band for positioning in front of the telescope at the appropriate distance *(left)*. It produces five points of light with increasing brightness levels *(seen at center and right)*. Unused stars are then covered with an included magnet (not shown).

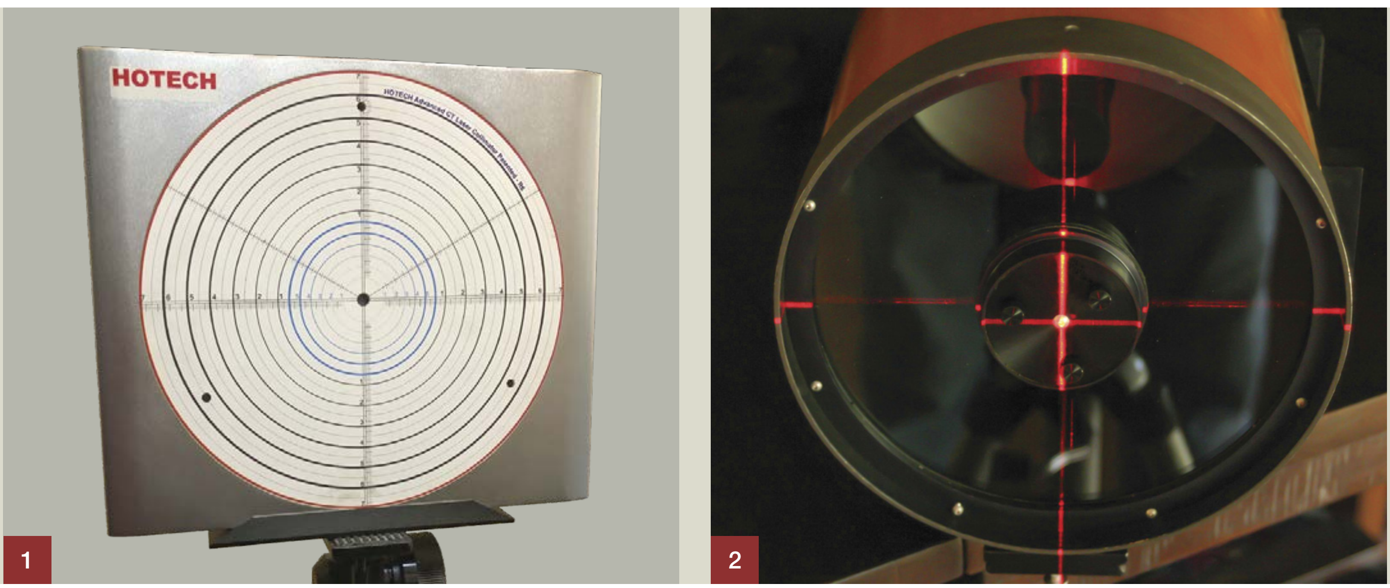
viewing the corrector plate from the front. Orient the star diagonal (if used) so that the eyepiece is pointed upward, opposite the lower collimation screw. Install a high-power eyepiece and center a moderately bright star. Polaris is a good target star because its location near the celestial pole ensures it remains in view without the need of motorized tracking.

Let's start by establishing coarse alignment. Insert an eyepiece that produces about 150×. Defocus the target star so that it's enlarged to fill about ¼ the field of view. A collimated telescope will present a doughnut-like series of concentric circles surrounding the dark shadow of the secondary mirror (see previous page). If the dark doughnut hole appears offset from the center, a collimation adjustment is necessary. If the secondary shadow is offset toward the bottom, for instance, turn the bottom knob counterclockwise. If it's offset toward the top, turn the bottom knob clockwise.

It's important not to overtighten any of the screws. If you encounter resistance while tightening a collimation screw, slightly loosen the two other screws to permit the third screw to rotate. You have to maintain some tension on all three screws at the same time, however, which is why large adjustments are made in several small increments.

Most adjustments require only small movements of the collimation screw. The challenging part with bigger SCTs is to view the collimation target through the eyepiece while simultaneously adjusting the collimation screw. A team effort is often best. Have a friend tweak the collimation screws while you direct the adjustment from the eyepiece. An alternative is

▼ **LASER ALIGNMENT** *(1)* Hotech's Advanced CT Laser Collimator uses multiple laser beams, reflectors, and a precision target to align SCT optics. To help align the Hotech collimator with your telescope, laser crosses are projected into the telescope and reflected back to the collimator target. When the crosses are square with the front of the telescope *(2)* and the laser target (*3*), the collimator is aligned with the telescope optics and you can begin adjusting the secondary mirror. After centering the corrector plate in its cell, the middle laser-reflection doughnut should fall in the center of the collimator target. When the secondary is properly adjusted, the three laser reflections will land within the same outer concentric ring *(4)*.



to attach a small camera (such as those used for planetary imaging) to view the star image on a laptop or tablet as you make adjustments. The star will shift as each collimation screw is adjusted. Simply nudge the scope to return the target star to the middle of the field before evaluating the doughnut's symmetry after each correction.

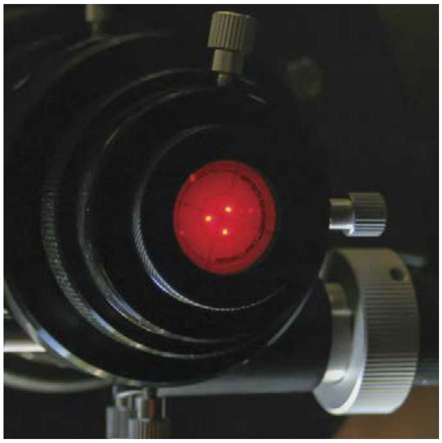
Once the doughnut appears concentric, switch to higher magnification and re-focus the star until the doughnut is as small as you can make it while still leaving the secondary shadow visible. Now make small adjustments until the concentric rings within the star's diffraction pattern are centered. This requires stable seeing conditions, which can be rare.

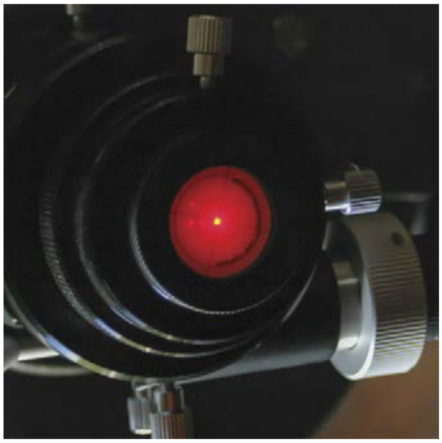
Some find collimation with wrenches or screwdrivers tedious. Worse, such tools have the potential to be accidentally dropped onto the corrector plate. A popular aftermarket accessory is knurled knobs that you can adjust with your fingers, offered by Bob's Knobs (**bobsknobs.com**). Installing them requires replacing one screw at a time. I find it easiest to aim the scope at a distant object on the horizon, replace a screw with a knob and tighten it until the horizon target is centered again, then repeat the process for the other two screws.

Collimation with Artificial Stars and Lasers

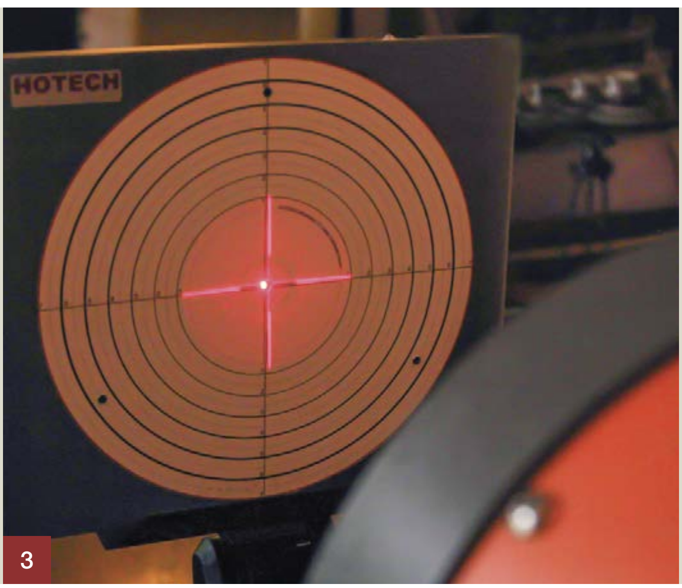
When extended cloudy periods or poor seeing prevent you from collimating with a real star, an artificial star allows you to perform the task under controlled circumstances. The simplest approach is to add pinholes to a sheet of aluminum foil placed over a flashlight to create an artificial star. The pinhole's size matters: The pinhole needs to be large enough for you to see during daylight, but if it's too big then the "star" becomes too blurry to use effectively. It can take some trial and error to make a satisfactory one.

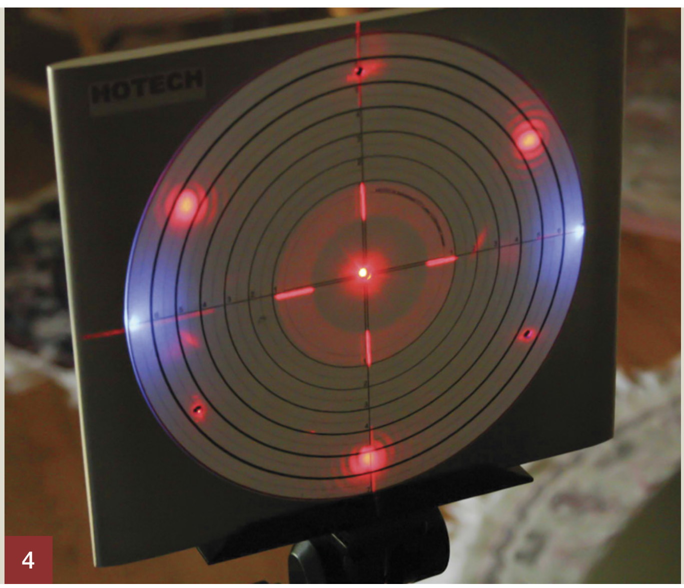
Some artificial stars, like the Hubble Optics 5-Star model (see **hubble-optics.com**), include multiple apertures so that you can choose the one that's bright enough for your conditions. These small, battery-operated artificial stars are easy to use — I simply strap it to a tripod with rubber bands, turn it on, and aim it at the telescope. But like with any high-power view, the thermal effects of hot asphalt or other objects radiating heat will distort the star image. That's why aiming over grass or shaded ground is best. A simple, ballpark tip for determining the minimum distance to the artificial star is to position it at a distance in meters that's about equal to the telescope's aperture in centimeters. For example, an 8-inch (20 cm) f/10 SCT needs the artificial star to be roughly 20 meters (66 feet) from the front of the telescope. Any closer and you're at the end of





◀ **FINAL CHECK** The Hotech collimator's semi-transparent window is shown here installed in a SCT visual back. Turning the telescope focus knob merges the three laser dots. If they meet in the center of the reticule *(below)*, then the mechanical and optical axes of the telescope are perfectly aligned.





the primary mirror's travel range and at the mercy of the OTA's mechanics.

Due to the folded optical path of an SCT, a standard, single-laser collimator won't work for aligning its mirrors. A better option is the Hotech Advanced CT Laser Collimator (available at **hotechusa.com**), which allows an optical-bench-like approach to collimation. The device shines four low-intensity lasers into the SCT to enable collimation and alignment. It takes some time to level this tripod-mounted collimator and to square the lasers with the scope's optics, but the collimator uses a clever system of projected crosses to aid in the process.

A partially silvered, semitransparent reflector is provided with the Hotech collimator that's installed in the visual back of the OTA. This reflector serves two purposes: It provides a target reticle to ensure the optical axis is aligned with the telescope's mechanical axis, and it reflects the lasers back to the collimator's target screen.

The laser target screen has both a cross-shaped reticule for aligning the collimator with the telescope and large, concentric rings to help center the secondary mirror. You can tell the secondary is aligned when the three alignment laser reflections hit the target within the same set of concentric rings. Additionally, a solid illuminated doughnut appears in the middle of the target. If the doughnut sits at the center of the concentric rings, the radial alignment of the corrector plate is satisfactory. Turning the focus knob merges all three laser spots on the reflector installed in the visual back. If they overlay the center of the reflector's reticule, the optical and mechanical axes are parallel. This method is especially useful if at some point the corrector plate was removed from your scope.

Cleaning SCT Optics

A Schmidt-Cassegrain's corrector plate is a huge piece of glass at the front of the telescope that will, in time, accumulate dust and pollen. However, dust on a corrector plate has very little perceptible effect on the sharpness of the focused image. Rather, significant dust causes scattering which in turn reduces contrast in the views through the scope. Grease or fingerprints on the corrector also scatter a significant amount light and degrade the image at the eyepiece. To clean the plate, Celestron recommends using a 50/50 solution of distilled water and isopropyl alcohol, applied with a clean, white, unscented tissue and very little pressure. Dampen your tissue with this solution and use straight, radial strokes sweeping away from the secondary mirror while slowly turning to the tissue to lift the dirt and avoid dragging it across the glass. Use a folded soft, clean paper towel to blot any remaining droplets off of the corrector.

Observatory-housed telescopes can become hot in the summertime. The heat's effect on telescope optics can be

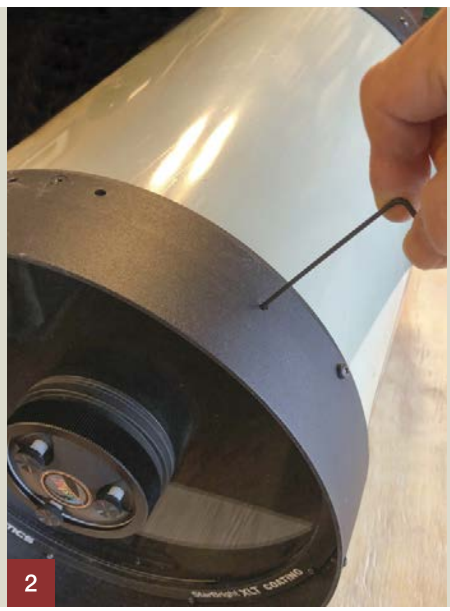
▲ **TOOL-FREE COLLIMATION** Replacing the stock collimation screws with ones from Bob's Knobs enables tool-free collimation adjustment of a Schmidt-Cassegrain secondary.

▶ **ADVANCED MAINTENANCE** *1:* The corrector plate in most SCTs is held in place by a retainer ring secured with small Phillips- or hex-head screws.

▶ **FINE CENTERING** *2:* Recent Celestron SCTs use four screws to laterally position the corrector plate. Back each screw out exactly two turns so they can be returned to their original position during reassembly. Note that the screws are in direct contact with the corrector plate and can shatter the optic if over-tightened.

▶ **LIFTING OUT** *3:* After loosening the corrector plate's centering screws and removing the front retainer ring, the corrector plate can be lifted out of its cell by grasping the secondary mirror cell.

▶ **ROTATIONAL ALIGNMENT** Although the corrector is marked along its edge *(4),* place a bit of masking tape with a mark along the edge of the corrector and the cell, then use a razor to slice the tape along the gap *(5).*



likened to the inside of an automobile windshield that eventually becomes hazed by deposits baked out of the plastic and upholstery in the car. Similarly, long exposure to heat will eventually outgas material from lubricants and paint inside the telescope and fog up the inside of the corrector plate. Clean this in the same manner as the outside of the corrector, but first, you'll need to remove the corrector plate from the telescope. This requires some precautions to ensure the corrector is reinstalled in precisely the same position.

If you need to remove the corrector plate, understand that it was installed at a specific rotational angle to best correct the spherical aberration in the telescope's mirrors. Usually, the edge of the corrector is marked, and a corresponding mark is placed on the edge of the primary mirror during telescope assembly at the factory. But often the primary mirror mark isn't visible from the front of the telescope. If you need to remove your corrector, you should place a bit of masking tape along the edge of the corrector and the cell and mark its middle. You then use a razor to slice the tape in the seam between the corrector and the cell.

On older Meade and Celestron SCTs, the corrector plate is held in place by a retaining ring secured with small screws. It's centered in its cell by thin cardboard or cork shims. Be sure to mark their locations to ensure they are returned to their original positions. Then carefully grasp the secondary mirror holder and slowly lift the corrector out of its cell.

Celestron made two major changes to their SCT OTAs over the years. The one that impacts the removal of the corrector plate came in 2009, when the company introduced the EdgeHD variant of the SCT. The EdgeHD series added a field corrector installed near the visual back of the OTA, making centering of the corrector plate more critical; four recessed, hex-head screws have replaced the spacers around the perimeter of the plate's cell to permit fine adjustments. Since then, all Celectron SCTs have included centering screws, so it's important to loosen them before removing the corrector. To retain the precise centering of the corrector, back each screw out exactly two turns. Upon reassembly, sequentially tighten the screws exactly two turns to return the corrector to its original placement. (Be careful not to overtighten them, as they press directly on the edge of corrector itself.) After reinstallation, you'll need to collimate the telescope.

▲ **CORRECTOR CLEANING** Manufacturers recommend a 50/50 mixture of distilled water and isopropyl alcohol to clean the secondary mirror if necessary. Use a clean, unscented tissue and very little pressure to make radial sweeps from the corrector outward while turning the cloth to avoid sleeking the coatings with debris embedded in the tissue.

An SCT is a marvel of optical engineering and capable of providing a lifetime of enjoyment. With periodic collimation and cleaning, you can be sure your scope will always deliver its best views of the skies above.

■ **ROBERT REEVES** is the author of *Photographic Atlas of the Moon: A Comprehensive Guide for the Amateur Astronomer*, available on **amazon.com**.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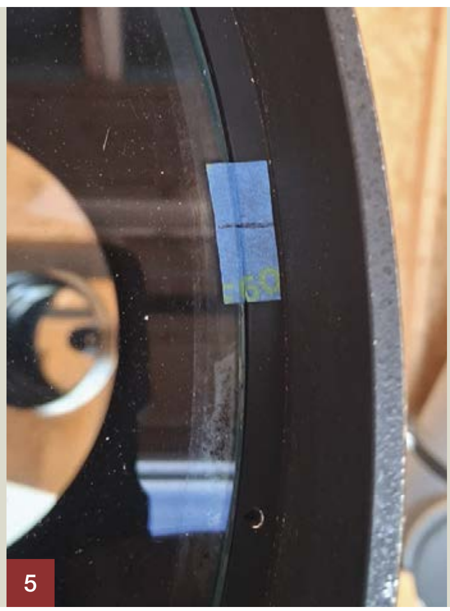
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The Heliostar 76 Solar Telescope

Sky-Watcher's little refractor promises fantastic views of the chromosphere. Does it deliver?

▲ Sky-Watcher's Heliostar 76 H-Alpha Solar Telescope is shown here with the optional SolarQuest mount.

WE'RE JUST PAST the peak of the Sun's 11-year activity cycle, and it's still putting on a great show every day. This is especially true if you have a solar telescope specifically designed to pass the hydrogen-alpha (Hα) wavelength, where highly dynamic activity in the chromosphere is visible. Telescopes equipped to view this narrow sliver of the solar spectrum (centered on 656.3 nanometers) reveal prominences and spicules along the solar limb as well as dark filaments, plage, sunspots, and bright flares.

In November of 2024, Sky-Watcher announced a series of dedicated Hα solar telescopes, unveiling the first model, the Heliostar 76 at the Northeast Astronomy Forum (NEAF). There I arranged to borrow one along with its SolarQuest mount for this review.

A Complete Solar Package

The Heliostar 76 and SolarQuest mount arrived in three boxes: one with the scope and accessories, another with the mount head, and the last containing the tripod. The scope itself was inside a hard-sided, foam-lined carry case that also had cutouts to accommodate the included accessories. The telescope is a 76-mm aperture, f/8.3 refractor measuring 61 centimeters long (24 inches) and weighing 3.8 kg (8.4 lbs). Included in the package is a 1¼-inch-format 90° diagonal with an integrated blocking filter, a 2-inch-to-1¼-inch eyepiece adapter, hinged aluminum tube rings, a carry handle with built-in solar finder, a Vixen-style dovetail mounting bar, 20-mm eyepiece, smartphone adapter, and a very handy clip-on sunshade.

The objective lens is covered by a full-aperture energy-rejection filter so you can't simply look down the tube to see what's going on inside. The scope includes a 2-inch, dual-speed Crayford-style focuser. The diagonal/blocking filter unit is inserted into the focuser and secured with two thumbscrews. Because the diagonal contains an 11.5-mm aperture blocking filter that's an integral part of the solar filter, the system will not work using a standard prism or mirror diagonal. Eyepieces and cameras are secured with a compression ring that won't scratch their barrels.

The Heliostar 76's light and fairly short tube makes it a good match for most lightweight telescope mounts and an excellent match for the SolarQuest Mount. This mount is a small, alt-azimuth unit with motorized drives and can work with any telescope weighing up to 5 kg and fitted with a Vixen-style dovetail bar. Think of it as a Go To system designed to find and track a single target. The mount sits atop an included adjustable aluminum tripod with 1¼-inch diameter legs and a 12-inch extension pier (only needed if necessary). On the inner side of the altitude axis is a small sensor that locks onto the Sun, allowing the mount to track it all day long. The mount is powered by eight AA batteries or via an included 12-volt adapter. A small, 8-position control on the back of the head lets you fine-

▶ The telescope's objective is covered by a full-aperture, energy-rejection filter that prevents dangerous ultraviolet and infrared wavelengths from entering the etalon and damaging its components.

ALL IMAGES ARE BY THE AUTHOR

Heliostar 76mm H-Alpha Solar Telescope

U.S. Price: $3,395.00, $3,895 for kit with SolarQuest mount*
skywatcherusa.com

What We Like

Excellent contrast and image brightness

Simple etalon adjustments

Integrated solar finder

What We Don't Like

Imaging through the diagonal blocking filter

**Prices subject to change*

▲ The Heliostar 76 optical tube assembly comes equipped with hinged tube rings attached to a Vixen-style mounting bar. Also included are a solar finder, a 2-inch-to-1¼-inch eyepiece adapter, 20-mm eyepiece, clip-on Sun shield, mobile phone bracket, and a hard-shelled case.

tune the pointing or scroll across the solar disk when shooting mosaics.

Etalons and Contrast

Sky-Watcher's Heliostar 76 uses an etalon-based solar filter (called Solis Etalon Technology) that doesn't require external power to operate like some narrowband solar filters. There are three main components in this system. The first is an *energy-rejection filter* located in front of the objective lens. This blocks infrared and ultraviolet light from entering the telescope that would otherwise quickly heat up and destroy internal parts (not to mention your vision).

The second component is the *etalon*, a sort of ultra-narrowband filter that does the bulk of the work constricting the bandpass to less than a single wavelength. The etalon exploits interference between two precisely spaced optical surfaces to achieve this. Etalons pass other light besides Hα, so a third and final component, the *blocking filter*, is needed to ensure only the desired wavelengths reach the eyepiece.

The total width of the bandpass in a solar Hα filter is important because the narrower it is the higher the contrast in the views it produces. A single etalon typically passes 1 nanometer or less, which is sufficient to reveal solar prominences and *spicules* — fine, hairy looking features seen along the limb of the Sun. Some solar telescope vendors offer "double-stack" options that combine a pair of etalons to narrow the bandpass further, say, from 1 to 0.5 nanometers. This dramatically improves views of the chromosphere across the entire solar disk, revealing *filaments* (prominences that are in front of the Sun) as well as plages, active regions, and flare events. In short, the narrower the bandpass, the better the view. However, the drawback is a substantially dimmer solar image — prominences become difficult to view simply because they are the dimmest features.

According to Sky-Watcher, what sets the Heliostar 76 apart from other solar telescopes is their Solis Etalon Technology, which boasts the contrast performance of a double-stacked filter but with a single etalon. If true, testing should show a bright image with great contrast on both the chromosphere and limb features (spoiler alert: It did).

Under the Sun

The Heliostar 76 was extremely easy to use, particularly when paired with the SolarQuest mount. Simply affix the scope to the mount and flip on the power switch. Using its built-in GPS and HelioFind auto-alignment, the mount levels the scope, then slews toward the Sun in about a minute. Although the Sun wasn't always placed in the 2.2° field of the included eyepiece, it was usually very close. This wasn't a problem as the Heliostar's integrated solar finder made centering nearly effortless. Sunlight passes through a tiny aperture producing a bright dot projected onto a small, frosted screen. You then center the tiny Sun by moving the mount with its multi-axis control. The finder was very well collimated, too — the Sun was almost dead center in the eyepiece field

▼ *Left:* Tuning the etalon is achieved with the silver Trifid Tuner lever in the middle of the tube between the two tube rings. *Middle:* The 1¼-inch-format, 90° diagonal contains an 11.5-mm blocking filter, which is an integral part of the filtering system. *Right:* The scope includes a 2-inch, dual-speed Crayford-style focuser with 1¼-inch eyepiece adapter that firmly holds focus with a variety of eyepieces and cameras.

▲ A clever solar finder comes attached to the carry handle that bridges the tops of the tube rings. It works by projecting a small image of the Sun onto a frosted screen. The disk is visible from the focuser end of the scope *(right)* or when standing aside the objective lens *(left)*.

of view when placed in the middle of the finder target. After centering, the SolarQuest would track the Sun as long as I was observing.

The 20-mm, 70° apparent-field-of-view eyepiece that comes with the Heliostar 76 yields a magnification of 31.5× and shows the entire solar disk. I also used some of my own eyepieces to zoom in more and see what this scope can really do.

Once you have focused the Sun's image, you typically need to also adjust the Trifid Tuner to find the setting that produces the highest contrast. This adjustment is accomplished with the lever located at the midpoint of the tube. The Trifid Tuner is so named because it uses three support vanes to apply pressure on the two plates that make up the etalon. Changing the spacing between these plates tunes the etalon to the precise wavelength of light we want. Like focusing, it's easy to see the effects immediately when tuning the image. Simply move the lever until you see the most contrasty details on the solar disk. When tuning, I noticed that the bandpass was uneven across the field of view — the area near the center had the highest contrast. For best results, I centered the Sun in the eyepiece and tuned the Trifid lever.

And what a view it is when tuned in! I'm no stranger to solar telescopes, having used many Coronado, Lunt, and Daystar models over the years. Despite this, I've never seen such a well-defined solar disk with so much contrast. Prominences were bright protuberances, while filaments were rendered as dark swatches and squiggles snaking across the solar disk. The Solis Etalon produced such a bright, contrasty image that I feel the 0.5-nanometer bandpass specification given by Sky-Watcher may be a bit conservative, especially when I compared it side by side with other instruments that were also rated at 0.5 nanometers.

I used a variety of eyepieces to examine the Sun and found the higher-magnification views equally stunning. With my 10-mm Takahashi LE eyepiece, which produces 63× in the Heliostar scope, the entire solar disk ringed with prominences completely filled the field of view. The background sky was dark, if not black, and without distracting glare. I pushed the magnification up to 126× with a 5-mm Takahashi LE eyepiece, and the filaments in the penumbra of sunspots began to resolve. Beyond this magnification, however, the image simply became larger and softer, likely due to both the scope's aperture and my location's often less-than-perfect seeing. Bear in mind that the Sun is a large target, so magnifications above about 100× reveals an amazing amount of detail.

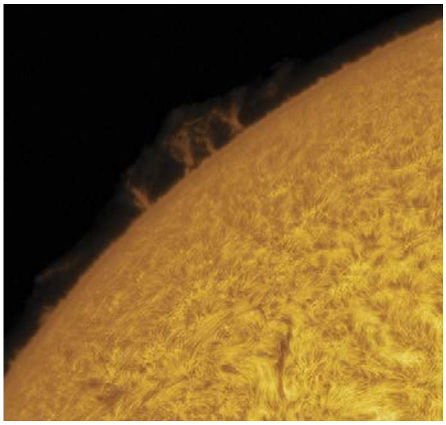
Sky-Watcher helpfully includes a clip-on blocker to shade the observer's eyes from direct sunlight while looking into the eyepiece.

Photography with the Heliostar

Capturing solar images with the Heliostar was also a breeze. I first took a few quick snaps with my iPhone using the included smartphone adapter. This device clamps directly to the included eyepiece and has a simple armature to correctly position most smartphone cameras. (The clamp area appears to be designed specifically for the included eyepiece, so it may not work with other oculars having wider tops or tapered bodies.) The device works as expected, placing my phone's camera lens as close to the eyepiece lens as possible. However, color images of the Sun in Hα taken with a phone (or any color camera) appear blazing pink and need a bit of post-processing to have as much contrast as you see visually.

For serious solar imaging I suggest using a dedicated monochrome camera. Such cameras are small and come with 1¼-inch nosepieces that slide easily into the diagonal. I used two monochrome cameras from Player One Astronomy with the scope: an Apollo-M MAX and the Ares-M. Both easily captured the solar disk and prominences in their entirety. Small sensors work quite well on the Heliostar 76, as the solar disk spans just 6 mm across at the focal plane.

To resolve smaller features like spiculae or the filamentary structures in the penumbra of sunspots, I used a Tele Vue 3× Barlow in front of the camera. It did its job, though it made for a spindly setup while the camera is raised high above the diagonal filter. This configuration would be especially awkward if the scope were on an equatorial mount instead. I also tried imaging with the Powermate in front of the diagonal blocking filter, but the 11.5-mm aperture of the filter introduces significant vignetting into the images. For imaging, a straight-through arrangement would be more compact and much less susceptible to wind-induced vibration. Hopefully Sky-Watcher will make a blocking filter that allows a straight-through setup in the future.



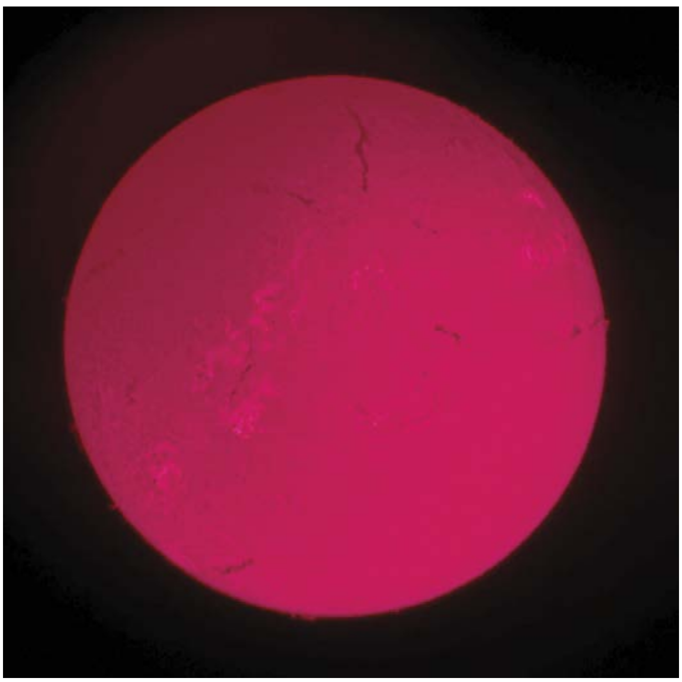
▲ Images taken through the Heliostar 76 didn't require non-linear stretching to make the prominences visible. This photo was recorded with a 2× Tele Vue Powermate and Player One Ares-M camera.

Despite this minor limitation, the Heliostar 76 really does shine as a solar imaging platform. The bright image from that single etalon and the very narrow bandpass produce results that are surprisingly easy to process. My first reaction to seeing spicules, filaments, plages *and* large, bright prominences together onscreen was disbelief. How can I be seeing so much detail in both the chromosphere and the prominences at the same time? The answer of course is the instrument's incredibly narrow passband. I did some side-by-side testing against a similarly sized scope with a comparable filter, and the Heliostar image was far brighter and just as contrasty. This permitted much shorter exposures, which led to sharper images overall.

Sky-Watcher may be new to the Hα solar telescope market, but this instrument shows they did their homework and could become a major contender in this niche of the hobby. The Heliostar 76 delivers on its promises and produces the best images of the chromosphere that I have ever observed or photographed. Highly recommended.

■ Contributing Editor **RICHARD S. WRIGHT, JR.** generally likes to stay out of the Sun. He'll make an exception for stunning views of the chromosphere.

▼ *Left:* An adapter is included to aid in taking photos through the eyepiece with a smartphone. The bracket worked well with the author's iPhone 14 Pro, though it was hard to avoid reflections (seen at top left). *Right:* The image contrast and brightness produced by the Heliostar 76 make it easy to get amazing disk detail as well as prominences in the same exposure with a planetary camera, like this image recorded on April 19, 2025, with a Player One Apollo-M camera.



Why Doesn't It Look Like the Picture?

IT'S LIKELY THE FIRST question people ask after looking through a telescope at anything besides the Moon and maybe the planets: Why doesn't the view look like the pictures I see in magazines, on websites, or in social media posts? The reason is simple, really: Our eyes function quite differently than cameras do.

The human eye reacts to light instantaneously, whereas a camera is a digital detector that's designed to accumulate light over an extended period of time. This allows photographs to reveal colors and details too faint for the eye to see. And most everything in the night sky except the Moon, planets, and brightest stars are simply too faint to register as more than a feeble glow on your retina, even with the aid of a telescope. Aside from this handful of targets, everything else is too dim to activate the color-sensitive cones in your eyes. This makes objects appear as varying shades of gray.

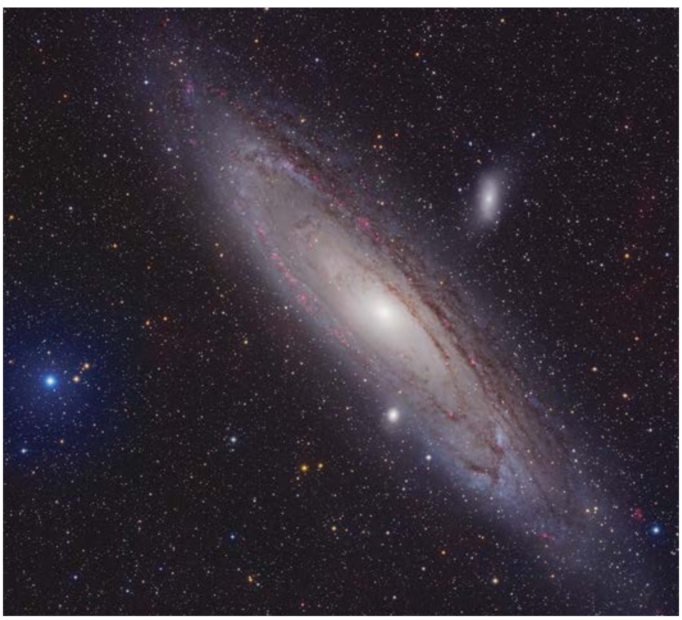
Pictures of nebulae, star fields, and galaxies are largely the photographer's interpretations of a set of data, because we can't actually see those colors with our eyes. However, that doesn't mean the photos are the product of imagination. While the image is informed by the levels of the signal recorded through each color filter on the camera's digital sensor, astro-imagers often try to approximate what the target would look like if we had eyes sensitive enough that we really *could* see it in color.

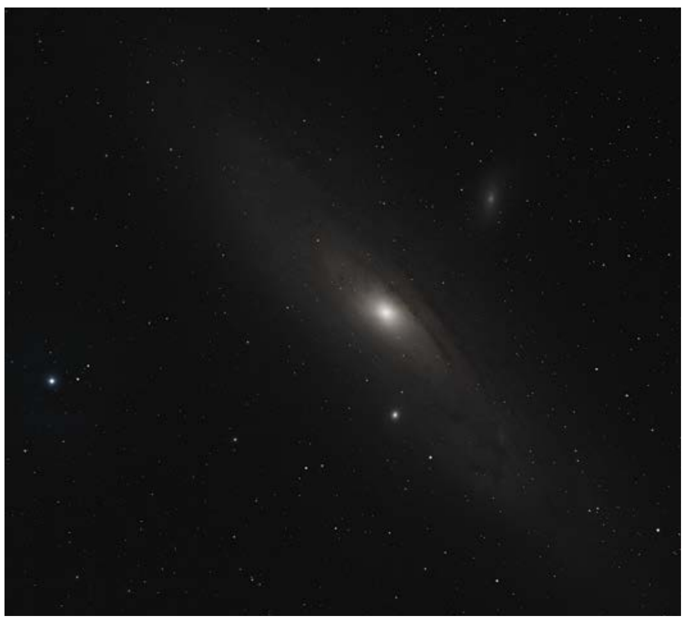
To make matters worse, not only does a camera accumulate light differently than your eyes do, but the devices we use to view the resulting pictures lack the *dynamic range* (the range of brightness between black and white) necessary to accurately display the image. To overcome this, images require additional processing to compress the brightness range to match the capabilities of the display media, be that a computer screen or a print. This is why the 10-minute exposure of M31 you took looks almost completely black save for the very core of the galaxy and a few foreground stars. Our remarkable eye-brain combination has far greater dynamic range than any of today's technology.

There are some cases, though, where other considerations override reality in order for an image to convey specific information. Narrowband photos of nebulosity are one example. These are recorded through filters that isolate several specific regions of the spectrum where certain gases fluoresce. Color images assembled using these data show the gases in the Milky Way as if painted with every color in the spectrum. And while they don't show an object's true appearance, the hues are meant to highlight differences in the chemical composition of the gases. This type of *representational color* is also known as "false color."

Given all this, it's tempting to ask why anyone would bother to look through a telescope at all. The answer is likely to be personal. I do it for the direct connection I get from the experience. Nothing compares to the satisfaction of being able to see a galaxy that's tens of millions of light-years away with my own eyes in real time. And I can even use some of those dazzling photos to identify parts of it! Sure, the view isn't like the photo. But it doesn't have to be. ■

▼ **DIFFERING VIEWS** These images of M31 show the galaxy as a deep astrophotograph *(left)* as well as a version that simulates the author's view through a 4-inch telescope *(right)*.





SEAN WALKER / *S&T* (2)

The Rigid Shroud

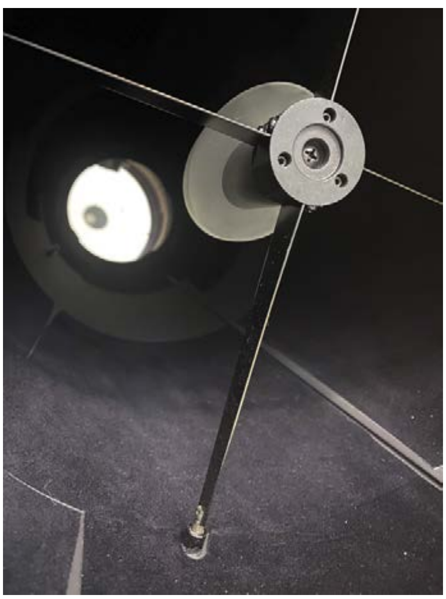
Contrast critical: The importance of controlling stray light.

▲ Lauren's Orion SkyQuest XT10i Intelliscope with a few prominent modifications visible.

ON A DARK FIELD in Oregon, two observers trade views. Lauren Wingert, whose work has graced this column several times over the years, told me about a friendly "shoot-out," as she put it, between a pair of 10-inch (250-mm) Newtonians.

In one corner, we have Lauren with her heavily modified scope. We'll talk about her extensive modifications to her commercial Dobsonian (an Orion SkyQuest XT10i Intelliscope) in a later article. But for now, know that it's been heavily optimized for arresting stray light — and that the tweaks here are applicable to reflectors of any aperture.

Also on the field is my predecessor, Jerry Oltion. He's observing with his famed trackball telescope. Jerry's optical tube assembly is built in an open-truss configuration, around a handmade mirror — two sharp departures from the XT10i. They compared many objects, finding in each case that Lauren's telescope delivered a better deep-sky view.



▲ The dark interior of Lauren's XT10i Intelliscope — note that the gaps in the flocking show how much darker her finish is compared to the original paint.

"We were both a little surprised," Lauren explains, that the views in her scope were both noticeably brighter and displayed better contrast.

I've observed similar results myself. In the shadow of the Green Bank Telescope in West Virginia, a certain 10-inch outperformed a 12-inch reflector. The 10-inch was a long-focal-length handmade mirror with a solid, fully enclosed OTA, its interior obsessively blackened and flocked. The 12-inch is a truss scope, with modest stray-light optimization. The result? Views of M51, the Whirlpool Galaxy, appeared on a different level in the solid-tube scope, with clear spirals and tidal warping visible in the eyepiece.

When observing, two kinds of stray light are of concern. Any amount of light that isn't from space will dilute the signal-to-noise ratio of our view. This is true even at very dark star parties, as Lauren found.

First is incident light, which is obvious. Imagine a cone of light projected through your eyepiece's field stop and the focuser's edge — if the focuser catches any light shining directly on a surface, that light mixes straight into our view. Worse yet is if this area contains an actual light source. (I fell victim to this at a star party, forgetting my plastic baffle at home. The dim, red LEDs adorning all the imaging rigs around me easily washed out my deep-sky views; I fixed this by stretching a black garbage bag over the upper cage assembly.)

Second, and sneakier, is diffuse light. Little can be done about the light pollution passing straight into the objective, but diffuse sky glow also hits the tube walls, and any exposed interior surface. This light is then scattered by diffuse reflection. If it isn't prevented, some of this light will also make its way into the image, further reducing contrast.

There are several ways to handle this. Blackened surfaces absorb more incident light, diffuse or not (though matte black scatters light and glossy black reflects it). Baffling, or interior rings with thin edges, reduce the amount of direct and diffuse light entering the tube. Flocking, on the other hand (typically made of dark, velvety material or gritty paint), tends to absorb diffuse light and is favored for darkening interiors.

Some observers swear by the darkened interior afforded by a solid tube. They often have larger cargo space to haul their scopes to dark-sky sites than those of us who stand firmly by our truss-tube Dobsonians. Others, regardless of tube configuration, swear by blackening everything — down to the backs of their mirrors and screw heads. The return on this investment is the subject of ongoing debate.

ALL IMAGES COURTESY OF LAUREN WINGERT

After the first scope showdown, Jerry remarked "Huh, flocking . . . who knew?" Later, the XT10i and the trackball had a rematch. This go-round, Jerry added a shroud and flocked all surfaces he could. Both observers agreed that this time, "the views between the two scopes were now virtually identical."

The importance of controlling both stray and diffuse light reiterated, Lauren had a new problem. Certain designs don't lend themselves to telescope shrouds (a six-pole truss, like the one I featured in my October column, comes to mind). Lauren has Mel Bartels's famed Zip Dob, an unfolding design in which an integrated azimuth bearing bridges the upper and lower assemblies (*S&T:* July 2021, p. 72). A typical shroud is untenable here, since it would overlap the bearing surfaces (and be pulled into the optical path near the struts).

Her solution came in the form of corrugated cardboard panels, sealed (and hinged) with duct tape, and lined on the inside with flocking material. She cut out a rough, oversized cardboard mockup for each panel, and then tested the fit and marked up the pieces. Once perfected, she used these as templates to cut out the final panels. Next, she covered the interior faces in flocking material, then sealed the exterior with duct tape to resist dew and create hinges.

This shroud fits perfectly around the cavity of the Zip Dob; it attaches with Velcro, and when not in use, folds flat for storage. Lauren shares that she "found the rigid shroud materials easy to work with and use with the scope and is a great solution for scopes that can't be wrapped."

■ Contributing Editor **JONATHAN KISSNER** is currently pricing out corrugated plastics and adhesive velvet.

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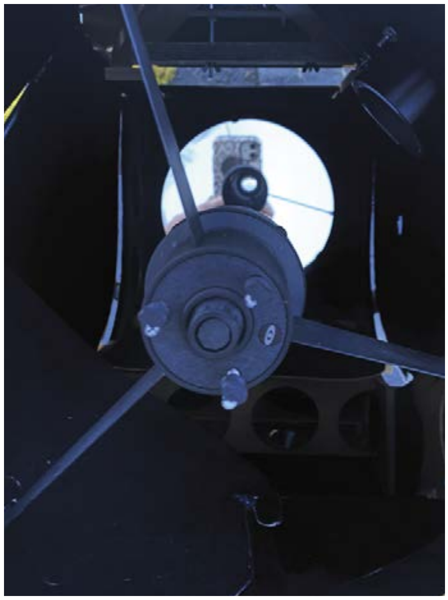

▲ *Left:* This photo shows off the interior darkness of the Zip Dob (under a bright daytime sky, no less) when the rigid shroud is installed. *Right:* The Zip Dob's spacious interior (and hard-to-baffle geometry) on full show.

▲ Lauren's solution for the Zip Dob is a custom-fitted, corrugated-plastic panel with flocking on the interior faces.

△ A RARE PASS

Jeff Phillips

Titan, Saturn's largest moon, casts its shadow on the planet's butterscotch cloudtops at 9:22 UT on the morning of August 19th. Dione is seen approaching the planet to the left of the narrow rings.

DETAILS: *Celestron C14 Schmidt-Cassegrain Telescope with ZWO ASI224MC camera. Stack of multiple video frames.*

◁ NEBULOUS PINCUSHION

Vikas Chander

Open star cluster NGC 3532 in Carina is the brightest cluster in the constellation and easily visible to the naked eye. This deep image reveals faint tendrils of hydrogen-alpha (Hα) nebulosity that permeate the region. South is up.

DETAILS: *PlaneWave CDK24 Corrected Dall-Kirkham telescope with Moravian C5A-100M camera. Total exposure: 4 hours, 13 minutes through LRGB and Hα filters.*

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Photographing Invisible Objects

Where exactly is the line between science and art?

HOW DO YOU TAKE realistic pictures of invisible objects?

I ask because many of us strive to make our astrophotos "realistic," yet we photograph things that no eye can ever see, even through telescopes or from outer space. Strictly speaking, we're attempting to reveal the invisible.

Does a typical picture of M31, the Andromeda Galaxy, show how the spiral "really looks"? No. The picture is much brighter and more colorful than the galaxy would be, even if you saw it up close.

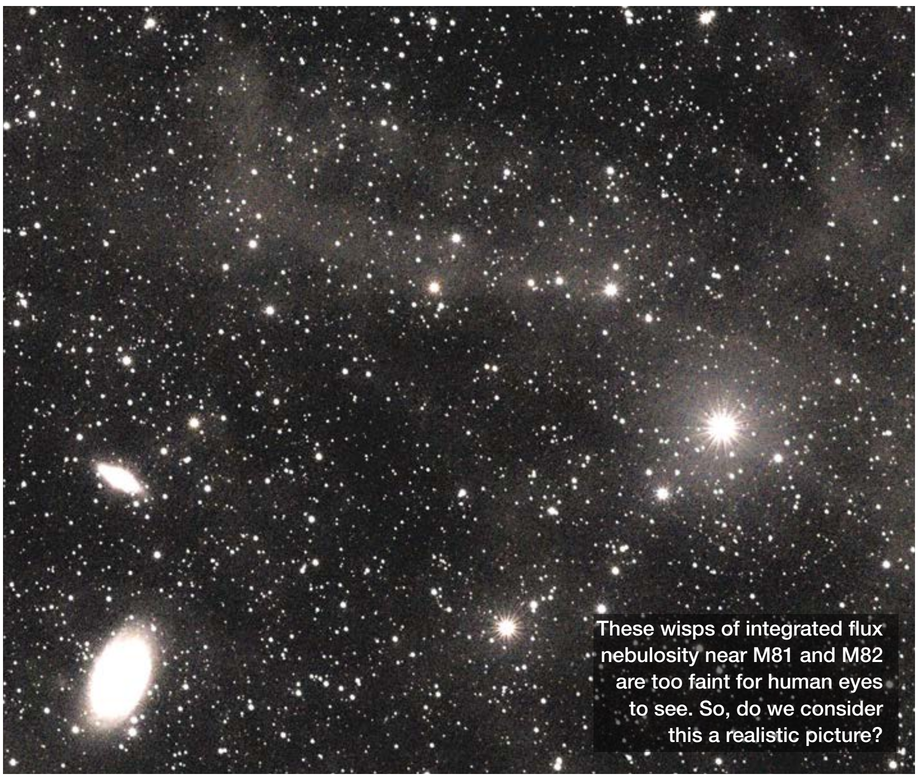
We often image objects that no eye can see — the human eye just can't detect the faint, delicate structures, colorful nebulae, and detailed dark lanes of deep-sky objects. The Horsehead Nebula that we've all admired in numerous photos is a great example — but it's barely visible in a telescope under ideal conditions. And take integrated flux nebulosity — human eyes don't see it (except for a few enigmatic reports over the years), but it's routinely photographed.

So how do we convince people that we aren't engaging in fakery when we "process" pictures to bring out things no eye ever saw?

The answer is that though our pictures can't show *what the eye would see,* they can still show *what is really there,* with nothing artificially added or removed. This is akin to medical X-rays revealing what's inside your body — but not in a way that it would look to human eyes.

I want to distinguish astrophotography from creative space art. The latter can be good art — like the fictional landscapes painted in the 1800s — but it must be judged by different criteria. It's not a scientific record.

That doesn't mean astrophotographers aren't artists. We frame, expose, and process our pictures to show the beauty of the sky. But we are like explorers photographing terrain. We trust Ansel Adams didn't rearrange the mountain peaks (with X-Acto knife and airbrush) when he photographed Yosemite Park. Likewise, we aim to show what is really out in space, within a specific brightness range and set of wavelengths.



These wisps of integrated flux nebulosity near M81 and M82 are too faint for human eyes to see. So, do we consider this a realistic picture?

MICHAEL COVINGTON

What types of image processing are legitimate, then, and what types are not?

In think the key is that the processing must work uniformly across the whole picture or automatically in response to measured characteristics of the image. The astrophotographer isn't free to take out particular stars or add nebulosity, but the overall settings will determine what types of objects are visible.

In my view, legitimate processing includes stacking, calibration (removing unwanted signal), adjusting color and contrast, and even sharpening. Gradient removal is riskier, since it might remove real nebulosity but is generally accepted and safe.

That leaves us with plenty of artistic decisions to make, and they will favor certain details in the picture rather than others. That's fine. That's where the artistry comes in.

What I don't feel is legitimate is adding or removing stars or nebulae, or even manually selecting regions of the picture to have different processing than the rest. When that's done, the picture no longer shows what was actually there. It may still be good art, or even good science. But it isn't really "real."

■ **MICHAEL COVINGTON** is the author *Digital SLR Astrophotography* and other books. By day he does artificial intelligence research in Athens, Georgia. The idea for this essay partly arose from fruitful conversations with Vicent Peris.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