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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JANUARY 2025

The TUMULTUOUS Lives of Galaxies

Page 12

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The Hickson Compact Group 40, in Hydra. Northeast is up.

PHOTO: NASA / ESA / STSCI / ALYSSA PAGAN (STSCI)

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Eclipse Prep

WHEN IT COMES TO upcoming solar eclipses, it can be hard to keep straight what kind is happening when and where.

Every year, between two and five solar eclipses occur. But for each event, are we talking a total, annular, partial, or hybrid solar eclipse? On average in any given year, the chance that any given eclipse will be total is about 26.7%, annular 33.2%, partial 35.3%, and hybrid 4.8% (figures from Fred Espenak's useful primer at **https://is.gd/SEprimer**).

But there's no easily grasped rhythm to which type happens at any given time or place. For example, while we had memorable total and annular eclipses in recent years, even a rare hybrid in April 2023, there are no total, annular, or hybrid solar eclipses in 2025 anywhere on the planet. This is disappointing to eclipse aficionados, who will go to almost any length to witness totality.

▲ Totality during the April 2024 total eclipse, as seen from Dardenelle, Arkansas

SEAN WALKER

There are two *partial* solar eclipses in 2025. But as the table on page 27 shows, there are no partials at all during the following six years, save for in 2029. And that year, as if to make up for the dearth, will feature *four* partial solar eclipses. Go figure.

Arguably as disheartening for eclipse lovers is the near-complete lack of totals, annulars, or hybrids in most of North America from 2026 through 2035. Have a look at the map on page 28. As you can see, the only non-partial solar eclipses during that 10-year period skirt the farthest fringes of the continent — in Greenland (2026), Panama (2031), and Alaska (2033). That's a far cry from the continent-crossing totals we enjoyed in 2017 and 2024.

To a layperson, it can all seem arbitrary, as though which type occurs where and when is just a roll of the celestial dice. Yet it's anything but. Nature's choreography of solar eclipses follows well-defined patterns (*S&T:* Jan. 2024, p. 60).

For the average person, though, keeping track of even the next few years' eclipses can leave your head spinning. Which is why Joe Rao's "Upcoming Solar Eclipses: 2025 to 2035" (page 26) is a welcome guide. It gives basics on the what-where-when for the entire decade-plus to help eclipse devotees prepare.

For as Rao notes, "It's never too early to begin planning your next eclipse adventure — or your first." If you'd like to share the experience with fellow eclipsophiles, see **skyandtelescope.org/tours**. There you'll find trips to view the 2026 and 2027 total eclipses as well as the 2025 partial in Greenland.

To all chasers of solar eclipses — of whatever type, territory, and time of year — here's to clear skies on the big day.

Peter

Editor in Chief

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▲ Joe Rao — see his eclipse feature on page 26 — proudly displays his souvenir T-shirt from his first solar eclipse in 1972 (left) and the replica gifted to him 52 years later (right).

Eclipse Chasers

For my very first total solar eclipse, my family and I journeyed to Cap-Chat, Quebec, in July 1972. While there, I picked up a T-shirt that commemorated the big celestial event in French.

This past April, as my wife, kids, and I headed for Plattsburgh, New York, for the total eclipse, my sister Lisa inquired as to what happened to my 1972 eclipse T-shirt. I had had it for maybe 10 years, then outgrew it, and *I think* our mom ultimately used it as an old rag or towel before finally tossing it . . . or maybe donating it to Goodwill.

Well, the other day, my wife and I drove to the Bronx to meet with Lisa at a restaurant to have a belated birthday brunch. After we finished our meals, she handed me a gift and said, "I think you're going to like this." It turns out that one of her friends is a graphic artist whom she asked to replicate the design of my original 1972 eclipse memento on a brand-new white T-shirt!

So, 52 years later, I am reunited with a facsimile souvenir of my very first totality. I even have the original badge from that event, which still adorns my "lucky" eclipse baseball cap (in which I've chased 14 eclipses, 12 successful).

What a great piece of nostalgia!

Joe Rao
New York, New York

I loved "Reports from the Shadow Path" by *S&T* Staff and Contributors (*S&T:* Aug. 2024, p. 62), especially the Texas entry, for that's where we ended up on April 8th. Texas was predicted to be the best location, which was the decider for our destination. (Also, it was the closest to our home in California.)

We rented a place on Lake Buchanan, about 50 miles northeast of Fredericksburg, which was mentioned in the article. Our experience was a near duplicate of the experience there, except that we saw all of totality — just barely. We consider ourselves very lucky to have ended up in the apparent sweet spot of the event, especially since pretty much everywhere else around us suffered one way or the other.

By the way, the next day it poured!

Kevin Clark
Via email

Observing in Comfort

As it's similar to the one described in "The Bucket-Seat Binocular Mount" by Jerry Oltion (*S&T:* Aug. 2024, p. 74), I am sure Jerry Oltion has heard of "The Couch-Potato Telescope" built by Sim Picheloup in the 1990s. In 1999, he had a display at the RTMC Astronomy Expo, and I had to have one. At that time, he sold plans and a kit with all the parts except the wood. I purchased a kit and assembled the telescope.

Twenty-five years later, I still use that original binocular chair! I now do more astrophotography than observing and enjoy scanning the sky with 10×50 Fujinon binoculars while my photo rig is in auto mode. At 79, the 10×50s are getting heavy for hand holding, but not for the Couch-Potato Telescope!

Binocular observing while riding a lazy Susan mount needs to be experienced at least once.

Ralph Ford
Redondo Beach, California

More Ways Than One?

In "The Challenging History of New Worlds" (*S&T:* Aug. 2024, p. 28), Christopher M. Graney points out that recent findings indicate great diversity of star systems and exoplanets. He also points out the low probability of the single-celled-organism merger that led to complex life on Earth.

This challenges the idea of life on other worlds, but some additional questions need to be asked. Is the primordial history of Earth and the solar system the only kind that can produce life? Are there additional routes to complex life? The universe has shown itself to be diverse. There is the possibility that the routes to life, complex life, and civilizations could be diverse as well.

We should keep an open mind and keep on exploring!

James W. Scott
Vernon, New Jersey

The Learning Curve

A clear message from the history of astronomy is how easy it is to be wrong. A great example comes to mind in Graney's article where he writes, "Pre-telescopic astronomers, from Ptolemy in the 2nd century to Tycho Brahe in the late 16th, repeatedly measured the apparent diameters of stars to be roughly 1/30 that of the Moon."

We now realize it is highly desirable to see if you get the same results when you measure things in at least two different ways. Had pre-telescopic astronomers realized this, they could have easily checked stellar diameters. The Moon takes about two minutes to move one arcminute against the background stars, so a naked-eye astronomer watching a star blink out instantaneously during a lunar occultation would have quickly realized that stellar angular diameters are considerably less than one arcsecond. This simple test makes it much more plausible that stars are suns.

Gerald Newsom
Columbus, Ohio

The Perseids Perform

I'm a huge fan of *Sky & Telescope*'s podcast (**https://is.gd/SKYpodcast**)! I eagerly look forward to the first of every month, when new episodes drop.

I'm 36, live in suburban New Jersey, and have a 6-inch Dobsonian to indulge in my hobby. But I had never witnessed a meteor shower in all these years. This year's Perseid shower was my first, and holy moly, did I get my mind blown!

My balcony faces north-northwest. I had a full view from Ursa Minor to Aquila, with Drago bang in the center.

I was craning my neck trying to locate Perseus. Then I remembered Kelly Beatty mentioning in the podcast that the appearance of the meteors radiating from Perseus is only a trick of perspective, whereas, in reality, they would be visible all over the sky.

There was a particularly bright red streak that will be forever engraved in my memory.

I have seen shooting stars before. But this was different. It was an incredible celestial event! I was extremely bummed that I couldn't see the aurora earlier this year, but this more than compensated for it.

I wanted to drop a note and say thanks to Kelly Beatty and everyone at *Sky & Telescope* for all the incredible work you do. The research that goes into every episode and the succinct narration is brilliant. It's like little nuggets of gold for stargazers who are just getting into the hobby — like me.

Keep up the good work! I wish you all clear skies!

Tiru Raghavan
Union, New Jersey

FOR THE RECORD

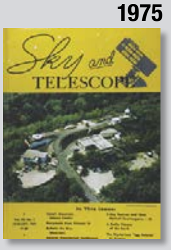
- In "Intermediate-mass Black Hole in Omega Centauri" (*S&T:* Nov. 2024, p. 9), the fastest stars in the cluster's center are moving at a projected velocity of 113 kilometers per second (250,000 mph).
- In "Wil Tirion, 1943–2024" (*S&T:* Nov. 2024, p. 10), the two volumes of *Uranometria 2000.0* were coauthored with Barry Rappaport and George Lovi.
- In "Portrait of a Supernova" (*S&T:* Nov. 2024, p. 12), in the light curve of SN 2023ixf, the visible filter is in blue and the blue filter is in green. Also, the date June 14 should read June 4.

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

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

1950

1975



2000

◖ January 1950

Seeing "Enrique Gaviola, of the National Astronomical Observatory at Cordoba, Argentina, has made an excellent beginning in the evaluation of photographic seeing [with a 60-inch reflector. The *sharpest* images] were several times larger than the theoretically expected values while the average diameters were 15 to 23 times larger. . . .

"Many years ago America's 'father of astrometry,' the late Frank Schlesinger, [noted that] star images wandered from their mean positions even during good seeing . . . Another aspect that Schlesinger discussed was the refraction of our atmosphere as a whole. He showed that all stellar images should be short spectra, vertical with the blue end nearer the zenith. . . .

"What, then, does Gaviola add? [He lists] three main characteristics of seeing: *dancing,* change of position; *pulsation,* change of size; *scintillation,* change of intensity."

Astronomers' early studies of bad seeing paved the way for today's adaptive optics.

◖ January 1975

Star Tracking "My telescope is an Edmund 4¼-inch reflector, equipped with a common $^1/_{15}$-r.p.m. synchronous motor. The polar axle turns at the solar tracking rate, [but] I became interested in astrophotography and decided I needed a variable-speed control, the kind that changes the frequency of the alternating current (a.c.) to the motor. I went to a friend back in school, electrical engineering graduate student Capt. James R. Harris, and we designed one. . . .

"The three integrated circuits (IC's), filament transformer, and other components are all easily obtained. By going mainly to surplus electronics stores, I held the overall cost of parts down to about $10, a fantastic saving over commercial speed controls."

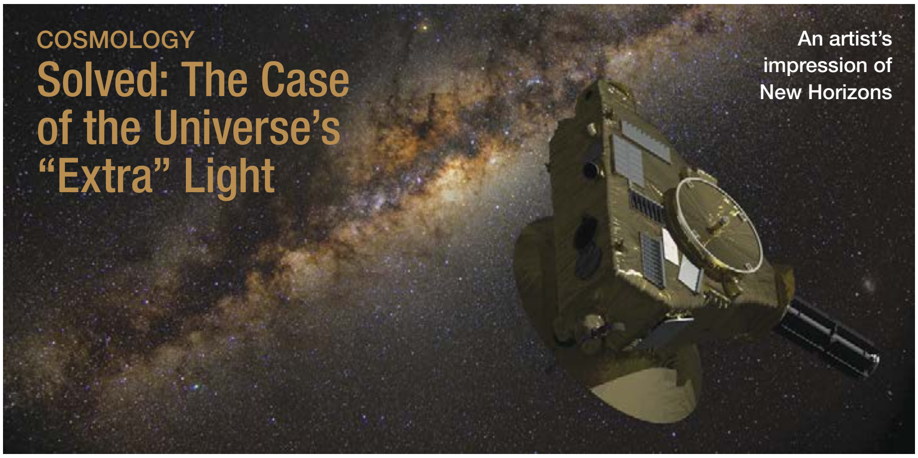
The advent of IC's and the ubiquity of Radio Shack stores were a godsend for hobbyists. The drive-control circuit of Capt. Vernon P. Saxon, Jr., rode that wave. I built one while editing his article and in a follow-up note told how to make the scope track at solar, lunar, sidereal, and guiding rates.

◖ January 2000

Water from Space "The 8,100 residents of Monahans, Texas, will forever remember March 22, 1998 — the day two fist-size meteorites plunked onto their town . . . One landed not far from seven children playing basketball. The stony chondrites soon made their way to the laboratories of NASA's Johnson Space Center, whose scientists found something amazing inside: microscopic droplets of liquid water. More remarkably, the droplets are trapped in purplish crystals of nearly pure salt (halite). . . . [Each] 4.6-billion-year-old meteorite has quite a story to tell. 'It takes a large body of water to make large halite crystals,' notes investigator Michael E. Zolensky . . ."

COSMOLOGY

Solved: The Case of the Universe's "Extra" Light



An artist's impression of New Horizons

USING NASA'S NEW HORIZONS, astronomers have shown that the faint, visible glow of apparently empty space is due to diffuse light from distant galaxies, with any "extra" due to dust-scattered starlight. The new result rules out the need for anything more exotic.

For decades, astronomers have been puzzled by the *cosmic optical background* (COB). This pervasive glow is somewhat analogous to the cosmic microwave background. But unlike the microwave background, which comes from radiation left over from the Big Bang, the visible-light background comes from other sources, such as distant stars and galaxies. Exactly which sources, though, has been difficult to ascertain (*S&T:* Oct. 2023, p. 24).

One of the biggest hindrances to measuring the COB from near Earth is *zodiacal light*, the diffuse glow of sunlight scattered off interplanetary dust. Enter New Horizons, the mission sent to the backwaters of the solar system to explore Pluto and the Kuiper Belt. At New Horizons' location 9 billion kilometers (5½ billion miles) from Earth, zodiacal light ceased to be an issue.

Yet the mystery remained: Marc Postman (Space Telescope Science Institute) and Tod Lauer (National Science Foundation's NOIRLab) led a team that used the Long Range Reconnaissance Imager (LORRI) aboard New Horizons to estimate the intensity of the COB light in 2021, and again in 2022. Even after accounting for other sources of background light (like scattered starlight), they found double the amount of radiation thought to be emitted by all the galaxies in the universe.

One potential explanation was that galactic censuses had missed a population of faint galaxies. Some even suggested more exotic options, such as *axions* — a hypothetical particle candidate for dark matter — which could decay into a litany of photons.

Now, it seems, we have the answer, and it's more prosaic than expected. Using new data from the European Space Agency's Planck satellite, the team estimated how much starlight scatters off of dust within our Milky Way Galaxy. By considering this effect, combined with new LORRI images designed to minimize interference from galactic dust, the astronomers can account for all of the COB.

"The results show that the great majority of visible light we receive from the universe was generated in galaxies," says Postman. "There is no evidence for significant levels of light produced by sources not presently known to astronomers." The result is published in the September 1st *Astrophysical Journal.*

Christopher Conselice (University of Manchester, UK), who wasn't on the team, thinks the results should hold up. He notes that some uncertainty remains because the amount of galactic dust is inferred rather than directly measured. "There remains the possibility that anomalous light could still exist, but it's unlikely," he says.

■ **COLIN STUART**

NASA / APL / SWRI / SERGE BRUNIER (ESO) / MARC POSTMAN (STSCI) / DAN DURDA

MOON

Glass Beads Suggest Recent Lunar Volcanism

ANALYSIS OF TINY glass beads from the Moon suggests that volcanic eruptions occurred there within the past 120 million years.

Apollo-collected rocks gave us our first hands-on evidence of lunar volcanism dating back to at least 3.1 billion years ago. Then, initial studies of samples from China's Chang'e 5 mission — the first lunar material returned since the 1970s — showed evidence of volcanic activity 1 billion years later (*S&T:* Feb. 2022, p. 9). Now, tiny glass beads in the Chang'e 5 samples suggest volcanism occurred far more recently.

The Chinese team, led by Bi-Wen Wang and Qian Zhang (both at Chinese Academy of Sciences), started with some 3,000 micron-size glass beads created in the sudden heat of either impacts or volcanic processes. The team used various methods to zero in on 13 of them that showed hints of volcanic histories, ultimately settling on three with firmer evidence.

One line of evidence comes from sulfur *isotopes*, which contain different numbers of neutrons. As material vaporizes in the intense heat of an impact, lighter sulfur atoms more readily float away in the Moon's low gravity, leaving heavier sulfur behind in resolidified material.

Volcanism, on the other hand, results in material that retains more of the lighter isotopes. Three beads have a balance toward lighter sulfur isotopes, suggesting a volcanic origin, the team writes in the September 6th *Science.* The beads' ages were determined using radiometric dating.

The results align with orbital imag-

SPACE & SOCIETY

First of "Thousand Sails" Fly

A CHINESE COMPANY, Shanghai Spacecom Satellite Technology, has launched the first 18 spacecraft of the megaconstellation named Qianfan ("Thousand Sails" in Chinese), which will ultimately include more than 10,000 communications satellites in low-Earth orbit. Their altitudes, near 800 kilometers (500 miles), are above those of SpaceX's Starlink satellites, which are at 500 km, and below those of Eutelsat's OneWeb constellation at 1,200 km (*S&T:* June 2021, p. 16).

Several observers saw the satellites as well as debris from the Long March 6A rocket, which broke apart after delivering its cargo into orbit. Experienced visual satellite observers began recording the satellites' brightness once the ephemeris data became available. Observations from Richard Cole, Bram Dorreman, Scott Harrington and myself suggest that near zenith the satellites have a brightness of about magnitude 4.

In the U.S., SpaceX is working with astronomers to address the problem of bright spacecraft, and Starlink has succeeded in significantly reducing the brightness of its satellites. There are, however, no regulations in place as yet that govern satellite brightness. The Thousand Sails spacecraft at their current brightness would seriously interfere with astronomical research as well as aesthetic appreciation of the night sky.

■ ANTHONY MALLAMA

▲ An artist's illustration shows bright satellites on orbits that crisscross the sky.

SATELLITE ILLUSTRATION: LEAH TISCIONE / *S&T*; GLASS BEADS: T. ZHANG & Y. WANG

SPACE & SOCIETY

Astronomers and Starlink Partner for Quieter Radio Sky

STARLINK IS INFAMOUS in astronomy for its satellites' unwanted brightness, but the satellite constellation disrupts high-quality radio observations, too. Now, radio astronomers and Starlink engineers have developed a technique to help prevent the satellites' radio transmissions from adversely affecting astronomical observations.

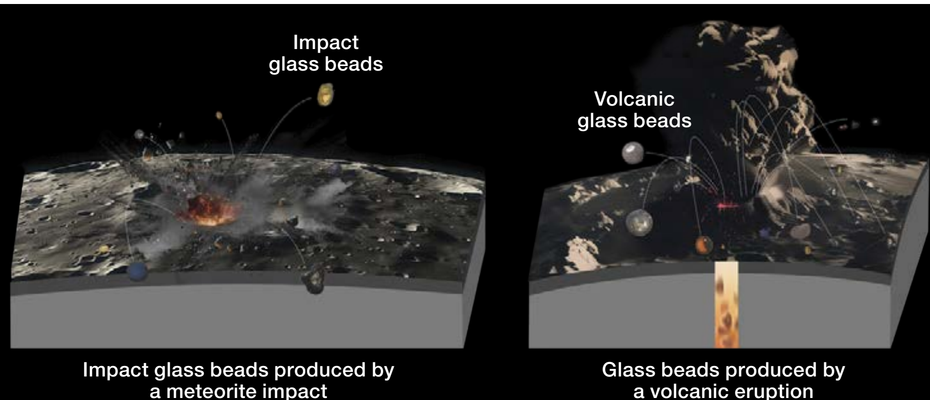
The U.S. National Science Foundation's National Radio Astronomy Observatory (NRAO) and SpaceX first entered an agreement to coordinate data in 2019. Now, they've developed an autonomous system that will inform satellites about the telescope's current operations, including in which direction of sky the telescope is pointing and the radio frequency at which it's observing. Satellites flying near that region can then either briefly redirect their transmission or shut it down altogether to avoid interference. Scientists have tested this technique in two separate experiments using the Green Bank Telescope and have demonstrated its feasibility.

"My immediate reaction is that this is a significant step in the right direction," says Federico Di Vruno (Square Kilometre Array Observatory). "The NRAO team and SpaceX have proven that beam avoidance is implementable and that it has a noticeable impact."

For now, Starlink's agreement involves only NRAO facilities; however, SpaceX is in discussions with other observatories to expand implementation. For it to be truly effective, other satellite companies and governments will need to adopt it as well.

Even with this system, though, some science will require longer observations and more aggressive "cleaning" of radio data to root out artificial noise. Unintentional transmissions from satellite electronics also remain an issue.

■ JURE JAPELJ



▶ Meteorite impacts and volcanic eruptions can both produce glass beads on the Moon.

ery that points to eruptions within the past 50 to 100 million years (*S&T:* Jan. 2015, p. 14). Likewise, centuries of visual observations of *transient lunar phenomena* (TLP) have sometimes been attributed to volcanism.

Benjamin Weiss (MIT), who was not involved in the study, says "it would suggest that the Moon has been volcanically active essentially yesterday." However, given the small sample size, he would like to see more examples with similar properties. That may yet happen, if these methods are applied to the more abundant samples brought back by Apollo astronauts.

These findings are "part of this growing awareness," Weiss suggests, "that maybe the Moon had this longer and more protracted history of geologic activity."

■ DAVID L. CHANDLER

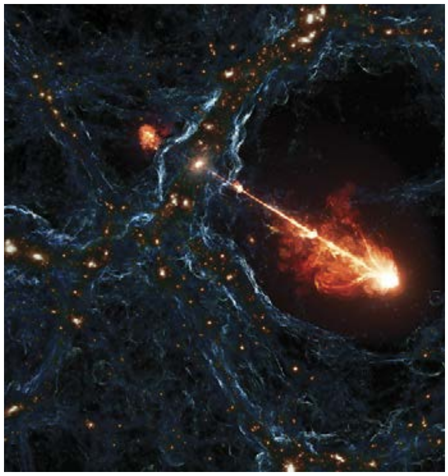
COSMIC STRUCTURE

Black Hole's Colossal Jets Pierce the Void

A NEWLY DISCOVERED pair of plasma jets span far beyond their host galaxy, potentially affecting the cosmic web around it.

The jets, powered by a supermassive black hole at the galaxy's center, span 23 million light-years from tip to tip — almost 10 times the distance between our Milky Way and the Andromeda Galaxy. Astronomers have nicknamed the record-breaking system "Porphyrion," after the king of the giants in Greek mythology. And the giant is indeed the king of many: A new catalog of such radio-emitting giant jet pairs tallies thousands of them.

"Giant jets were known before we started the campaign, but we had no idea that there would turn out to be so many," says Martin Hardcastle (University of Hertfordshire, UK), coauthor on two associated studies. Porphyrion's discovery is published in the Sept. 19th *Nature*; the accompanying catalog will appear in *Astronomy & Astrophysics*.



▲ An artist's illustration of the longest black hole jets ever observed, nicknamed Porphyrion

When astronomers looked for black hole-powered jets in a radio survey by the Low-Frequency Array (LOFAR), based in the Netherlands, they were surprised to find giant jets by the thousands. "Giant" here has a technical definition: These jets' tip-to-tip length as projected on the sky is more than 2.3 million light-years. (Porphyrion spans 10 times that length.)

Rafaël Mostert (Leiden University, The Netherlands) and colleagues combined the power of citizen science with machine learning to find more than 11,000 giant radio jets in LOFAR's Two-metre Sky Survey. The number suggests this giant variety is fairly common.

Martijn Oei (also at Leiden) led the study on Porphyrion, whose jets penetrate a cosmic void of mostly empty space. To power such long, straight streams of gas, the supermassive black hole's feeding rate and spin axis must have been stable for about a billion years, Hardcastle says.

The power carried by giant radio jets like Porphyrion and its legion can heat and expand filaments of the cosmic web that feed growing galaxies — though how much they do so remains a question for future work.

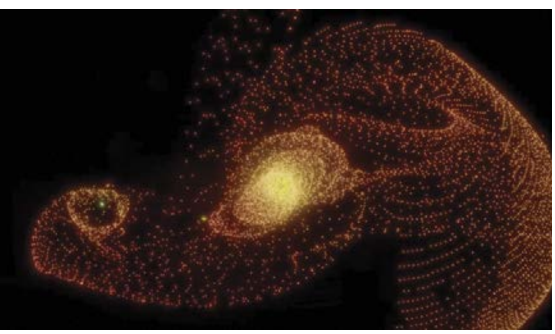
■ **MONICA YOUNG**

SOLAR SYSTEM

Visiting Star Might Have Reshaped Outer Solar System

BILLIONS OF YEARS AGO, the close pass of another star might have sculpted our solar system's outermost regions. On September 4th in *Nature Astronomy*, astronomers suggest such a flyby could explain some peculiarities of the solar system's most distant worlds, known as *trans-Neptunian objects* (TNOs).

The Nice model of solar system formation holds that TNOs' orbital properties resulted from a phase when the four giant planets migrated about the solar system. But the Nice model can't easily explain distant TNOs beyond the planets' reach.



◀ This snapshot from a simulation shows the Sun at center and the visiting star at left, with TNO populations represented as dots. Watch the simulation at **https://is.gd/starvisit**.

Susanne Pfalzner, Amith Govind (both at Jülich Research Center, Germany) and Simon Portegies Zwart (Leiden University, The Netherlands) have now carried out simulations of a close stellar encounter and its effects on TNO dynamics. They find that the flyby most likely happened in the first 10 million years of the Sun's history, when it was still part of the cluster it was born in. A star with 80% of the Sun's mass passing within 110 au of the Sun "gives a near-perfect match" to TNO orbits, they write. It even reproduces the recently discovered population of TNOs with retrograde orbits.

However, Alessandro Morbidelli (Observatory of Côte d'Azur, France), one of the originators of the Nice model, is "not impressed" by the new results, arguing that even the distant TNOs are easily explained as objects scattered from the giant planet region while the Sun was still embedded in its birth cluster. "All the rest," he adds, "are consistent with the giant planet instability scenario."

Other recent results seem to bolster the stellar-flyby scenario: The new computer simulations predict that distant TNOs are common, and, indeed, Japan's Subaru Telescope on Mauna Kea, Hawai'i, has uncovered more than expected — a finding supported by readings from the dust counter on NASA's New Horizons mission.

According to Pfalzner, the future Vera C. Rubin Observatory will provide an observational test of the flyby theory. Expected discoveries could determine, for example, how common distant or retrograde TNOs are. As the researchers writes in their paper, "[the work] presented here can only be a first step."

■ **GOVERT SCHILLING**

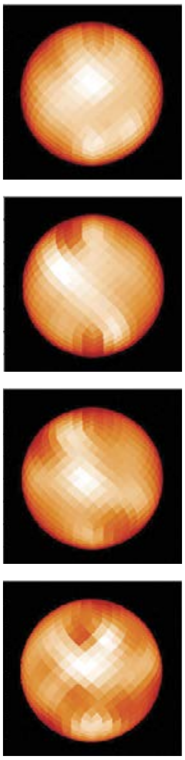
ARTIST'S ILLO OF PORPHYRION JETS: E. WERNQUIST / D. NELSON (ILLUSTRISTNG COLLABORATION) / M. OEI; STELLAR FLYBY SIMULATION: JÜLICH RESEARCH CENTER

STARS

See the Spotted Surface of Polaris

ASTRONOMERS HAVE USED an array of telescopes to reconstruct images of the surface of Polaris for the first time. The new images have been published in the August 20th *Astrophysical Journal*.

Polaris is the nearest Cepheid variable star to Earth, and it has a much fainter stellar companion. A team of astronomers led by Nancy Evans (Smithsonian Astrophysical Observatory) initially set out to map their mutual 30-year orbit, but that takes time and patience.



◀ CHARA observations of the surface of Polaris, taken over four nights between 2018 and 2021

"The small separation and large contrast in brightness between the two stars makes it extremely challenging to resolve the binary system during their closest approach," Evans says.

To pull it off, Evans turned to the Center for High Angular Resolution Astronomy (CHARA) array, a set of six 1-meter telescopes on the summit of Mount Wilson in California. By adding the new data to older measurements, including some from the Hubble Space Telescope, the team has now covered three-quarters of the stars' long orbit. In the process, they've upped the estimate of Polaris's mass from 3.5 to 5.1 solar masses.

In undertaking this study, the team also used a camera attached to CHARA to capture fuzzy views of Polaris's surface. The images show that Polaris is 46 times the diameter of the Sun. Remarkably, they also show surface details: large bright and dark spots on its surface that change over time.

The starspots may help explain Polaris's peculiarities, such as its unusually low pulsation amplitude; the difference between its dimmest and brightest points is smaller than that of other Cepheids. The spots may add "noise" that muddles the pulsation's signal.

The starspots also open the door to measuring Polaris's spin. Astronomers have already noted a 120-day variation in Polaris's pulsations, and Evans speculates that this time interval could mark the star's rotation.

"We plan to continue imaging Polaris in the future," says team member John Monnier (University of Michigan). "We hope to better understand the mechanism that generates the spots on the surface of Polaris."

■ **COLIN STUART**

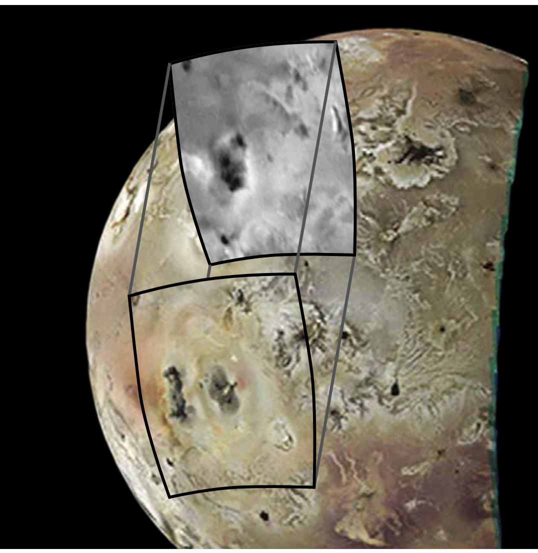
POLARIS'S BRIGHT AND DARK SPOTS: EVANS ET AL. / *ASTROPHYSICAL JOURNAL* 2024; IO: NASA / JPL-CALTECH / SWRI / MSSS / EUROPLANET

IN BRIEF

Omega Centauri Has *No* Mid-size Black Hole

Astronomers recently discovered evidence for a mid-size black hole in Omega Centauri (*S&T:* Nov. 2024, p. 9). But the globular cluster might instead contain tens of thousands of stellar-mass black holes, according to a study posted on the arXiv astronomy preprint server. The study, led by Andrés Bañares-Hernández (University of La Laguna, Spain), included observations of the motions of more than 1,000 stars as well as timing data for five pulsars. Combined, the measurements suggest thousands of stellar-mass black holes, containing 200,000 to 300,000 Suns' worth of mass, are spread throughout the cluster center. Or, if there *were* a single, larger black hole, it would contain less than 6,000 solar masses — significantly less than the 8,200 to 50,000 solar masses estimated by the previous study, which was based on the motions of seven unexpectedly speedy stars. One reason for the mass discrepancy is that Bañares-Hernández's team estimates a higher mass for the cluster, which leads to a higher escape velocity. That means individual stars can speed around the center without requiring a giant black hole to keep them bound. Simon Portegies Zwart (Leiden University, The Netherlands), who was not involved in either study, says that, while he'd found the potential discovery of a single, larger black hole "super exciting," the evidence just isn't there yet.

■ **ARIELLE FROMMER**



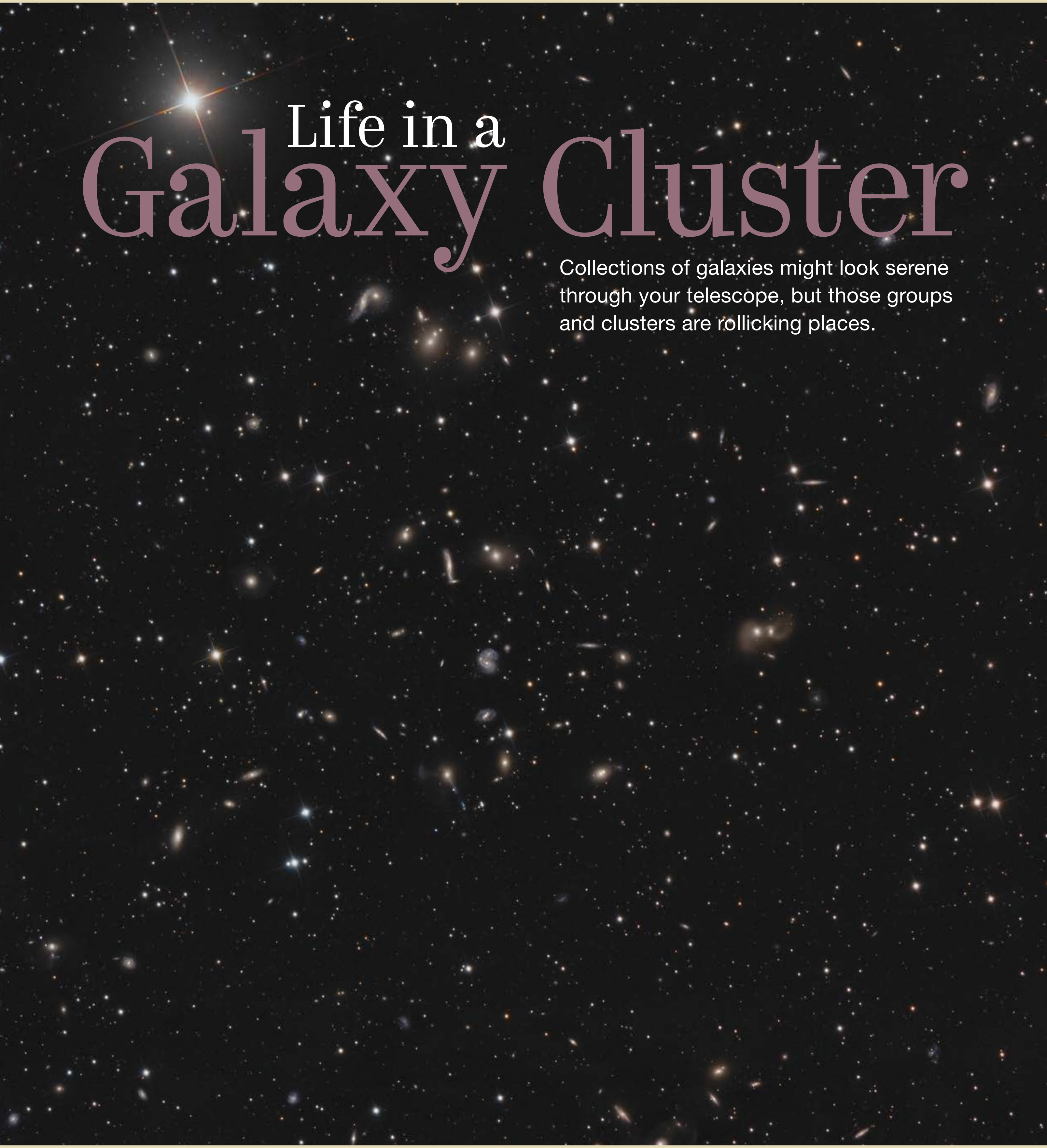
New Volcano on Io

NASA's Juno mission has spotted a new volcano on Jupiter's moon Io: The image at left shows the new feature to the east of an existing feature. The volcano is fresh since the Galileo mission, which saw only featureless terrain in the same region in 1997 (*inset*). Now, multiple lava flows and deposits cover a region about 180 kilometers (110 miles) on a side. Michael Ravine (Malin Space Science Systems), speaking at the 2024 Europlanet Science Congress on behalf of the JunoCam team, presented images of this "large, complicated volcanic feature that appears to have formed from nothing." The new volcano spewed sulfur into space, which then fell back onto Io's surface, staining the area to the east of it red. On the western side, two dark streams of lava run for about 100 km, pooling at the farthest point. There, the lava's heat vaporized surface material, creating two overlapping dark gray deposits. The new images come from several close passes by Io conducted during Juno's extended mission. All of JunoCam's images are publicly available at **missionjuno.swri.edu**.

■ **MONICA YOUNG**

Life in a Galaxy Cluster

Collections of galaxies might look serene through your telescope, but those groups and clusters are rollicking places.



Galaxies are found in a wide variety of environments. Some galaxies, like people, live in rural environments — the low-density "field" where galaxies have very few neighbors. Others are more suburban, living in groups like our own Milky Way Galaxy and its close companions Andromeda (M31) and Triangulum (M33).

But massive galaxy clusters are the true cities of the universe. These clusters are home to hundreds or even thousands of bright galaxies, all packed within a few million light-years of one another — quite close by astronomical standards.

All types of galaxies swarm inside these clusters: giant ellipticals, blue star-forming spirals, disky lenticular galaxies, faint dwarf ellipticals, and dwarf irregular galaxies. They're joined by strange neighbors, such as ghostly *ultra-diffuse galaxies* (UDGs), whose stars are spread so thinly in space that their light is almost lost in contrast to that of the night sky, and dense *ultra-compact dwarf galaxies* (UCDs) — objects so small and point-like that they are almost indistinguishable from foreground stars in the Milky Way.

What gives rise to such a wide variety of galaxy types inside clusters? It turns out that life as a cluster galaxy is hard, and it leaves scars.

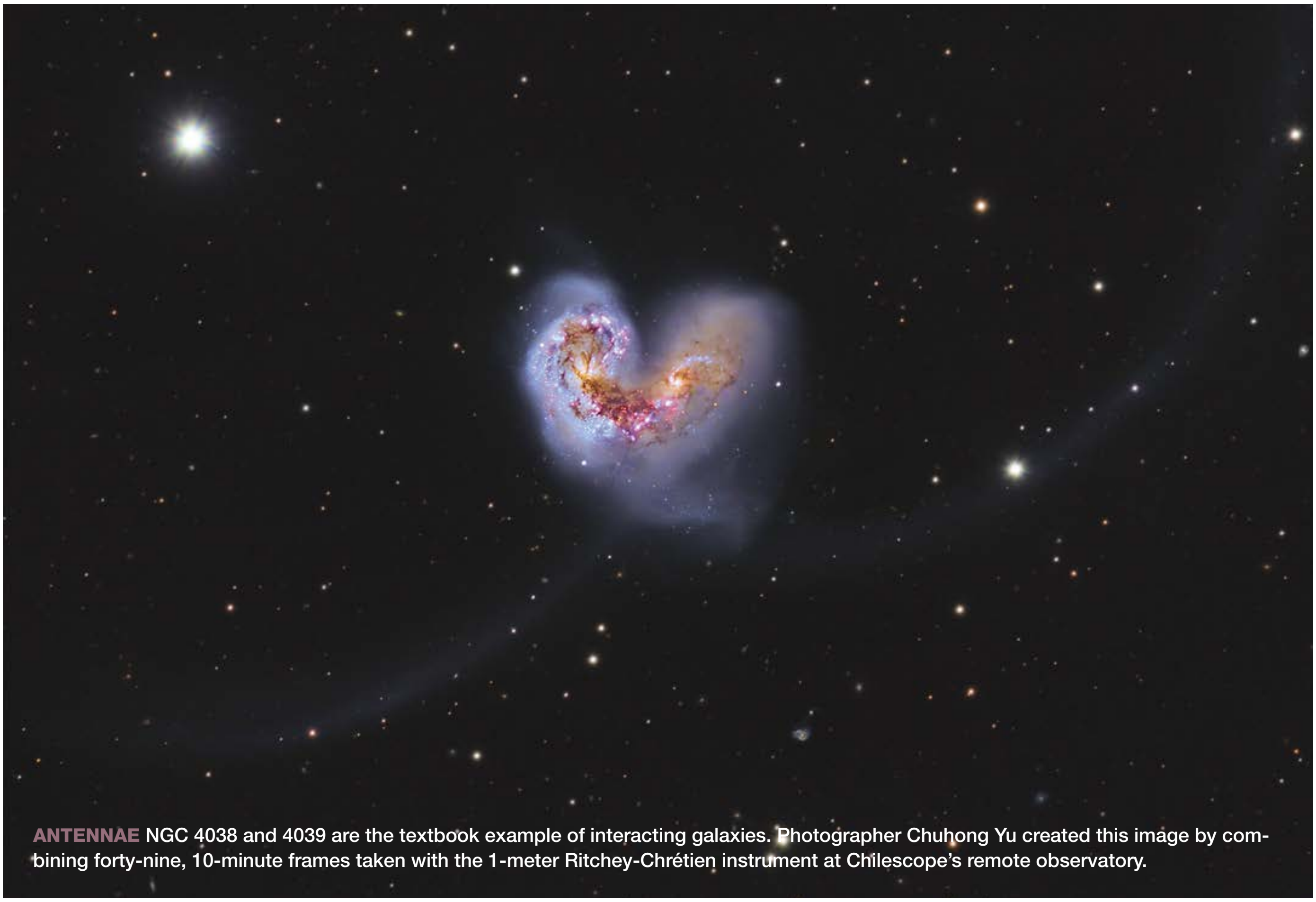
As galaxies plunge through the dense environment of the cluster, they can be rocked by collisions with other galaxies, swept clean of their star-forming gas, stripped apart by intense gravitational forces, or swallowed whole by massive galaxies in the cluster core. Over time, these complex forces work together to reshape, damage, and even destroy cluster galaxies. Compared with field and group environments, where galaxies are predominantly spirals and irregulars, rich galaxy clusters have a much higher fraction of elliptical and lenticular galaxies and fewer star-forming spirals. Astronomers call this the *morphology-density relation*.

These processes don't only reshape cluster galaxies. Their effects are also written into the *diffuse intracluster starlight* that fills the space between the galaxies. Together, the starlight and the galaxies can reveal to us a cluster's history.

◀ **HERCULES CLUSTER** Abell 2151 is a fairly young cluster, relatively rich in spiral galaxies. It's both less populated and more spread out than the older Coma Cluster. This color composite by Bob and Janice Fera combines 38 exposures taken with a 17-inch Cassegrain.

Groups: Distorted, Frayed, and Disrupted

To understand in detail how the cluster environment shapes and reshapes the properties of cluster galaxies, we have to start in the early universe, when galaxies and clusters are starting to coalesce. Structure in the universe — galaxies, clusters, and the vast cosmic web they're part of — forms



ANTENNAE NGC 4038 and 4039 are the textbook example of interacting galaxies. Photographer Chuhong Yu created this image by combining forty-nine, 10-minute frames taken with the 1-meter Ritchey-Chrétien instrument at Chilescope's remote observatory.

over time through a process astronomers call *hierarchical assembly*: Gravity draws smaller things together to build larger things.

In this picture, galaxy clusters do not form all at once, but instead grow steadily as galaxies first assemble into galaxy groups that then fall together to form small galaxy clusters. The growing gravitational pull of the cluster draws more galaxies and galaxy groups into the cluster, along with massive amounts of dark matter and diffuse intergalactic gas. As this intergalactic gas falls into the cluster, it is heated to millions of degrees, emitting X-rays and giving rise to the bright X-ray halos we see in massive clusters today.

In a place like the Coma Cluster, the stars we see in its galaxies make up only a small fraction of the cluster's total mass. Compared to the stellar mass of all the galaxies combined, there's nearly 10 times more mass in the hot intracluster gas and 100 times as much dark matter. The galaxies, along for the ride in this maelstrom of assembling gas and dark matter, are irrevocably changed by the forces at work.

For many galaxies these changes begin early, in the small groups that are fated to eventually fall into the main cluster. The total amount of matter in these groups is relatively small, typically just a few galaxies' worth of mass, and so galaxies are not accelerated to the high speeds they will eventually obtain when they enter the main cluster. Instead, when the galaxies encounter each other, they are moving at a more leisurely pace of only a few hundred kilometers per second (hundreds of thousands of miles per hour).

But in the world of galaxy collisions, it is these slow encounters that do the most damage. Because these collisions

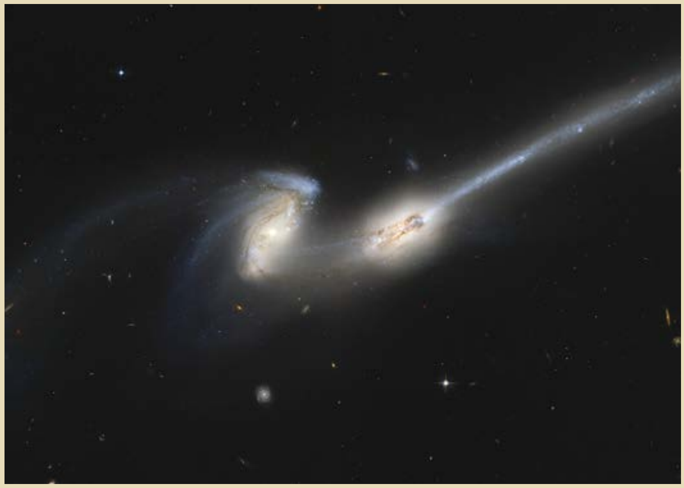
ROGELIO BERNAL ANDREO

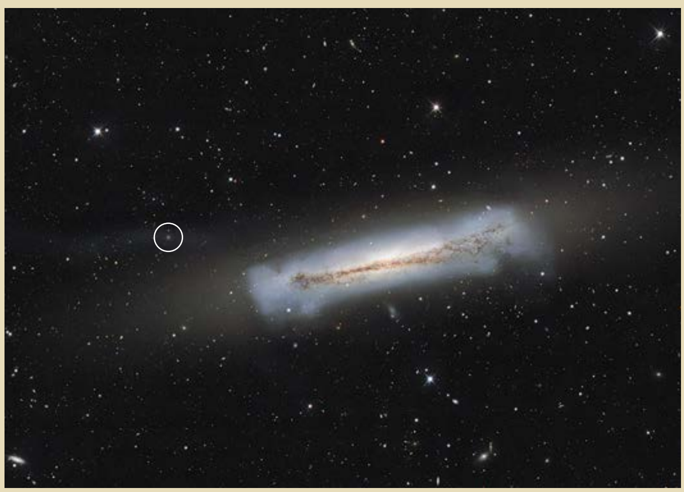
▼ **GALACTIC METROPOLIS** The Virgo Cluster is the closest large galaxy cluster and contains more than 1,000 members. This wide-field mosaic shows the cluster's central region through foreground dust clouds in the Milky Way. The cluster's central dominant galaxy, M87, sits just below and left of the image's center.

▶ **THE MICE** *Top:* NGC 4676 is a pair of merging galaxies on the outskirts of the Coma Cluster. Their dance has torn long tails of stars and gas from each galaxy, earning them their nickname.

▶ **THE AFTERMATH** *Middle:* NGC 7252 is a strange-looking mish-mash, created when two galaxies merged.

▶ **LION CUB** *Bottom:* The spiral galaxy NGC 3628 in Leo dominates this scene, but embedded within the tidal tail that extends from the galaxy's left is the ultra-compact dwarf galaxy known as NGC 3628-UCD1 (circled). The tidal tail is about 300,000 light-years long — roughly three times the Milky Way's width.





NGC 4676: NASA / HOLLAND FORD (JHU) / ACS SCIENCE TEAM / ESA; NGC 7252: ESO; UCD IN A TIDAL TAIL: CTIO / NOIRLAB / DOE / NSF / AURA, IMAGE PROCESSING: T. A. RECTOR (UNIVERSITY OF ALASKA, ANCHORAGE / NSF'S NOIRLAB), M. ZAMANI (NSF'S NOIRLAB), D. DE MARTIN (NSF'S NOIRLAB) play out more slowly, there is more time for the gravitational forces to do their work. As one galaxy passes another, their mutual gravitational pull draws streamers of stars and gas out of them both, leading to the delicate *tidal tails* of starlight seen in many interacting systems. If the encounter is close enough, the galaxies can actually penetrate deep into each other's cocoons of dark matter. The ensuing gravitational distortion in the dark matter robs the galaxies of orbital energy and angular momentum. This effect, called *dynamical friction*, drags on the galaxies so much that they slow and reverse course, drawing them back together until they ultimately merge together into a single galaxy.

These mergers have a profound effect, especially on disk galaxies. As these galaxies coalesce, the rapidly changing gravitational forces disrupt the orderly motion of stars, scattering them onto more random orbits. If the merger involves two comparably large galaxies — what astronomers call a *major merger* — their disks can be completely disrupted, with the stars now moving randomly in all directions like bees buzzing around a beehive (*S&T:* Sept. 2015, p. 16).

Although the individual stars don't collide during one of these mergers, the interstellar gas clouds do. The collisions shock and compress the gas, and then gravitational forces drive much of it inwards to the center of the galaxies. Here, it may fuel an intense but short-lived burst of star formation. Once the galaxies completely merge and the starburst fades away, the resulting object resembles an elliptical galaxy: spheroidal, gas-poor, and no longer forming stars.

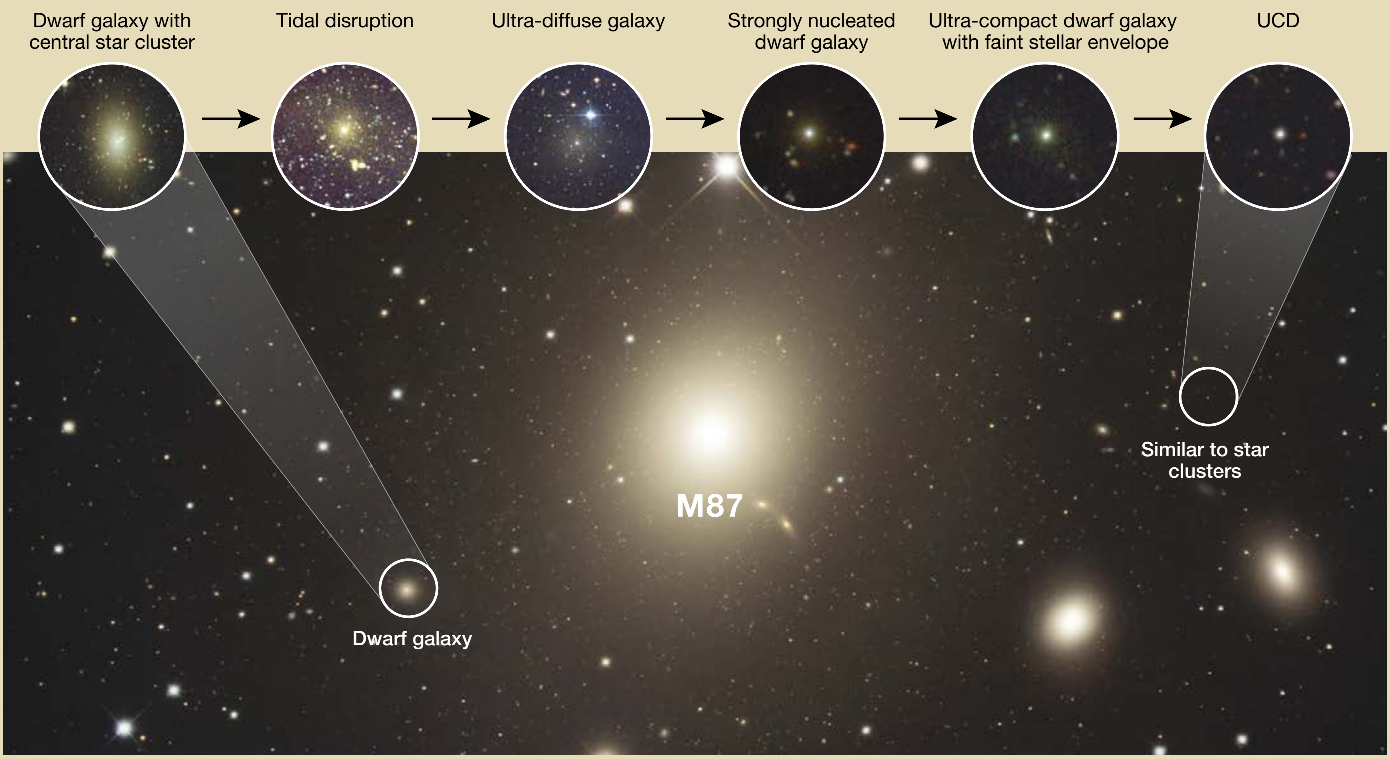
In *minor mergers*, in which one of the galaxies is much smaller than the other, the larger galaxy's disk survives the encounter but is left in a distorted state: warped, thickened, or sporting lopsided spiral arms. As the smaller galaxy spirals into its larger host, it may be ripped apart entirely by gravitational forces, or part of it may fall all the way to the large galaxy's center, adding stars to the growing central bulge.

These merger events continue to occur as more galaxies fall into the small galaxy groups. The groups grow in size over time, and their members undergo metamorphoses as ongoing mergers slowly transform many of the spirals into elliptical or lenticular galaxies: the beginnings of the morphology-density relationship.

Clusters: Cosmic Rough-and-Tumbles

Even bigger changes are in store. As gravity pulls groups together, they continue merging with one another to form a cluster. The growing mass of the cluster accelerates infalling galaxies to even higher speeds of 1,000 km/s or more. At these speeds, galaxies passing one another are typically moving too fast to merge. Instead, these encounters give quick and less-damaging "kicks," stirring galaxies up and pulling some of their stars out into intracluster space.

But while these fast encounters don't do as much damage



▲ **WHITTLED-DOWN DWARFS** A continuum of galaxies captured at different stages of the transformation process follows the evolution of a dwarf galaxy to an ultra-compact dwarf galaxy in the Virgo Cluster.

BEATRIZ INGLESSIS / *S&T*, ADAPTED FROM NOIRLAB / NSF / AURA / NASA / R. GENDLER / K. WANG / M. ZAMANI individually, their cumulative effect can be significant. With so many galaxies now in the cluster, the encounters happen quite often. Over time, these small kicks add up, particularly for dwarfs. Repeated kicks puff up these galaxies and strip off many of their stars, making them more and more diffuse as time goes by.

And it's not just these fast flybys that galaxies have to contend with. As the cluster continues to grow in mass, the gravitational pull of the cluster itself becomes stronger and stronger. Near the cluster core, the pull is fierce, creating intense gravitational tides that galaxies must navigate as they pass through the region. The tides strip even more stars out of the galaxies, gradually whittling galaxies down.

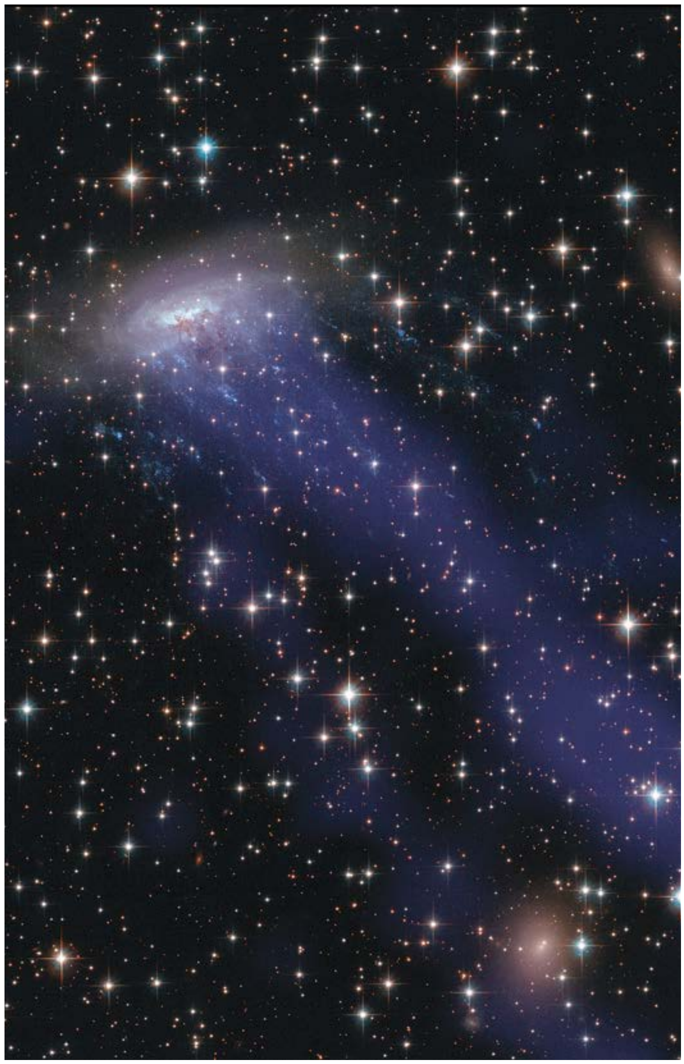
While massive galaxies can withstand a good bit of tidal stripping and stay intact, the process may completely disrupt dwarfs, leaving their stars scattered across the cluster. Some of these low-mass galaxies have cores dense enough to survive the whittling process. But with their outer stars now stripped away, the nuclei are left orbiting within the cluster as bare and compact stellar systems, transformed into ultra-compact dwarf galaxies.

Stripped Down to the Stars

There's more than just gravity at work transforming galaxies in these metropolises — the hot, diffuse gas that fills the cluster also drives strong evolution. As galaxies orbit, they continually move through this hot *intracluster medium*. While the stars in galaxies pass through unimpeded, the galaxies' star-forming gas is not as fortunate. Like wind filling a sail, the pressure of the intracluster medium sweeps up the star-forming gas and begins to blow it out of galaxies through a process called *ram-pressure stripping*.

In the outskirts, where the density of hot gas is low, this stripping mostly affects dwarfs and the outer parts of large galaxies. In the latter case, it leaves the rest of the star-forming gas intact and available to continue making stars. But for galaxies plunging through the denser cluster core, the outcome is dramatic. Here, ram-pressure stripping is so strong that it can remove a galaxy's gas entirely, completely shutting down the ability to form new stars. The galaxy's stellar populations, immune to ram-pressure stripping, remain in place, leaving the galaxy "red and dead," its light dominated by aging red giant stars. This process can transform blue spirals into red and disky lenticulars, while dwarf irregular galaxies fade to become red and diffuse.

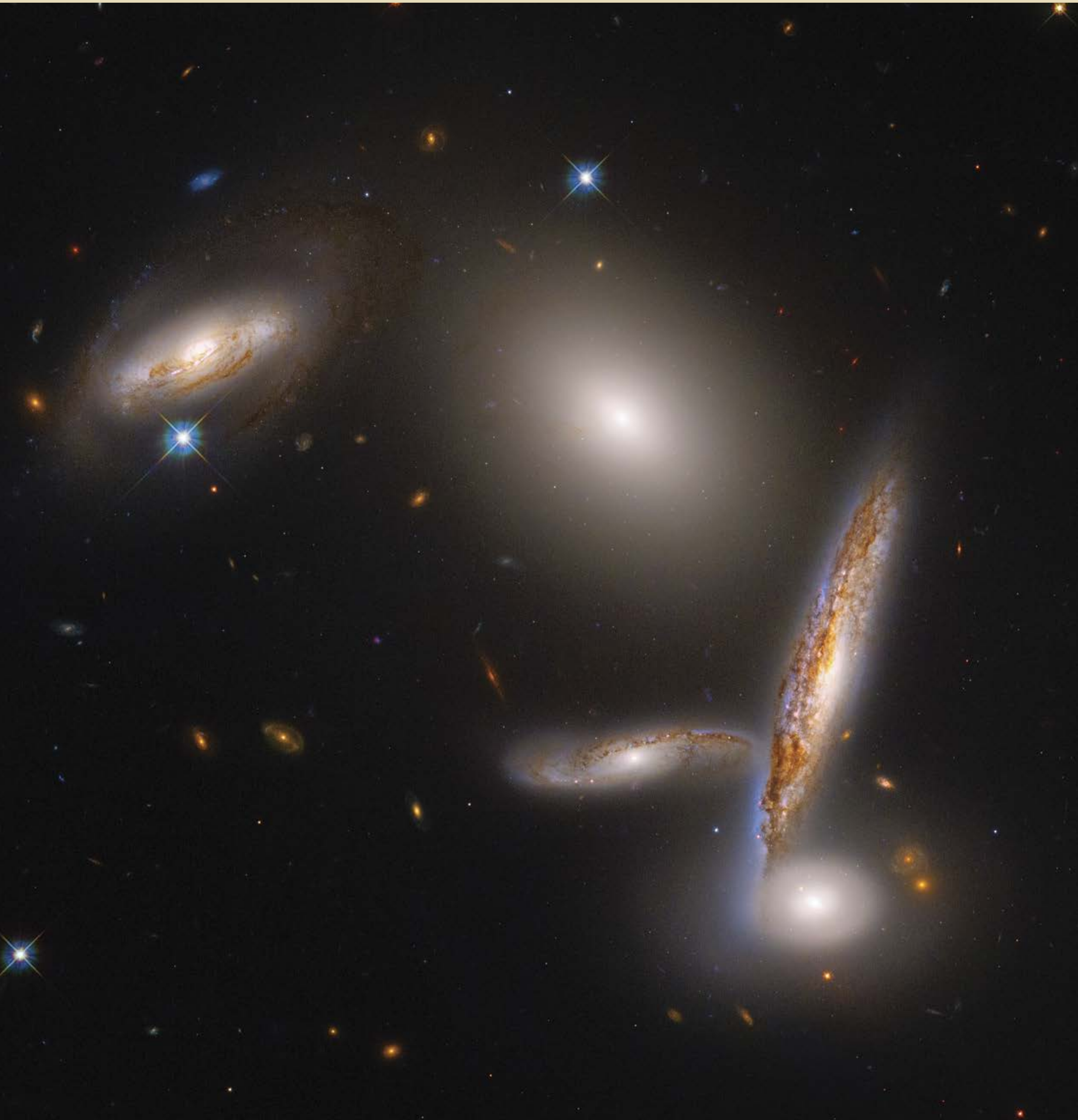
Meanwhile, deep in the cluster core, even more dangers lurk. The heart of a cluster is typically home to the largest



▶ **HOT BATH** *Top:* This composite image of X-ray and optical data shows the glow of hot gas in the Coma Cluster.

▶ **WINDSOCK** *Bottom:* This composite image shows the spiral galaxy ESO 137-001 plowing through the hot, X-ray-emitting gas (blue) in the Norma Cluster. Tattered threads of bright blue are the gas torn from the galaxy itself that have now erupted in star formation. The dark brown is dust that's also being dragged out.

HOT BATH: ESA / XMM-NEWTON / SDSS / J. SANDERS ET AL. 2019; WINDSOCK GALAXY: X-RAY: NASA / CXC / UAH / M. SUN ET AL., OPTICAL: NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA)



HICKSON COMPACT GROUP This group of five galaxies sits in a fairly isolated part of space in the constellation Hydra, the Water Snake. The galaxies will likely merge to create a giant elliptical in about 1 billion years.

galaxy, called the *central dominant* or *brightest cluster galaxy* (BCG). These giant ellipticals are the most massive galaxies in the universe, home to hundreds of billions of stars and 10 times that mass in dark matter. And they're ravenous.

While across the cluster as a whole galaxies are moving too fast to easily merge, deep in the cluster core the high density of matter makes the process of dynamical friction extremely efficient. As more galaxies fall into the cluster, dynamical friction continues to bring the most massive ones to the cluster center, where they merge into the growing BCG. Strong tidal forces also tear apart lower-mass galaxies passing close to the cluster center, dispersing their stars throughout the core and building a large and diffuse envelope of light around the central galaxy.

A Sea of Orphan Stars

The interplay of all these different dynamical factors during cluster formation and evolution transforms the member galaxies into the myriad types we see in massive clusters today. Over time, the galaxy populations slowly change from being characterized largely by star-forming spirals and dwarfs. They become dominated by ellipticals and lenticular galaxies as well as dwarf galaxies that are diffuse and dim, robbed of their star-forming gas and destined to be disrupted by the cluster's gravitational field.

Also strewn throughout the cluster are stars torn from their parent galaxies by these processes. Spread thinly through intracluster space, the light from these stars is exceptionally diffuse and dim, more than 100 times fainter than the brightness of the darkest night sky. We call this glow the *intracluster light* (ICL). Through advances in deep-imaging techniques, astronomers have been able to detect this light in clusters across the universe, including my own team's work mapping the ICL in the nearby Virgo Cluster.

The intracluster starlight can be quite large, amounting to 15% or more of a cluster's total light. Importantly, the ICL's structure holds information about the galaxies' cluster-driven evolution. In Virgo, for example, we see a number of thin ICL streams coming from small galaxies torn apart by the tidal forces in the cluster core. We also see several ultra-diffuse galaxies sporting faint tidal tails, evidence that tidal stripping might have transformed otherwise normal dwarfs into these UDGs. Some of these UDGs in turn house compact nuclei at their centers. If continued tidal stripping whittles away the rest of the galaxy, these nuclei may be left bare, becoming new ultra-compact dwarf galaxies.

In the Virgo core, an extended envelope of light surrounds the massive central elliptical galaxy, M87, a behemoth built through mergers and stellar stripping. Meanwhile, infalling groups in the cluster's outskirts show additional plumes and streams of diffuse starlight, destined to mix in with the Virgo ICL once the galaxies merge into the main cluster. Over the next year, our team's new Hubble Space Telescope observations will resolve Virgo's ICL into individual intracluster stars, building upon earlier studies to give us the stars' ages and chemical compositions. This information will tell us about the kinds of galaxies that the cluster has disrupted to form the intracluster light.

▲ **INTRACLUSTER LIGHT** This enhanced image reveals the hazy glow of countless orphan stars (teal) in the galaxy cluster Abell 85. The cluster contains more than 500 galaxies and lies some 700 million light-years away in the constellation Cetus, the Sea Monster.

This process of cluster growth and galaxy transformation continues today. Looking out into the universe, we see clusters of all types. Some clusters, like the massive Coma Cluster, consist mostly of red-and-dead ellipticals and lenticular galaxies, with few star-forming dwarfs or spirals. These clusters may have been some of the earliest to begin assembling.

Other clusters appear dynamically younger, like the Virgo and Hercules clusters, which have a much higher fraction of star-forming spirals. The presence of distinct "neighborhoods" — sub-groups of galaxies within these cosmic cities — also suggests that these clusters are still actively accreting members, growing in mass and size as new galaxies fall in.

But even old clusters continue to grow. When we look into the core of Coma, we see not one but two massive ellipticals, likely destined to merge and build an even larger central galaxy in perhaps several hundred million years. The cluster's distorted X-ray halo also indicates that Coma has been digesting an infalling galaxy group for the last 1 or 2 billion years.

Ultimately, the accelerating expansion of the universe will keep clusters from growing indefinitely, as matter thins out too much for gravity to pull galaxies together. But in the meantime, cluster galaxies are in for a wild ride.

■ **CHRIS MIHOS** is the Warner Professor of Astronomy at Case Western Reserve University. He studies galaxies and galaxy clusters using computer simulations and ground- and space-based observatories.

Auriga Has It All

This easily recognizable constellation harbors a smorgasbord of delights.

How many constellations contain one of nearly every class of deep-sky object within their boundaries? Okay, let's narrow that down to those where such objects are all visible with a telescope no bigger than, say, 10 inches? If Auriga, the Charioteer, didn't come to mind, then prepare to be amazed! Let's enter a deep-sky decathlon where we'll sojourn to a wide and wonderful variety of objects.

Double Vision

Let's kick off with the constellation's brightest open cluster, which is **NGC 2281**. Or is it **M37**? While several catalogs list NGC 2281's magnitude as being slightly higher (5.4), M37 (5.6) was actually discovered at least 128 years prior. To settle the matter of which is easier to see, I put my naked eyes to the test and compared their visibility on several nights.

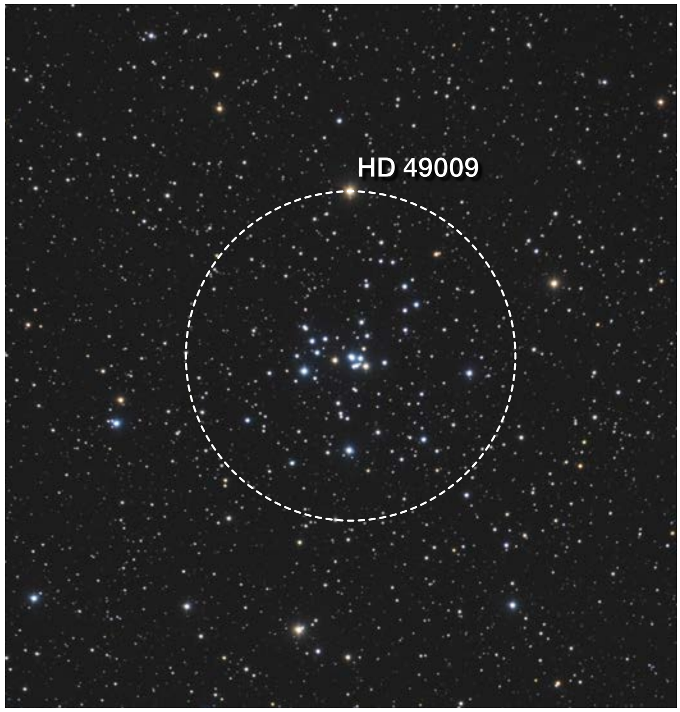
▲ **CELESTIAL CHARIOTEER** Our tour will visit several of the brightest nebulae in Auriga, two of which are visible on either side of this image by Alan Dyer. A pair of hot *B*-type stars illuminate NGC 1931, while AE Aurigae powers the reflection nebula IC 405. When you're in the area, you have to swing across the "Leaping Minnow" asterism to see how a filter brings out the glow of IC 410 tangled up in the open cluster NGC 1893. While it's fairly well known that the center of our galaxy lies in the direction of Sagittarius, it's less well known that the Galactic Anticenter lies in Auriga (at right ascension 5^h 45^m 37^s and declination +28° 56′ 10″, to be precise).

I found that M37 is just a touch more noticeable, even after I factored in the brightness of the 7.3-magnitude star HD 49009 on the northern edge of NGC 2281. In fact, binoculars reveal that the only reason NGC 2281 can compete at all is that its small but brilliant heart far outshines M37's core. To be fair, though, you need to see both clusters for a proper comparison.

To find NGC 2281, look about 8° east of 1.9-magnitude Beta (β) Aurigae until you land among so many Psi (ψ) Aurigae members that former *Sky & Telescope* Contributing Editor Sue French once wondered, "How many Psis can you spy with your eyes?" (*S&T:* Feb. 2010, p. 65). The cluster itself can be spied just 0.8° southwest of 5.0-magnitude Psi^7 Aurigae.

Holding my 8×56 binoculars steady, I see an isosceles-triangle-shaped compact group of stars with a scattering of fainter suns of similar magnitudes flung around it. This gives it the appearance of being a much larger and looser cluster than it actually is. With 12×60s, I can discern a dozen or so members within the cluster's true diameter, and while the western tip of the triangle comprises three stars I can't split them. Peering at the group in my 5.1-inch reflector at 27× allows me to resolve the tip into a trapezium of about half a dozen stars and detect a nice orange hue to HD 49009. More magnification will split the easternmost member into a pair (magnitudes 9.0 and 10.6, separated by 8.1″), just like William Herschel did for the first time in 1782 using his 6-inch telescope.

M37 is a snap to find as it lies almost 5° south-southwest of Theta (θ) Aurigae and in my 8×56s shows hints of graininess over an otherwise large, smooth glow. Switching to the 12×60s, the cluster now displays partial resolution, while its northwestern neighbors M36 and M38 show full resolution. M37's central brightening is irregular in shape and protrudes eastward. Jumping to my 5.1-inch at 27×, I see the cluster has a 9.2-magnitude lucida (HD 39183) almost dead center, while the stars around it are arranged like rose petals on a pond. With my 16-inch Dobsonian at 68×, the lucida is topaz-colored, and I can easily see the water-strider asterism that Contributing Editor Stephen James O'Meara mentions in his book *Deep-Sky Companions: The Messier Objects*.



▲ **BRIGHTER OF THE TWO** Which is easier to see — NGC 2281 (above) or M37? The author determined M37 to be a smidgen brighter by eye alone, despite the fact that it lies almost three times farther than NGC 2281, at around 4,500 light-years. Jim Thommes captured this image using a 6-inch Maksutov-Newtonian at f/4.8.

An Auriga Assortment

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 2281	Open cluster	5.4	25′	$06^h 48.3^m$	+41° 05′
M37	Open cluster	5.6	15′	$05^h 52.3^m$	+32° 33′
LDN 1477	Dark nebula	—	23′ × 16′	$05^h 03.6^m$	+44° 04′
IC 2149	Planetary nebula	10.6	15″ × 10″	$05^h 56.4^m$	+46° 06′
UGC 3596	Lenticular galaxy	12.8	1.2′	$06^h 55.6^m$	+39° 46′
NGC 1931	Reflection/Emission nebula	—	7′	$05^h 31.4^m$	+34° 15′
IC 405	Emission/Reflection nebula	—	30′ × 20′	$05^h 16.3^m$	+34° 25′
CRL 618	Pre-planetary nebula	~16.3	17″ × 3″	$04^h 42.9^m$	+36° 07′
Palomar 2	Globular cluster	12.6	2.2′	$04^h 46.1^m$	+31° 23′
HBH 9	Supernova remnant	—	140′ × 120′	$05^h 01.0^m$	+46° 40′

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

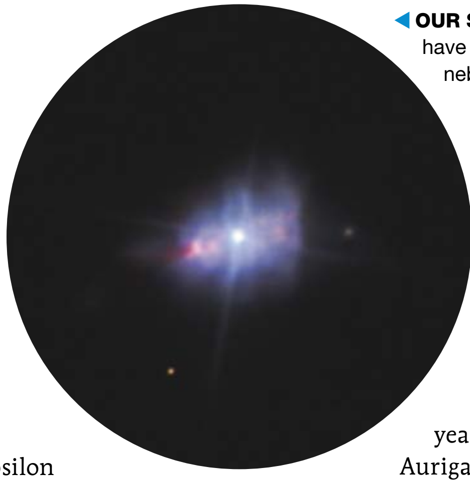
A Mixed Bag

Now that we've visited the two brightest deep-sky objects Auriga has to offer, let's head up near the star Capella to drop in on what might be the darkest. Cataloged as **LDN 1477**, I've found that thanks to its relatively compact size it lends itself extremely well to detection in handheld binoculars. It lies just 0.3° northeast of 3.0-magnitude Epsilon (ε) Aurigae and is visible as a disk of darkness featuring almost no stars in my 5.1-inch at 27×.

But LDN 1477 isn't the only "disk of darkness" in the area! Heading back to Epsilon Aurigae, this yellow giant dims by 0.8 magnitude every 27.1 years for almost two years. The dimming is predicted to happen again between 2036 and 2038, and astronomers attribute it to the presence of a companion star, partly shrouded in an immense disk of opaque material passing directly in front of the yellow giant.

While we're this far north, let's check out **IC 2149**, the brightest planetary nebula in Auriga. This gem evaded visual discovery for so long that it wasn't until 1906 that Harvard "computer" Williamina Fleming noticed it on objective prism plates. Little did she know that the reason its disk is so small is because it lies some 6,300 light-years away in the Perseus Arm of the Milky Way.

I see IC 2149 in my 8×56 binoculars as a 10.6-magnitude "star," arriving at it by carefully star-hopping 1.3° north-



◀ **OUR SUN IN THE FAR FUTURE** Some researchers have proposed that when our Sun enters the planetary nebula phase it will look very much like IC 2149.

northwest of Beta Aurigae. It begins to appear soft-looking in my 5.1-inch at 93×, while my 10-inch at 117× reveals a slight east-west elongation and a distinct blue hue. Staying with my 10-inch but increasing the magnification to 400×, I detect a high-surface-brightness ellipse with a central star shining even brighter.

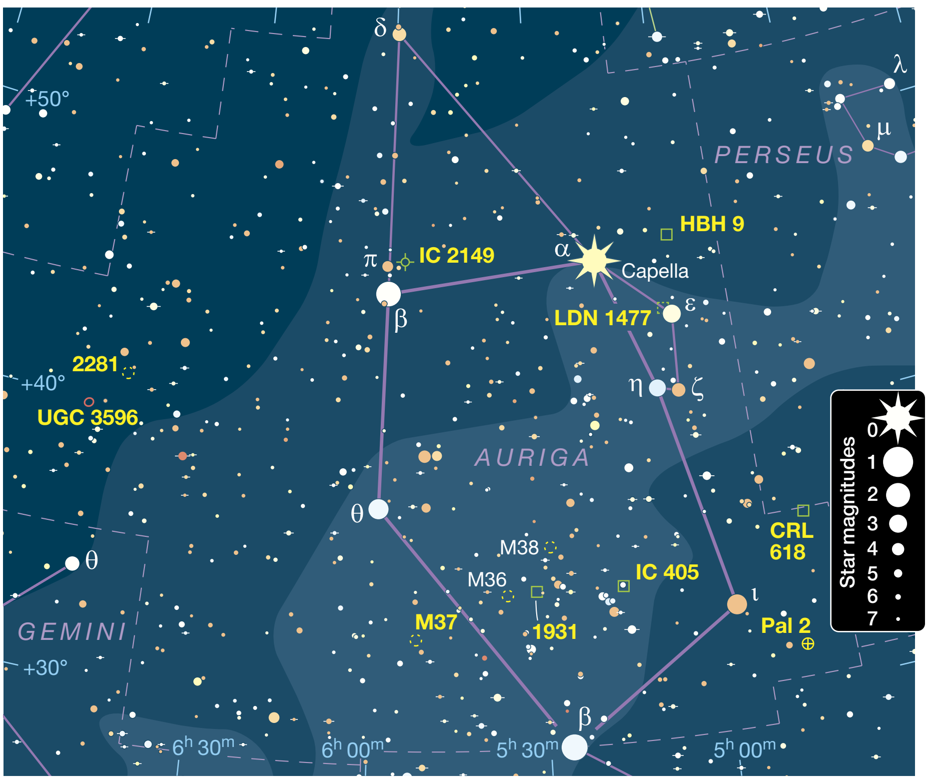
I'll be honest — up until just a few years ago, I had never seen a galaxy in Auriga. The *NGC* lists only two galaxies in the constellation, but researching the matter, I found it missed one. All three are found in Auriga's eastern reaches and have very similar magnitudes (12.6 to 12.8). Famed comet hunter Lewis Swift discovered two (NGC 2208 and NGC 2303) on the same night in 1886 using a 16-inch refractor, while the third (officially MCG +07-15-001, though better known as UGC 3596) was identified photographically more than 75 years later.

To determine which one was truly the brightest, I observed the trio using my 5.1-inch one evening. At 27×, I found NGC 2303 was too faint to detect (though it's visible at 93×), while UGC 3596 was slightly easier to see than NGC 2208 thanks to its higher surface brightness. Thus, 12.8-magnitude **UGC 3596**, a peculiar lenticular galaxy 250 million-light-year distant, appears to be the brightest galaxy in Auriga!

Its location isn't hard to find if you revisit the open cluster NGC 2281 — just scan 1.9° to the southeast. You'll find that this galaxy handles magnification well. In my 10-inch at 91×, it's a small, soft, compact glow that hints at a stellar center. Upping the magnification to 200×, the galaxy is still quite small and compressed down to a stellar center.

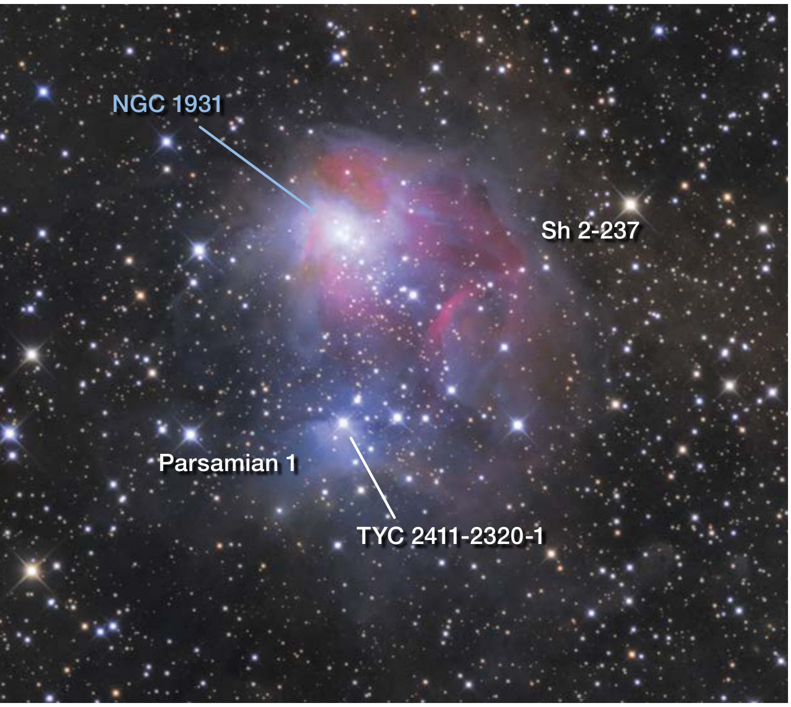
Fires in the Chariot

Before I started on this article, I believed that **NGC 1931** was the brightest emission nebula in Auriga since it's the only one I'd managed to see in my 7×35 binoculars. However, while researching this last winter, I came to realize I was wrong . . . it's the brightest *reflection* nebula in the constellation! In fact, it's a three-in-one delight, as you'll see.



◀ **AMAZING AURIGA** Join the author these winter nights on a quest for an assortment of deep-sky objects in the Charioteer.

J.-F. BAX / SERGE BRUNIER / OCA/C2PU



▲ **MIXED NEBULA** Like other very young nebulae still forming stars, NGC 1931 is a blend of both emission and reflection components. Note that compared to images like the one above, the extent of the nebula is much smaller at the eyepiece. Still, do look 3.7′ south of NGC 1931 for the fan-shaped reflection nebulosity Elma Parsamian first cataloged in 1965. Jean-François Bax and Serge Brunier acquired this image and the one of IC 2149 using the 1-meter telescope of the OCA/C2PU in the French Alps.

▲ **BALL OF STARS** As it's opposite to the center of our galaxy, the winter sky contains far fewer globular clusters. So nabbing Palomar 2 is a must if you still want to observe some. You'll find the globular a touch less than 3° southwest of Iota Aurigae. Palomar 2 lies at a distance of 85,400 light-years, which means its apparent diameter of 2.2′ translates to a physical size of 55 light-years. Rudolf Riedl captured this image using an 8-inch Newtonian at f/3.2.

William Herschel discovered NGC 1931 in early 1793, describing it as "very bright, irregularly round . . . seems to have 1 or 2 stars in the middle, or an irregular nucleus." Some three decades later, his son John reported seeing a close triple star at its heart, noting it was a "most curious object." Observers using the 72-inch Leviathan of William Parsons (the Third Earl of Rosse) eventually counted up to six stars. Interestingly, that was sufficient for Swedish astronomer Per Collinder to consider the object an open cluster, and he designated it Cr 68 in his 1931 catalog.

At around two million years of age, NGC 1931 is a young cluster with ongoing star formation hidden away in the H II region. Meanwhile, the main ionizing source of the dusty molecular cloud is probably its two brightest stars, which are hot *B*-types.

Using my 5.1-inch at 59×, the glow of NGC 1931 is only about 1.5′ across and reminiscent of a comet with a roughly 10.5-magnitude star for a nucleus. Switching to my 10-inch at 91×, the nebula is elongated northeast to southwest with a central knot of stars. At 260×, and with good and steady conditions, the knot resolves itself into a trapezium of five stars. Besides imparting the blue glow portrayed in excellent amateur images like the one above, what made me realize the brightest part of NGC 1931 was due to reflection was the fact that my Ultra-High-Contrast-style filter only enhanced the visibility of nebulosity outside the region right around the trapezium (which is an indication of emission).

In his second and final catalog of H II regions published in 1959, well-known American astronomer Stewart Sharpless noted that, photographically, NGC 1931 is merely the brightest part of a 7′-wide emission nebula (Sh 2-237) that predominantly spreads southward. It encompasses Parsamian 1 (named for Armenian astronomer Elma Parsamian), the reflection nebula around an 11th-magnitude star, which is visible in my 10-inch at 135× as a subtle glow off its southern side.

So, if NGC 1931 isn't the brightest emission nebula in Auriga, which one is? Well, going by what I've seen in binoculars, I'd wager it's **IC 405**, the Flaming Star Nebula. However, I'd be remiss if I didn't mention that it, too, contains a reflection component!

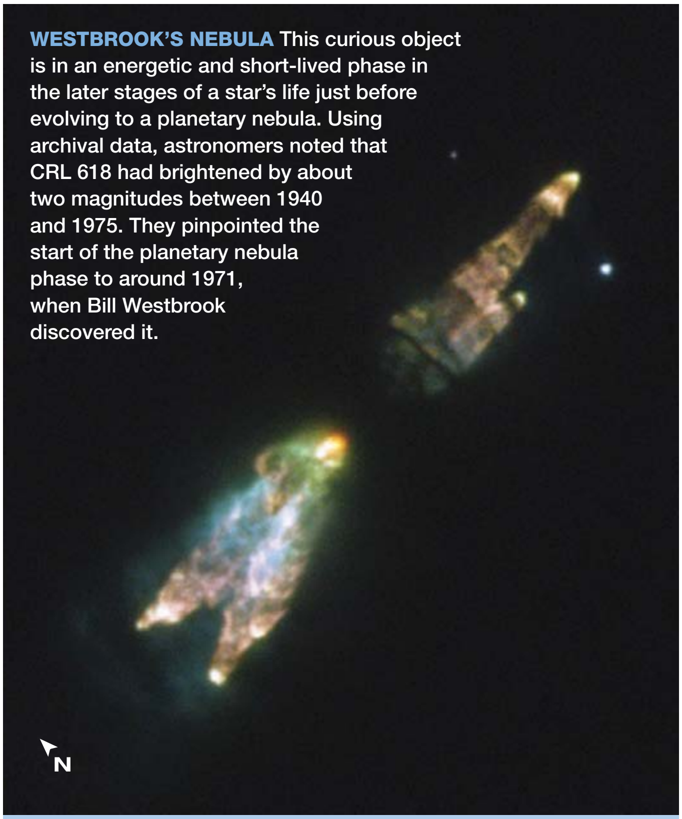
Scan about 4° east-northeast of 3rd-magnitude Iota (ι) Aurigae to reach IC 405. Using my 8×56 binoculars, it's a dull glow around 6th-magnitude AE Aurigae and the double star Espin 170 (magnitudes 7.7 and 11.3, separated by 23.7″) that takes a moment to notice. Looking through my 5.1-inch at 27×, the nebula's glow now extends a ways to the east-northeast of AE Aur. Adding a UHC-style filter, IC 405 expands and brightens considerably, encompassing even the 8.8-magnitude star HD 34010, which lies 18′ north-northwest of AE Aurigae.

Plus, I can even detect Simeis 126 — a faint glow that extends 0.5° west of Espin 170 before turning south!

AE Aurigae is a massive O-type star ionizing the surrounding interstellar cloud as it moves northward at a rate of more than 4″ a century. Fascinatingly, it used to form a binary pair with fellow O-type star Mu (μ) Columbae in the Trapezium Cluster — it seems they were ejected from the Orion Nebula about 2.5 million years ago . . . but in opposite directions! These types of stars have since become known as *runaway* stars.

To me, the most interesting object on our tour is the one that bears the name of a man who has almost been forgotten. The object is a pre-planetary nebula that was discovered in the early 1970s by the young California Institute of Technology graduate student William Westbrook. He found it while engaged in a study of previously unidentified bright infrared sources discovered in the Air Force Cambridge Research Laboratory's rocket-borne survey. Known commonly as Westbrook's Nebula and cataloged as **CRL 618**, the astronomer studied it with many of the largest telescopes of the day and found it to be the most interesting of them all. He postulated that it was "an extremely young planetary nebula, perhaps still in the process of formation."

Using my 10-inch, the eastern half of CRL 618 is just visible as a (by my estimate) 16.3-magnitude speck 4.1° northwest of Iota Aurigae, right at the border with Perseus. In my 16-inch at 440×, the eastern half is a nonstellar spot that with study seems to extend and fade to the west, reminding me of the pre-planetary nebula Minkowski's Footprint (see, e.g., *S&T:* June 2021, p. 57).



WESTBROOK'S NEBULA This curious object is in an energetic and short-lived phase in the later stages of a star's life just before evolving to a planetary nebula. Using archival data, astronomers noted that CRL 618 had brightened by about two magnitudes between 1940 and 1975. They pinpointed the start of the planetary nebula phase to around 1971, when Bill Westbrook discovered it.

A Forgotten Man

Tragically, William Westbrook died of cancer at the age of 25 (in 1975) shortly after submitting his paper on CRL 618 for peer review, leaving behind not only grieving family and colleagues, but also his wife, Joanne. A few years before they met at a school dance in 1968, he developed symptoms that doctors attributed to a tumor in his left lung — rhabdomyosarcoma, a rare type of cancer that forms in soft tissue mostly in children and adolescents.

Bill and Joanne married in 1971, hoping the cancer wouldn't return as he continued to undergo chemotherapy. He was a major force in the Caltech Infrared Lab and developed most of the equipment himself for the observations in his doctoral thesis. Joanne, whom I was fortunate to interview in 2023, remembered that he "had red hair and blue eyes, [was] always upbeat and jolly . . . and always engaged in . . . some project, studying something."

◀ **BILL WESTBROOK** This image, taken in the early 1970s, shows him standing outside the doorway of the "Monastery," the small dorm where visiting astronomers stayed at Palomar Observatory.

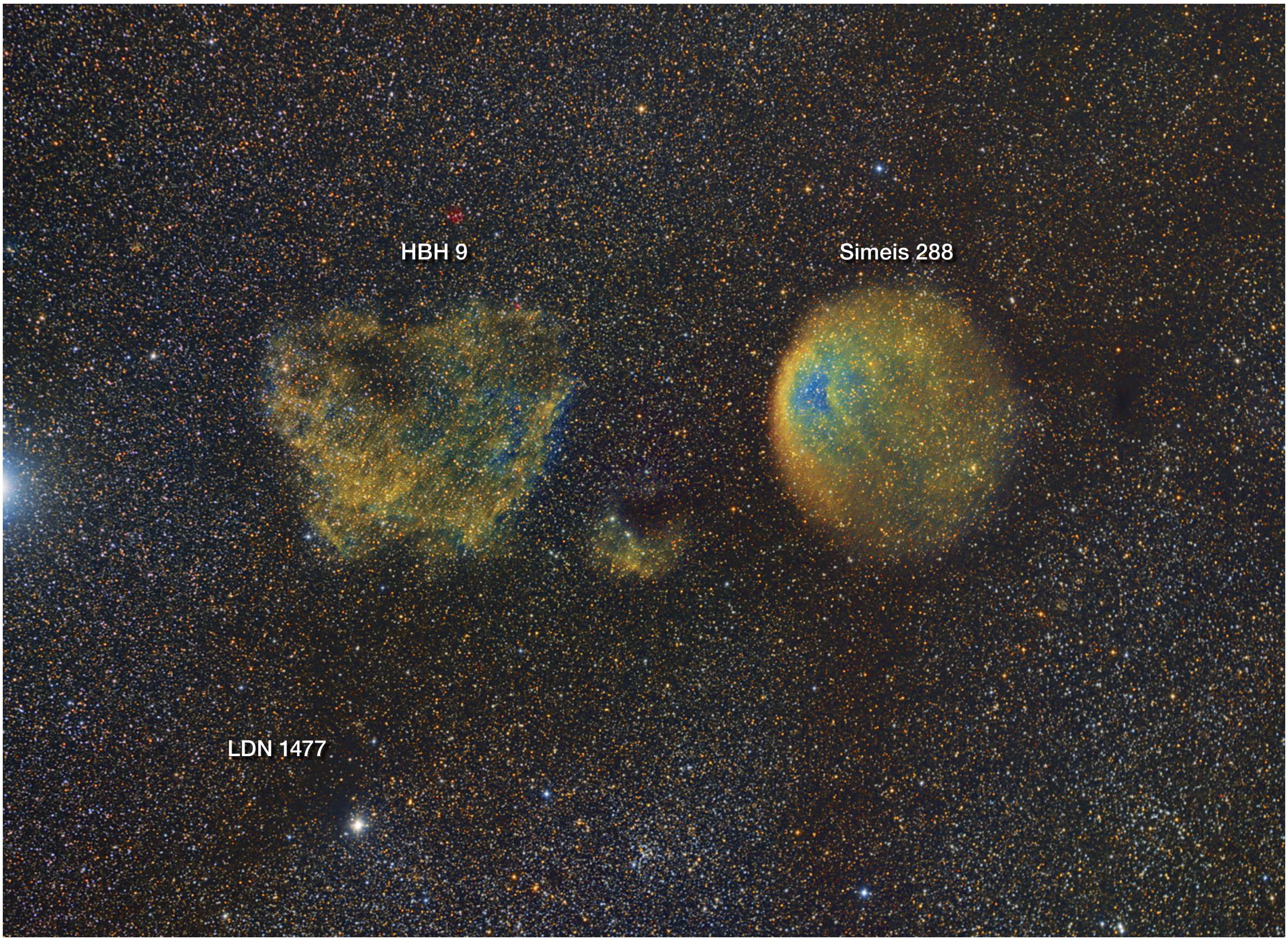
Go Far, Grow Close

Since we're in western Auriga, let's drop south to the globular cluster **Palomar 2**. It lies almost 3° southwest of Iota Aurigae and was first discovered in the 1950s on *National Geographic – Palomar Observatory Sky Survey* plates. But having to look out 85,000 light-years and *through* two of our galaxy's spiral arms (the Perseus and Norma/Outer Arm) has left us with a much dimmer view. In fact, if its light wasn't obscured by nearly three full magnitudes, the globular would be visible in binoculars!

That being said, it's visible in my 5.1-inch scope at 59×. With a detailed chart in hand, care and patience revealed this outer-halo cluster while directly overhead on a dark night. It appeared as a small, ghostly glow 2.2′ west-southwest of a 13.3-magnitude star. It's much easier in my 10-inch at 135×, where it's a mere 1.5′-wide glow.

Over the past couple of years, I've managed to observe three supernova remnants in Auriga using various telescopes. But I honestly can't tell you which one is the brightest since it's a subjective matter when it comes to such large nebulae. Instead, I'm going to focus on **HBH 9** (SNR G160.9+2.6), which was the first one discovered that is wholly within the constellation and currently the one I've seen with the smallest aperture.

CRL 618: ESA / HUBBLE / NASA; WESTBROOK: MICHAEL WERNER / PALOMAR OBSERVATORY



▲ **BORDER GUARDS** This fantastic image captured by Przemysław Ząbczyk shows Capella at the leftmost edge along with two large nebulae of roughly equal size. The one at left is the supernova remnant HBH 9, which resides completely in Auriga, while the nebula on the right is the planetary nebula Simeis 288, which instead is fully in Perseus. But what you can't easily tell is that HBH 9 is more than five times farther away than Simeis 288.

In 1953, Robert Hanbury Brown and Cyril Hazard (both at Jodrell Bank Observatory, England) published a list of 23 "localized" radio sources for which they'd determined fairly accurate coordinates. Many of the positions agreed closely with known radio sources, but a few bright ones had no obvious optical counterparts. The following year, with the help of Rudolph Minkowski (Palomar Observatory), Brown and Hazard matched their source #9 with a large nebula almost 3° west of Capella that consisted of "faint filaments." Their discovery was only the fifth nebula in the Milky Way to be identified with a radio source.

Later in the 1950s, Sharpless included HBH 9 in his second catalog of emission nebulae as Sh 2-221. But it was Sidney van den Bergh (University of Toronto) who in 1960 was the first to identify the 2°-wide nebula as a possible supernova remnant. Today, we know that HBH 9 lies approximately 1,800 light-years away and is between 4,000 and 7,000 years old.

Photographically, the object's eastern and western sides are the brightest. Cataloged as LBN 759 and LBN 754, respectively, I've yet to see either without using a nebula filter in my scopes. However, I can report that HBH 9 is unique for having a 0.75°-wide section centered near right ascension $5^h 04^m$ and declination +46° 30′ (part of LBN 759) that became faintly visible in my 6-inch reflector at 37× when I used a hydrogen-beta filter. Truthfully, though, I'll be spending more time on this one this new year!

I know that cold temperatures can make observing in the winter more demanding. But the region towards the Galactic Anticenter is so full of bright, exciting objects that you simply must explore it. As I like to say, Auriga truly *has it all!*

■ The research for this article took Contributing Editor **SCOTT HARRINGTON** on quite a journey. When he dreamed it up, he knew nothing about the discoverer of CRL 618, nor had he even heard of UGC 3596 or HBH 9! Now he wishes to thank Eric Becklin, Michael Werner, Steve Beckwith, and Ian Gatley for sharing their memories of their former colleague Bill Westbrook.

Upcoming Solar Eclipses: 2025 to 2035

Here's your guide to when and where to watch the Moon cross in front of the Sun.

Without question, interest in solar eclipses is at an all-time high. During last April's Great North American Eclipse, countless millions of people watched the new Moon pass between the Sun and Earth and cast its shadow across the continent. In the days leading up to this long-awaited event, electronic highway signs along the path of totality warned drivers of terrible traffic jams, while officials worried that the eclipse would be like "20 or 30 Super Bowls all at once." And yet, even in the event's often-chaotic aftermath, the most frequently asked question became, "When can I experience this amazing sight again?"

It's never too early to begin planning your next eclipse adventure — or your first. To help, we've compiled a rundown of what you can look forward to in the coming decade. A total solar eclipse is not only one of nature's greatest spectacles, but it also provides the perfect excuse to travel to a part of the world that you've long wanted to visit.

From January 2025 to December 2035, the shadow of the Moon falls upon Earth two dozen times, resulting in seven total, eight annular, one hybrid annular-total (more about that later), and eight partial eclipses. Each continent will experience at least one eclipse.

An Eclipse Menagerie

When the center of the Moon's disk crosses the center of the Sun, we get what is referred to as (naturally enough) a *central eclipse*. There are two kinds of central eclipses: *total* and *annular*. Total eclipses are the most spectacular. They can only occur when the *umbra* — the dark, inner core of the Moon's conical shadow — makes contact with Earth's surface. On such occasions the disk of the Moon

◀ **TOTALLY TRANSFIXED** The sight of a total solar eclipse is something no one forgets. These eclipse chasers are viewing the November 3, 2012, event from a location in Queensland, Australia. That eclipse was part of saros cycle 133. The next one in that cycle occurs 18 years later, on November 25, 2030.

TOTAL ECLIPSE SEQUENCE: OLEG BOUEVITCH; ECLIPSE VIEWERS: GARY SERONIK

ECLIPSE EVOLUTION From first contact to last, most total eclipses take about two hours to unfold completely. However, the most exciting phase by far is totality — the always-too-brief moments when the Moon completely covers the Sun. Eclipse chasers travel the world to experience the wonder and excitement of standing in the Moon's shadow. The coming decade offers eight opportunities to take in totality.

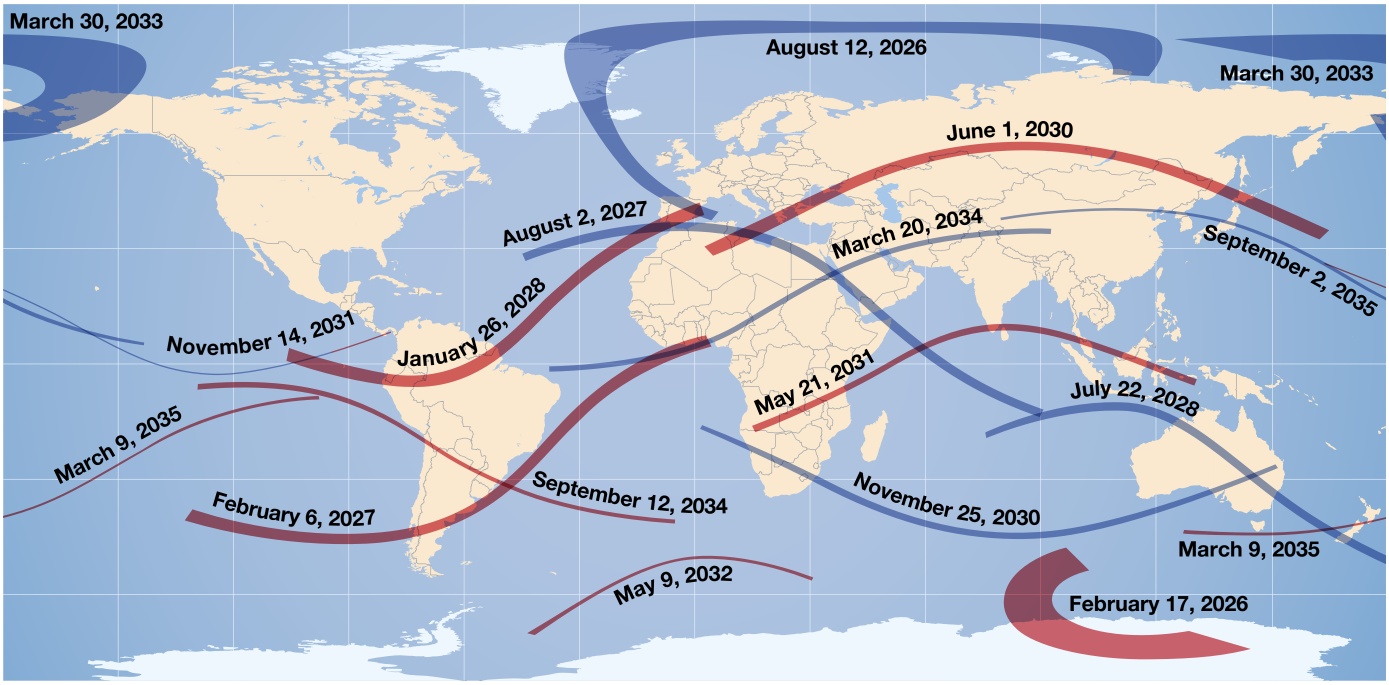
appears slightly larger than that of the Sun and blots out the blindingly bright solar photosphere, revealing crimson prominences and the feathery, ethereal corona. But because the Moon's orbit around Earth is elliptical, the apparent size of the lunar disk varies by as much as 14%. At times the Moon may be too far away and, therefore, appear too small to completely hide the Sun. On those occasions, we get annular eclipses, a name derived from the Latin *annularis* ("ring-shaped") for the thin ring of sunlight that remains at mid-eclipse.

The Moon's umbral shadow is surrounded by a vast outer shadow called the *penumbra*. Observers positioned within the penumbra see the Sun only partially obscured — the nearer you are to the umbra, the greater the portion of the solar disk that the passing Moon covers. If you're not on the centerline during a total eclipse, you'll experience a partial solar eclipse. However, when the Moon's path doesn't take it across the center of the Sun, only the penumbral shadow reaches Earth. As a result, we witness an eclipse that's exclusively partial.

Partial Solar Eclipses 2025 – 2035

Date	Magnitude*	Area of Visibility
March 29, 2025	0.938	Northeastern North America, most of Europe, northwestern Africa, northwestern Russia
September 21, 2025	0.855	Coastal plain of New South Wales, Australia, New Zealand, Antarctica
January 14, 2029	0.871	North America (except most of Alaska, and Northwest Canada), southern Greenland
June 12, 2029	0.458	Arctic, Scandinavia, northern Russia, Alaska, northwestern Canada
July 11, 2029	0.230	Southern portions of Chile and Argentina and Graham Land, Antarctica
December 5, 2029	0.891	Southernmost Chile and Argentina, Antarctica
November 3, 2032	0.855	Most of Asia
September 23, 2033	0.689	Southern third of South America, Antarctica

*Magnitude indicates the fraction of the Sun's diameter that the Moon obstructs.



▲ **ECLIPSE PATHS** The map above displays the coming decade of central eclipses. The paths colored red refer to annular eclipses, while those in blue are total. As this illustration makes clear, if you live in the contiguous U.S., Canada, or Mexico, you'll have to travel to enjoy one of these eclipses.

SKY & TELESCOPE, SOURCE: FRED ESPENAK

The table presented on page 27 gives details for the next decade's partial eclipses. The *magnitude* is defined as the maximum fraction of the Sun's diameter the Moon eclipses measured along a line connecting the centers of their disks. The closer the magnitude is to 1.000, the greater the surface of the solar disk covered. The magnitude depends on how near or far you are from the location of maximum eclipse. For example, during the partial event on January 14, 2029, the greatest magnitude (0.871) will be at a point 137 kilometers (85 miles) north of Yellowknife, the capital of Canada's Northwest Territories. Over parts of Washington State, Idaho, Montana, and North Dakota, the magnitude exceeds 0.800. But at San Jose, Costa Rica, the magnitude is only 0.074, and at Anchorage, Alaska, no portion of the Sun is obscured (the magnitude is zero).

As interesting as a partial eclipse like the ones coming this March and September can be, they're nothing compared to the splendor of a total or even an annular eclipse.

Total and Annular Eclipses

The map shown above displays all 16 central eclipses. Eight are annular, seven are total, and one is a special type known as a *hybrid* eclipse (more about this later). Let's look at the specifics of each eclipse in the coming decade. The summaries presented here were compiled using data from **EclipseWise.com** — an excellent, information-rich resource maintained by noted eclipse expert Fred Espenak.

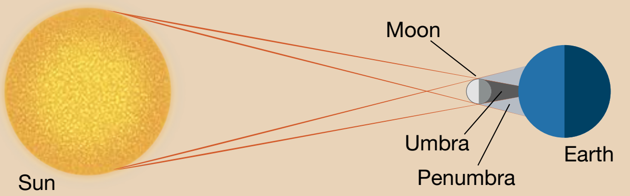
February 17, 2026 After an entire year of only partial eclipses, we finally get an annular. However, the path of this event lies mostly over Antarctica, where it sweeps across portions of Victoria Land, Wilkes Land, and East Antarctica. The point of greatest eclipse occurs over the Southern Ocean, where annularity reaches a maximum of 2 minutes 20 seconds ($2^m\ 20^s$).

August 12, 2026 The Moon's dark umbral shadow strikes Earth at local sunrise in the far north of Russia, over the eastern portion of the Taymyr Peninsula. The lunar shadow moves quickly due north into the Arctic Ocean, sideswipes the North Pole, and then streaks south through eastern Greenland. The point of greatest duration occurs over the North Atlantic just west of Iceland, where totality lasts 2^m 18^s. A slice of western Iceland, including the capital city of Reykjavík, finds itself within the path of totality and sees the new Moon blot out the Sun for 60 seconds, beginning at 17:48 UT. The shadow path then curves southeast and passes west of the British Isles before arriving in northern Spain, where it brings the glorious spectacle of totality to the cities of Bilbao, Zaragoza, and Valencia. Madrid, however, lies just south of the central line and sees a 99.8% sunset partial at 8:32 p.m. local daylight time. The shadow then sweeps rapidly over the island of Mallorca before lifting back into space over the Mediterranean Sea. This will be a very popular event, and several tours are already filling up — including ones operated by this magazine. (See **skyandtelescope.org/tours** for details about upcoming eclipse tours.)

February 6, 2027 The path of this annular eclipse begins in the South Pacific and spends its first 45 minutes over open water before making landfall in southern Chile. Quickly mov-

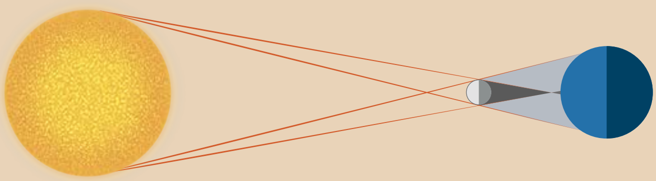
ECLIPSE FLAVORS The three main types of solar eclipse are displayed here. When the Moon is close enough to cast its shadow on Earth (top), we get a total eclipse. However, if the Moon is too far away for the lunar disk to completely cover the Sun (middle), we see an annular eclipse. And if only the outer portion of the lunar shadow — the *penumbra* — reaches Earth's surface (bottom), we experience a partial eclipse.

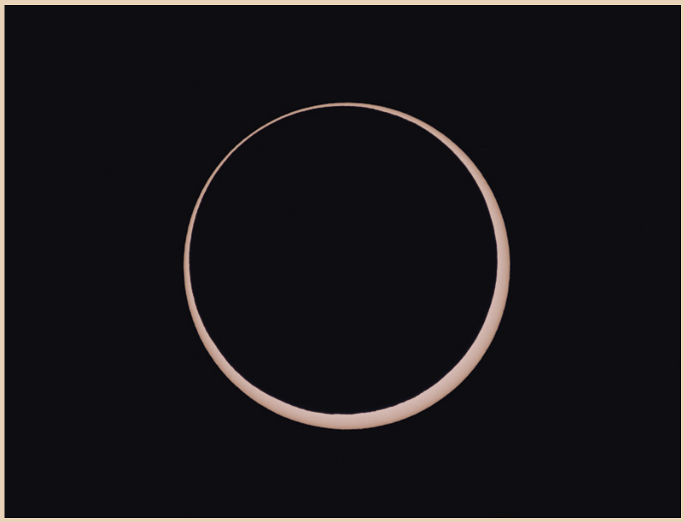
Total



▶ **MIDDAY DARKNESS** Everyone who has experienced a total solar eclipse knows that the sudden arrival of darkness affects all living creatures. During totality, flowers close, birds return to their roosts, and people stare skyward, transfixed by the spectacle.

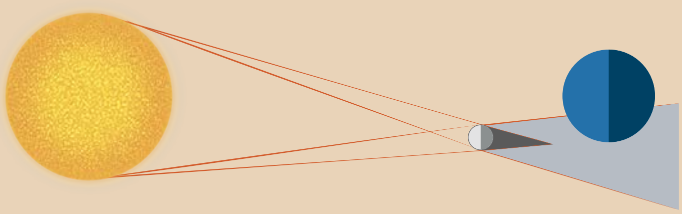
Annular





▶ **SOLAR RING** Annular eclipses are a breed apart. Unlike during totality, protective solar filters must be used at all times — at no point is the Sun's blindingly bright photosphere completely obscured by the Moon. Annulars, like the October 2023 eclipse portrayed here (captured from a location south of the centerline), occur when the Moon is far enough from Earth that its disk appears too small to completely cover the Sun.

Partial



▶ **CLOSE BUT NO CIGAR** A partially eclipsed Sun can perhaps best be described as "interesting" rather than "spectacular." As the table presented on page 27 indicates, the next decade has eight events that are partial only. This photo shows the October 2014 partial eclipse, which occurred around the time of solar maximum, when the Sun's face was dotted with numerous, impressive sunspots.

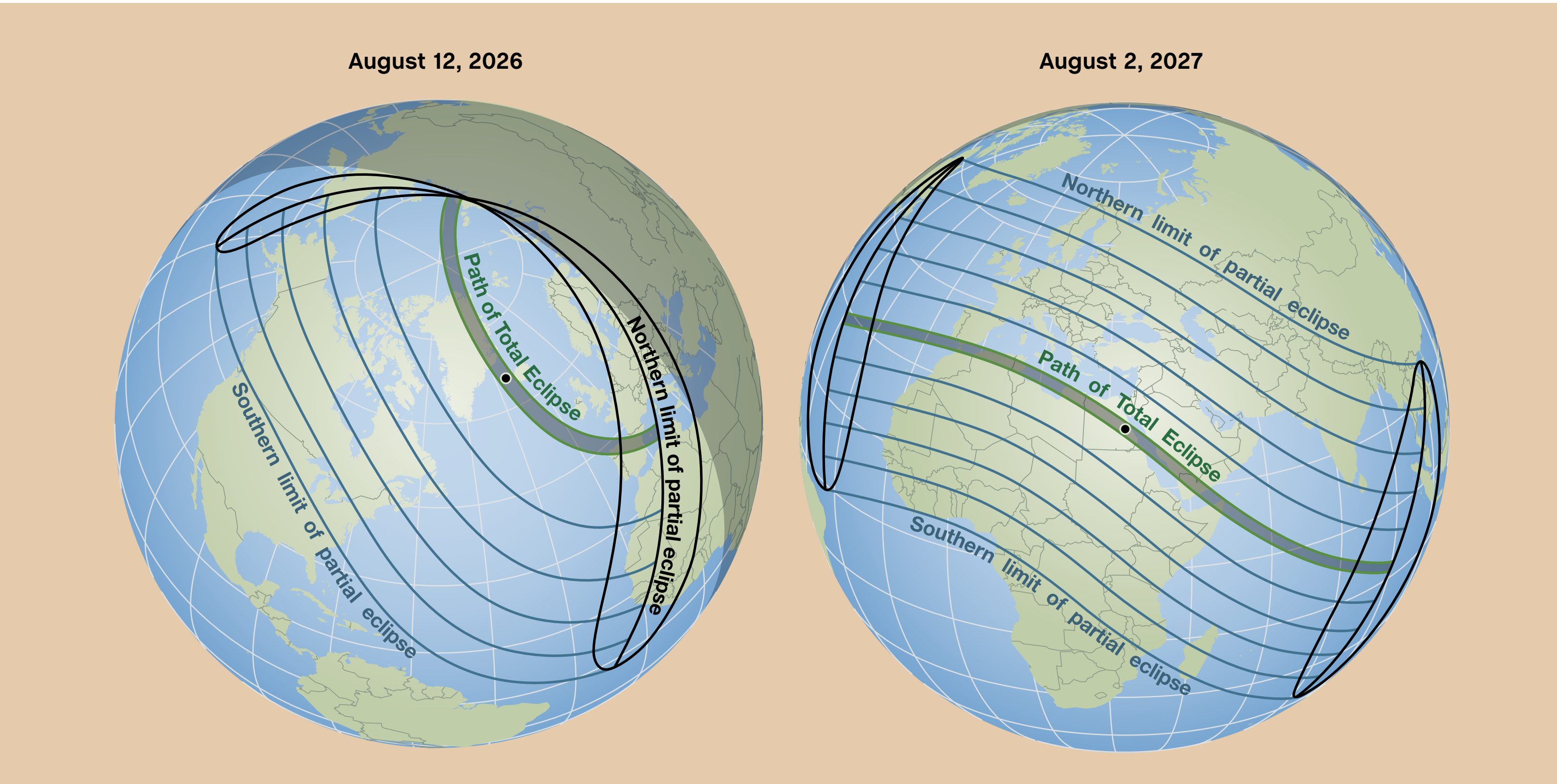
ECLIPSE TYPES: LEAH TISCIONE / *S&T*; TOTALITY: SEAN WALKER; SOLAR RING: ALAN DYER; PARTIAL ECLIPSE: GARY SERONIK ing into southeastern Argentina and along the Atlantic coast of Uruguay, the path of annularity passes southeast of the Uruguayan capital, Montevideo, where at maximum (12:36 p.m. local time) the Sun resembles a horseshoe with pointed tips. Greatest eclipse occurs at 16:00 UT over the South Atlantic Ocean, 285 km southeast of Porto Alegre, Brazil, with the ring phase lasting a generous $7^m\ 50^s$. After a 78-minute jaunt across the Atlantic Ocean, annularity reaches the African coast, sweeping rapidly through southern sections of Côte d'Ivoire, Ghana, Togo, Benin, and southwestern Nigeria, where observers in Lagos can watch the Sun set as a fiery ring.

August 2, 2027 This highly anticipated eclipse is a member of the same saros cycle (*S&T:* Jan. 2024, p. 60) that has produced some of the longest totalities in recent history. Saros 136's lineage dates back to 1360 and more recently includes the eclipses of 1937, 1955, and 1973 — each boasting totality exceeding seven minutes! The July 11, 1991, eclipse, which passed across Hawai'i and Mexico and is often referred to as The Big One, is also a member of this exclusive group. The August 2, 2027, eclipse maxes out at $6^m\ 23^s$, providing the longest totality until the year 2114. And if that weren't enticing enough, the path crosses some popular destinations. (Eclipse tours are already taking bookings.)

Beginning in the Atlantic, roughly 3,700 km west-southwest of Tangier, Morocco, the Moon's umbral shadow takes only about 20 minutes to reach the Strait of Gibraltar, where totality lasts a healthy $4^m\ 45^s$, with the Sun nearly 40° high in the eastern sky. Proceeding east-southeast, the path of totality cuts across swaths of Algeria, Tunisia, Libya, and Egypt, while also skirting the southern Mediterranean. Greatest duration occurs not far southeast of Luxor, in Egypt, where totality begins at 1:03 p.m. local daylight time with the Sun 82° high. After crossing the Red Sea, the umbral shadow skirts southern Saudi Arabia, briefly touches Yemen, slices across the Gulf of Aden, and clips northernmost Somalia before departing our planet over the Indian Ocean.

January 26, 2028 An exceptionally long-lasting annular eclipse crosses the Galápagos Islands as well as parts of Peru, Ecuador, Brazil, Colombia, Suriname, and French Guiana. The largest South American city to witness the "ring of fire" is Manaus, the capital of the Brazilian state of Amazonas. There, starting at 10:24 a.m. local time, annularity lasts $7^m\ 11^s$. Near Brazil's northeastern coast, greatest eclipse occurs at 15:08 UT, lasting $10^m\ 27^s$. After leaving South America, the eclipse path heads northeast for a 105-minute trek across the Atlantic Ocean, making landfall over regions that also experienced totality in August 2026 and August 2027. The event is visible from Seville (duration $7^m\ 15^s$), Gibraltar ($4^m\ 00^s$), and Valencia ($7^m\ 02^s$).

July 22, 2028 For the first 78 minutes, the path of this total eclipse falls over the open waters of the Indian Ocean. When it comes ashore in the Kimberley region of Western Australia, the duration of totality is approaching its maximum.

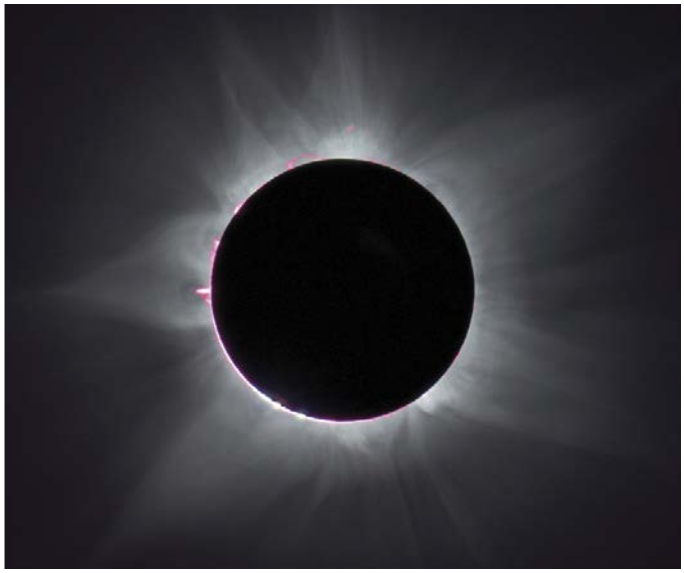


ALL ECLIPSE GLOBES: *SKY & TELESCOPE*, SOURCE: FRED ESPENAK

That happens within Mitchell River National Park, 2,140 km northeast of Perth. Here totality lasts a substantial 5^m 10^s starting at 10:50 a.m. local time. For the next 66 minutes, the Moon's umbral shadow tracks southeast across Australia and scores a direct hit on Sydney, the country's most populous city. Beginning at 1:59 p.m. local time, the Sun will be extinguished for 3^m 49s, standing 29° high in the northwestern sky. Before leaving Earth's surface over the South Pacific, the eclipse path passes over the South Island of New Zealand, bringing nearly three minutes of late-afternoon darkness to Queenstown and Dunedin.

June 1, 2030 This annular eclipse starts at sunrise over north-central Algeria, then sweeps northeast, encompassing parts of Tunisia, Libya, Greece, Bulgaria, and Turkey. The two largest cities within the eclipse path are Athens (duration 4^m 00^s) and Istanbul (4^m 32^s). Greatest eclipse occurs over southern Russia, where annularity lasts 5^m 21^s. Now heading southeast, the eclipse tracks across northern China and Hokkaido, Japan, before finally concluding at sunset over the Pacific Ocean.

November 25, 2030 The path of this total eclipse begins over the South Atlantic Ocean, then quickly heads southeast through Namibia, Botswana, South Africa, and Lesotho before moving out over the Indian Ocean, where greatest duration occurs about 650 km north of the group of islands known as the French Southern and Antarctic Lands.

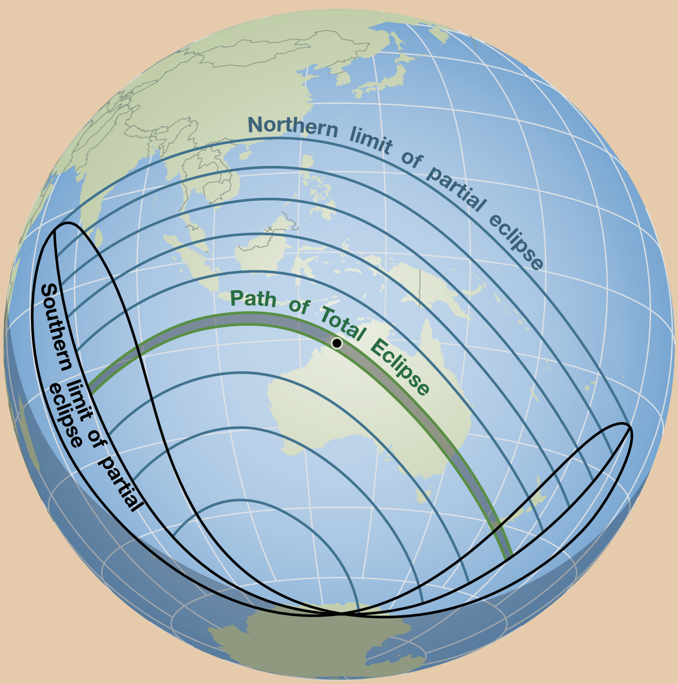


▲ **ECLIPSE RARITY** The least frequent type of solar eclipse is a hybrid annular-total. This photo is from the most recent one, which occurred in April 2023. The next hybrid eclipse doesn't happen until November 14, 2031. During a hybrid, the eclipse is annular at the beginning and end of the central path and total along the rest of its length.

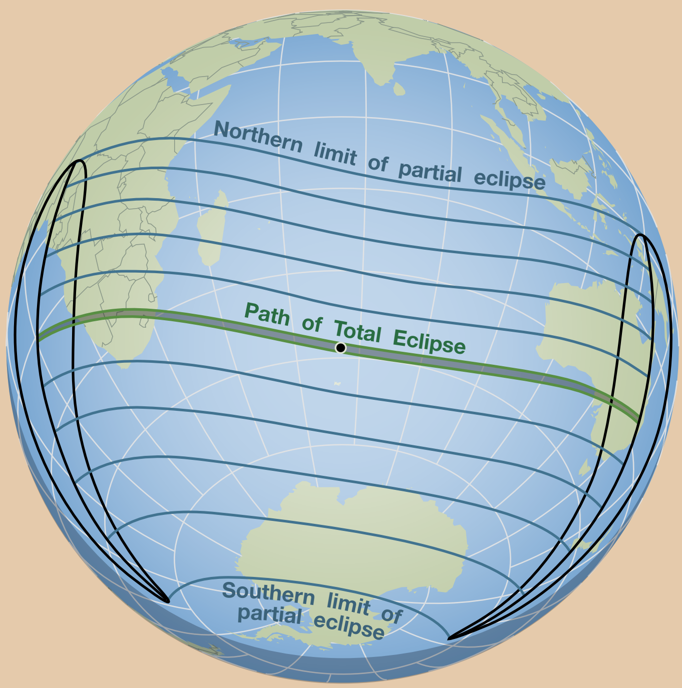
HYBRID ECLIPSE: GARY SERONIK

Here totality lasts 3^m 44^s. One and a half hours later, now moving on an east-northeast trajectory, the umbra makes its second landfall at South Australia's Eyre Peninsula and spends its final five minutes streaking across New South

July 22, 2028



November 25, 2030



Wales and Queensland before departing Earth at sunset, 225 km north of Brisbane.

May 21, 2031 Beginning over southern Angola, this annular eclipse crosses Zambia, the Democratic Republic of the Congo, and Tanzania, including Dar es Salaam, East Africa's most populous city. Eclipse watchers there get three minutes of annularity. At 7:15 UT, greatest eclipse occurs over the western Indian Ocean, with a duration of $5^m\ 26^s$. Twenty minutes later the eclipse path moves over southern India and northernmost Sri Lanka. Nearly an hour later, annularity crosses the border separating Thailand and Malaysia, and then continues on to Borneo and Celebes before leaving Earth at sunset over the Indonesian island of Seram.

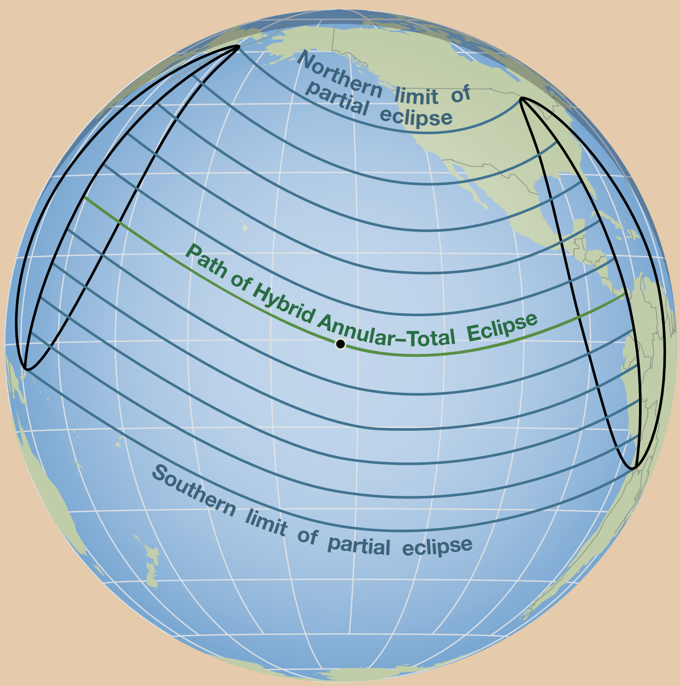
November 14, 2031 There are 224 solar eclipses during the 21st century, but only seven are *hybrid* annular-total events. Along the central line, such an eclipse starts out as annular, then transitions to total, before returning to annular at the path's end. This apparent sleight of hand is due to Earth's curvature — the portion of our planet that bulges toward the Moon just reaches the tip of the umbral shadow. The November 14th eclipse is one of these rare hybrid eclipses, the most recent previous one having occurred in April 2023. Unfortunately, virtually the entire length of the eclipse track lies on the open waters of the Pacific Ocean. Greatest duration occurs about 3,000 km southeast of the Big Island of Hawai'i, where totality lasts just 68 seconds within a shadow path that measures only 38 km wide. Transitioning back to annularity, the eclipse finally concludes at sunset over the Gulf of Panama.

May 9, 2032 The path of this remote and brief annular eclipse lies entirely over the South Atlantic Ocean. The solar ring is exceedingly thin — measuring only 0.4% of the Sun's diameter for much of the eclipse track. As a result, even at the sunset point where the ring widens slightly, the duration of annularity is only 43 seconds.

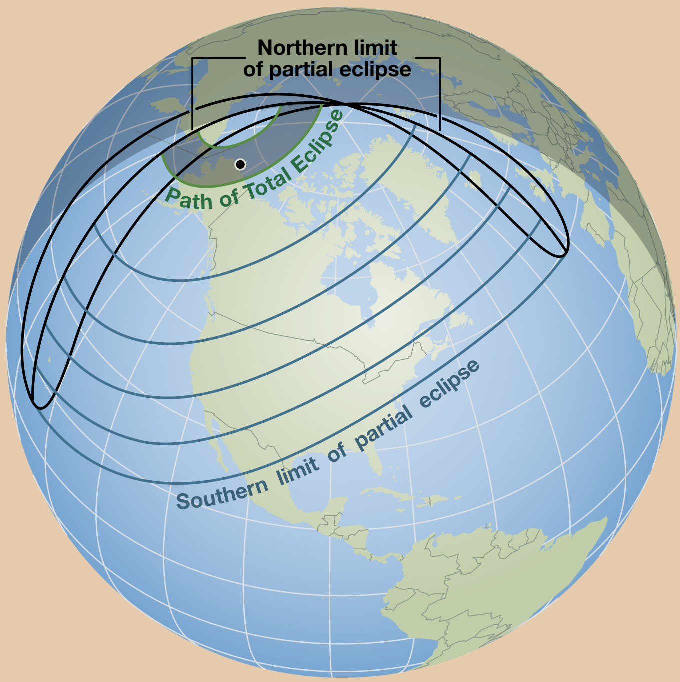
March 30, 2033 Because the Moon's shadow strikes Earth at a very oblique angle during this total eclipse, the Sun's altitude doesn't exceed 11° along the central line, and the path of totality is very wide at 834 km. Anomalously, this eclipse also begins and ends at sunrise. Totality sweeps from eastern Russia's Chukchi Peninsula to the northern and western portions of Alaska. From Nome, Alaska, totality lasts $2^m\ 30^s$, with the Sun low (8°) above the eastern horizon. The eclipse is longest ($2^m\ 37^s$) just off Alaska's northernmost coast.

March 20, 2034 Beginning in the Atlantic Ocean near the equator, the Moon's umbral shadow crosses Africa, Saudi Arabia, Kuwait, Iran, Afghanistan, Pakistan, and northern India before finally exiting at sunset in Tibet. Once again, Lagos, Nigeria, is favored with a central eclipse, but this time it gets to enjoy $2^m\ 33^s$ of totality. The point of greatest duration is in eastern Chad, where totality lasts $4^m\ 09^s$.

November 14, 2031



March 30, 2033



September 12, 2034 The first half of this annular eclipse occurs over the Pacific Ocean, but for about an hour, beginning at 16:26 UT, the path of annularity moves along a southeast trajectory from northern Chile to southernmost Brazil. Greatest eclipse is 2^m 58^s, occurring off the coast of Peru. The largest city in the path of annularity is Porto Alegre, in Brazil, which sees the Sun morph into an off-centered ring for 2^m 18^s beginning at 2:24 p.m. local time. The spectacle comes to an end about 40 minutes later at sunset over the South Atlantic Ocean.

March 9, 2035 The next eclipse is also annular and occurs almost entirely over the South Pacific Ocean. However, it begins at sunrise south of Australia, nearly skims the southern coast of Tasmania, then moves across New Zealand. The path's southern limit passes just north of the capital city of Wellington. Moving back out over open ocean waters, greatest eclipse occurs in the South Pacific, where annularity lingers briefly for 48 seconds. The event concludes about 2,000 km west of the Peruvian coast.

September 2, 2035 For the final eclipse in our survey, totality begins in western China and then extends eastward, passing over North Korea and onwards into central Japan. Several large cities lie within the path of the umbral shadow, including the capital of China, Beijing, and Pyongyang, the capital of North Korea. Tokyo, Japan, is just outside the southern limit of totality and witnesses a 99.4% partial eclipse. The point of greatest duration (2^m 54^s) occurs over the Pacific Ocean, about 1,900 km east-southeast of Tokyo. The umbra departs Earth's surface at sunset 2,200 km southeast of the Hawaiian Islands. This event is part of the same saros family (145) as the Great American Eclipse of August 21, 2017, which many of this magazine's readers experienced.

Joining the Great Chase

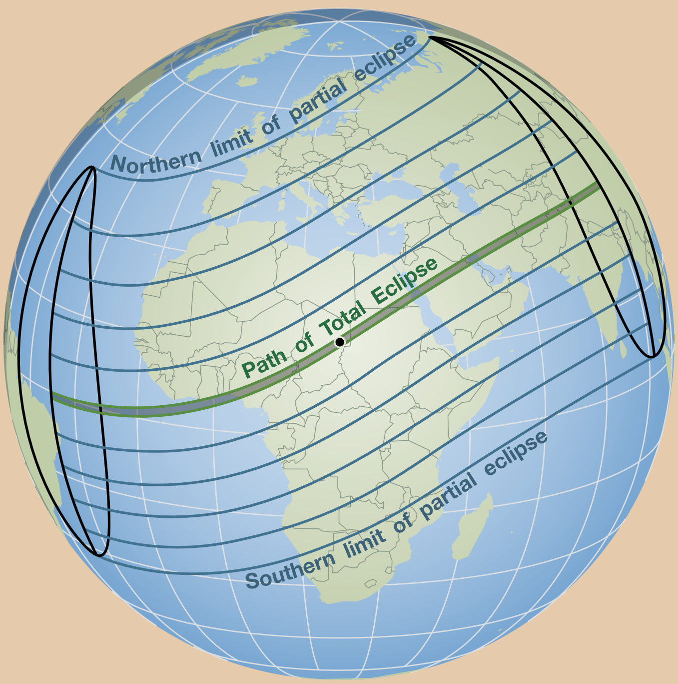
If you haven't yet witnessed a total solar eclipse, you may be wondering why anyone would be tempted to chase the Moon's shadow to some of the most remote corners of the globe? There are probably as many reasons as there are people who delight in the excitement of totality. No other celestial event evokes such intense and varied responses. Totality truly is one of those rare things that has to be seen to be believed.

Possibly the greatest benefit from eclipse-chasing is the opportunity to meet people from many different cultures. But eclipse chasers also get to experience a direct connection with the universe and an appreciation of our small place within it by watching its grand celestial clockwork ceaselessly ticking away, creating wondrous alignments of the Sun, Moon, and Earth.

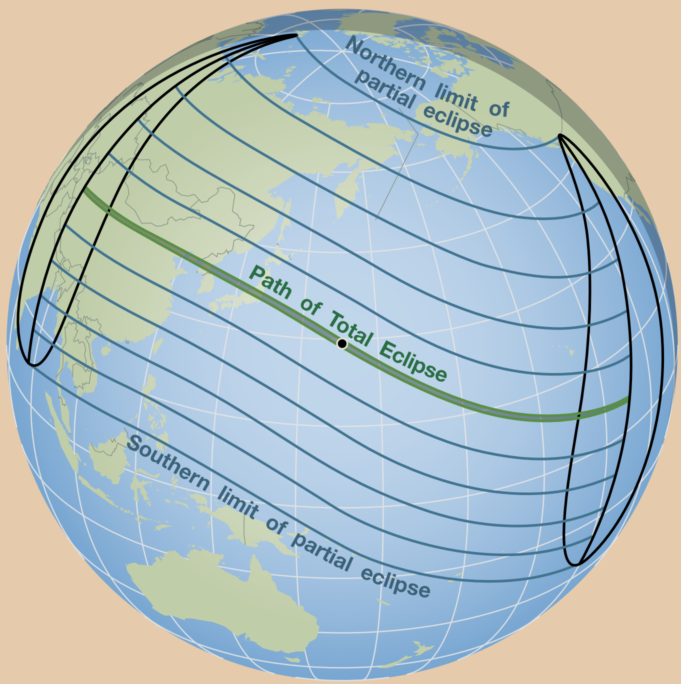
Let curiosity get the better of you and give eclipse-chasing a try. You'll be glad you did.

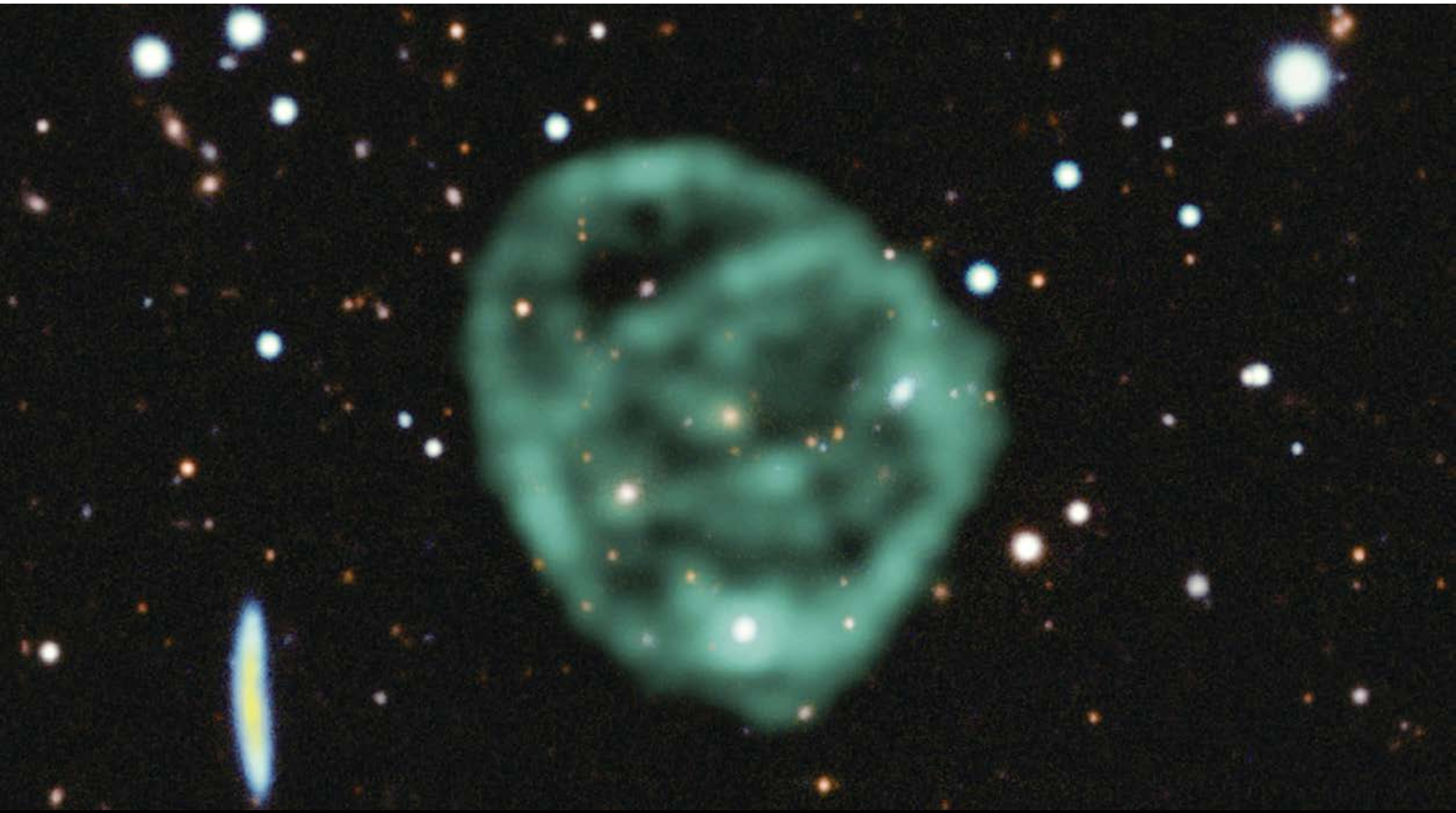
■ Starting with his first total solar eclipse in 1972 (see page 6), **JOE RAO** has basked in the Moon's umbral shadow for a total of nearly 34 minutes spread over 14 eclipses.

March 20, 2034



September 2, 2035





Odd Radio Circles

When astronomers discovered monstrous rings in the radio sky, they began a journey to uncover the objects' origins.

Gigantic circles of radio emission, spanning an arcminute or more, popped out of the first images from an ambitious survey called the Evolutionary Map of the Universe (EMU). The features look like round, edge-brightened thumbprints in fields otherwise covered in the smaller blots and dots that mark entire galaxies.

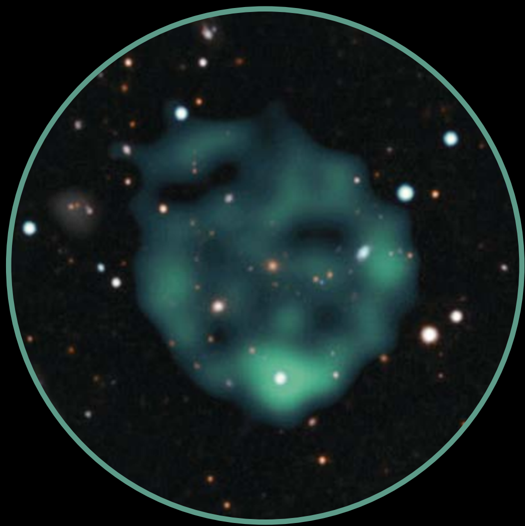
Undertaken with the Australian Square Kilometre Array Pathfinder (ASKAP), EMU's aims include tracing the cosmic history of stars and black holes in galaxies as they evolve over time. Ray Norris (Commonwealth Scientific and Industrial Research Organisation, Australia), who founded the unprecedentedly sensitive survey, knew one thing before the project even started: It would find novel things.

"I actually predicted in a paper, we're almost certain to find new types of objects," Norris says. But he thought it would be difficult, requiring advanced computing techniques. He continues with a smile: "So the first bit of my prediction was right; the second bit was totally wrong."

In fact, members of the EMU team were reviewing the very first tiles of the survey by eye when they found what are now called *odd radio circles*, or ORCs for short. But while those initial discoveries may have been eureka moments, understanding the oddly symmetrical shapes has taken years. Now, after observing the rings with other telescopes, analyzing additional data, and running simulations, the team thinks they've arrived at an explanation:

▲ **SMOKE RING** Radio data (green) superimposed on a visible-light view shows Odd Radio Circle 1, or ORC 1. The radio data, which come from a sensitive array known as MeerKAT, fill in details in the circle discovered by the Australian Square Kilometre Array Pathfinder (ASKAP).

JAYANNE ENGLISH (UNIVERSITY OF MANITOBA), WITH SUPPORT FROM RAY NORRIS, JORDAN COLLIER AND THE EVOLUTIONARY MAP OF THE UNIVERSE TEAM, DATA FROM MEERKAT AND THE DARK ENERGY SURVEY AT CERRO TOLOLO INTER-AMERICAN OBSERVATORY



▲ **DISCOVERY** The original image of ORC 1 shows a circle spanning more than 1 arcminute. If the circle is associated with the galaxy at its center (not shown in this radio image), then it's more than 1 million light-years across.

ORCs appear to be the result of gargantuan shock waves sweeping through intergalactic space.

The question remains, however: What created them?

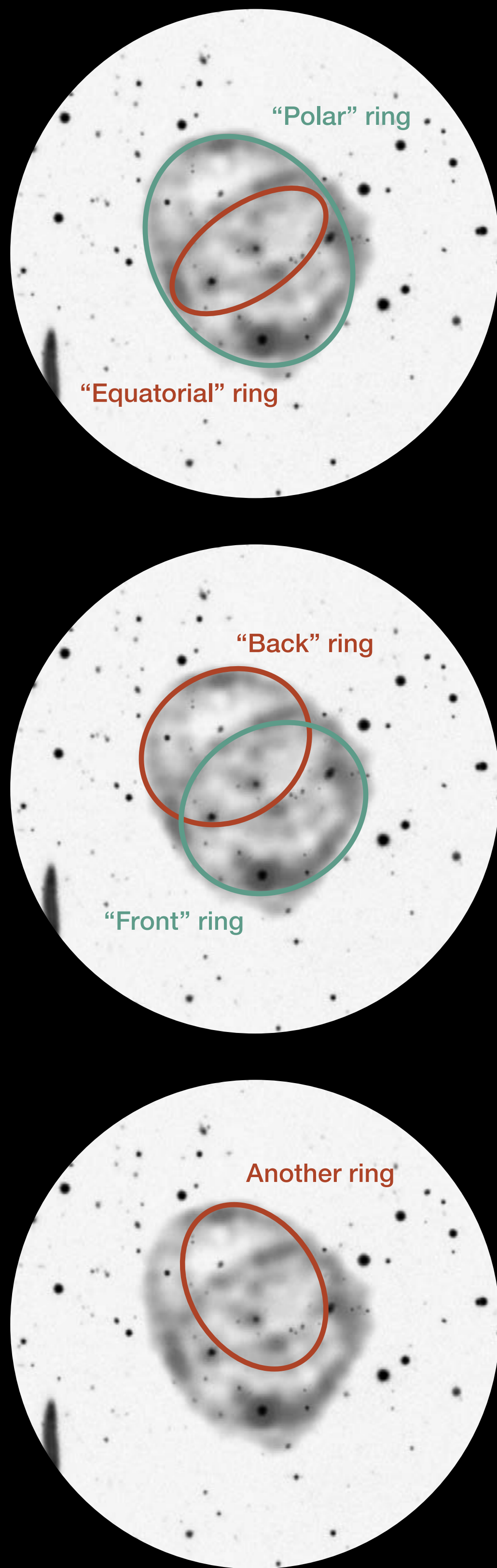
An Unexpected Journey

ORCs were actually discovered more than once in what Norris calls "an interesting bit of sociology."

Anna Kapinska (National Radio Astronomy Observatory) presented the first odd ring of radio emission at a conference in late 2019. She showed a black-on-white image, constructed from radio data, of a thick, fuzzy ring. She labeled it on the slide as one of Norris's coveted "WTF objects." (Here, WTF is supposedly short for "widefield outlier finder," the name of an algorithm he'd intended to use to find such objects.)

Yet neither Norris nor members of the team followed up on that discovery. It was only a couple of weeks later, when Emil Lenc (CSIRO, Australia) sent a tile of EMU data to Norris, that a second find caught Norris's attention. "He'd found this really dramatic circle," Norris says. "And that's when we got excited." That object also appeared as a ring, again spanning an arcminute, but this time crisscrossed with fuzz.

Lenc's discovery still stands as ORC 1; Kapinska's is ORC 2. (The two are located in the southern constellations Pavo and Indus, respectively.) Only a year later, when putting together a more exact chronology, did Norris realize that Kapinska had found hers first.



▶ **RINGS, RINGS, RINGS** These mark-ups show three possible interpretations of the details revealed in a higher-resolution image of ORC 1, taken by the MeerKAT radio array in South Africa.

Norris soon found a third ORC near Kapinska's circle (the two are probably a pair). By the time his team published the discoveries in 2021, the researchers had found a fourth circle in the archives of India's Giant Metrewave Radio Telescope and a fifth in new ASKAP data. With a growing number of discoveries, Norris and his CSIRO colleague Bärbel Koribalski estimated there might be 1,000 ORCs in the sky, hidden in plain sight because they are so faint and spread out.

Initial appearances were deceiving, though. More than five years after the first discovery, ORCs still number less than a dozen, with a number of additional candidates of undecided status. "I had expected to find many more ORCs," Koribalski says, "especially since EMU is now about 20% complete."

"It's embarrassing," Norris admits. "I still don't understand why we haven't found more."

At first, it was easier to say what ORCs are *not* than what they *are*. For example, Norris saw right away that ORC 1 wasn't simply an imaging artifact, because it had been imaged multiple times in the EMU survey and appeared in different places in different fields. A ring of the same size also showed up in data from other radio arrays.

With artifacts ruled out, the question then became what created the rings. Unfortunately, the radio waves show no absorption or emission lines with which to measure the rings' distance and, therefore, their true size.

The simplest explanation initially was that the phenomena came from supernovae within our galaxy that had blasted out bubbles of gas. Those bubbles appear as rings because more material is piled up along our line of sight on the edges; the middle region, even when filled in, appears more transparent. Such gaseous, star-blown shells litter the Milky Way. What's more, a nearby origin could explain the ORCs' large span on the sky, because closer things look bigger.

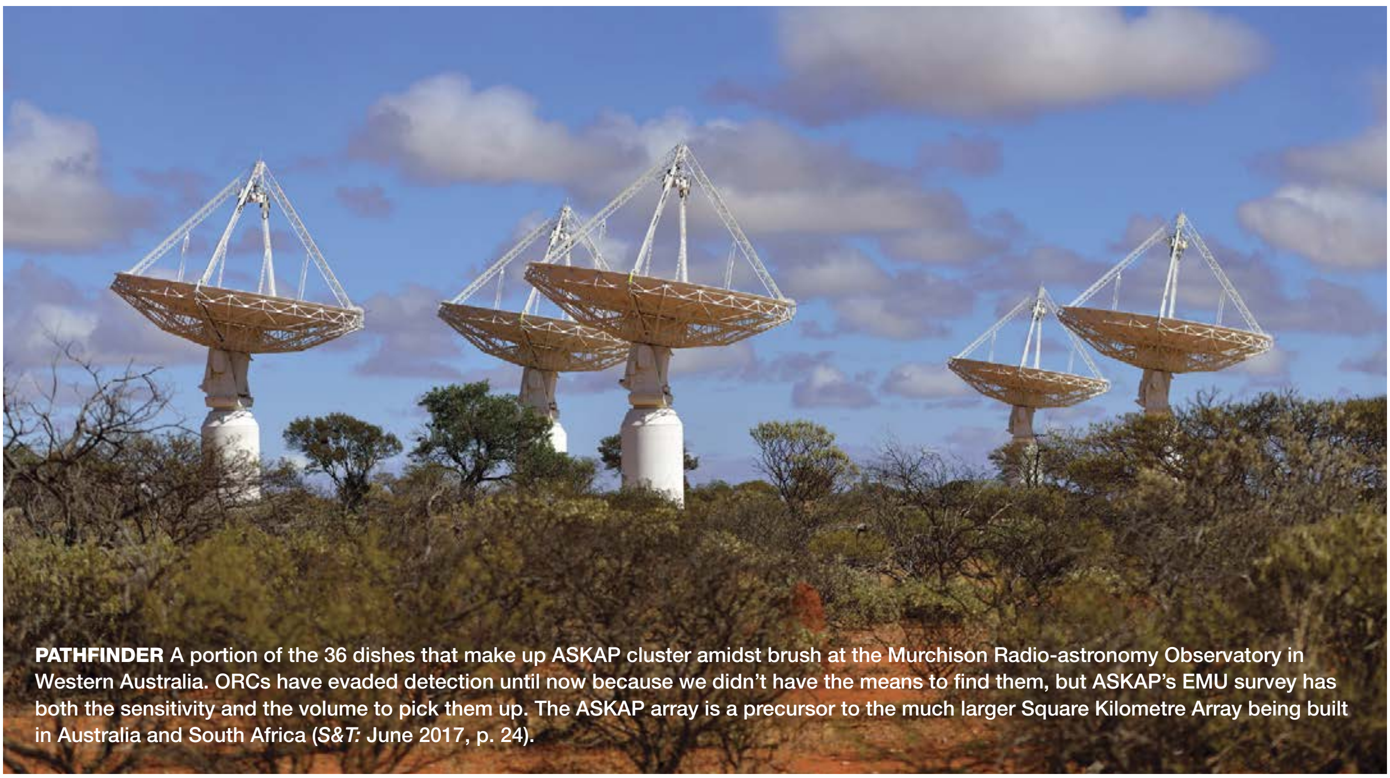
Norris soon ruled this scenario out, though: The handful of known ORCs didn't cluster along the galaxy's plane, making the supernova scenario unlikely. His team ruled out other more extreme possibilities, too, such as that the rings might come from more distant light bent into a circle by a foreground galaxy's gravity.

"I actually even checked their proper motion from the two observations," Norris says, "in case they were atmospheric or in the solar system." They weren't.

A clue came from visible-light images, which show a reddish, probably elliptical galaxy at the center of all the single ORCs. (The ORC 2 and 3 pair is an exception: Their galaxy lies off to one side.) The astronomers initially thought that these galaxies might be unrelated to the giant wreaths of radio around them. But as they found new ORCs, each associated with a central galaxy, the probability of such chance alignments lowered.

"I think it's the galaxies that really clinched it," Norris says. "Once we knew that [the ORCs] had these host galaxies, then they were clearly extragalactic."

But if ORCs aren't close by but actually — like the galaxies at their centers — billions of light-years away, then the circles have to be vast in size. Based on the distance to the galaxy at the center of ORC 1, for example, its ring must be about 1 million light-years across. A single star can't make that. Instead, these might be bubbles blown not by individual stars but by whole galaxies of them.



PATHFINDER A portion of the 36 dishes that make up ASKAP cluster amidst brush at the Murchison Radio-astronomy Observatory in Western Australia. ORCs have evaded detection until now because we didn't have the means to find them, but ASKAP's EMU survey has both the sensitivity and the volume to pick them up. The ASKAP array is a precursor to the much larger Square Kilometre Array being built in Australia and South Africa (*S&T:* June 2017, p. 24).

CSIRO

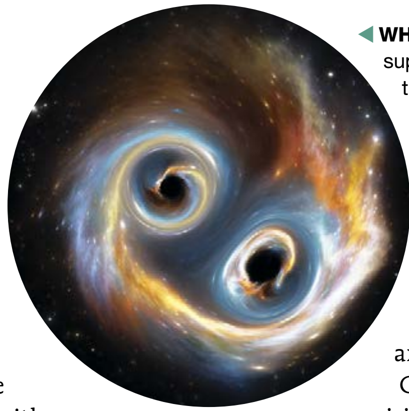
Rings of Power

As EMU team members began to talk about ORCs at workshops and conferences — even before the discoveries were officially published in 2021 — they began to hear ideas from others about possible explanations of the phenomenon.

Roland Crocker (Australian National University), who sat in the audience of a talk Norris gave in Adelaide, Australia, saw the giant rings as "weird, and cool, and odd." But his ears really "perked up" because he'd been involved in studying two loops on either side of the Milky Way plane, known as the Fermi Bubbles (*S&T:* Apr. 2014, p. 26). Crocker has suggested that sustained star formation in our galaxy blew out those bubbles, which span 50,000 light-years end to end. Now, he suggests a similar, albeit stronger mechanism might make ORCs.

The radio waves coming from ORCs have the characteristics of *synchrotron radiation*, emitted by energetic electrons spiraling around orderly magnetic fields. A powerful shock wave emanating from the central galaxy could energize intergalactic particles while sweeping out ambient magnetic fields to immense scales, explaining the radiation. But where does the underlying power in that wave come from?

One way to make a powerful shock wave is to have a galaxy churn out stars at a formidable rate. As the more massive of these stars explode in quick succession, they generate a furious wind — particles entangled with magnetic fields — that can escape the galaxy.



WHEN BLACK HOLES COLLIDE The merger of two supermassive black holes is one possibility for initiating the spherical shock wave that creates ORCs.

Crocker estimates the energy required to make these gargantuan circles is equivalent to that released by up to 1 billion supernovae. By the time the star-driven shock wave creates the large shell visible to us on Earth, the starburst itself is done. All that's left is a "red-and-dead" elliptical galaxy that has halted star formation long ago.

Confirmation of this idea came from a surprising source: a visible-light spectrum. "We've been putting in telescope proposals ever since we discovered these," Norris says. "And we'd get these comments like, 'Well, you only see this thing in the radio — why should we be interested?'" But then Alison Coil (University of California, San Diego) came across a sensitive MeerKAT image of ORC 1, published in 2022, showing radio arcs glowing within the larger ring. She's not a radio astronomer, but she immediately thought it looked like an outflow.

"My collaborators and I have been studying massive starburst galaxies that are driving these outflowing galactic winds for over a decade now," Coil says. ORC 1, she thought, might represent a later stage of those galaxies' evolution.

While most of the ORCs are Southern Hemisphere objects, the one discovered in archival data — ORC 4 — was accessible from the W. M. Keck Observatory in Hawai'i. It also happened to be in the sky when Coil had observing time. She and her team dashed off a 20-minute exposure using the Keck

ORCs

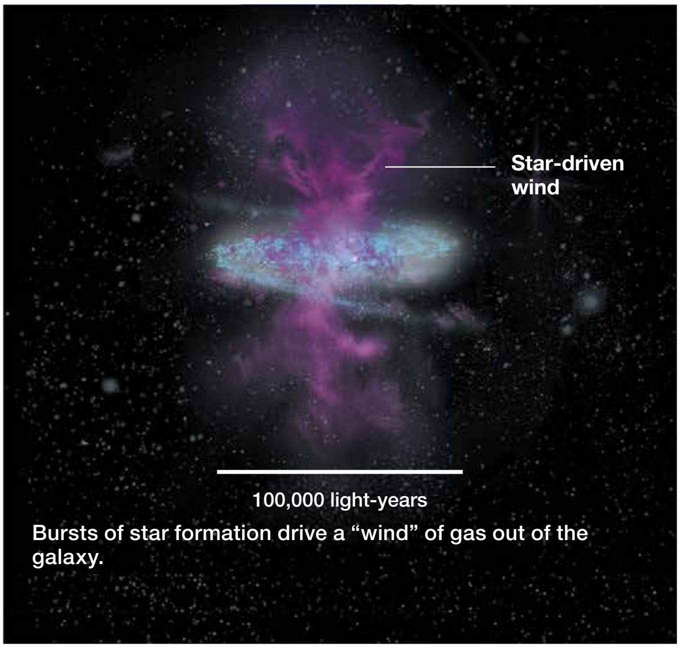
ORC Name	Redshift	Lookback time (millions of years)	Ring diameter (millions of light-years)	Telescope	RA	Dec.	Type
ORC 1	0.551	5,540	1.7	ASKAP/EMU	$21^h 03^m$	−62° 00′	ORC
ORC 2	0.31	3,540	1.2	ASKAP/EMU	$20^h 58^m$	−57° 36′	Ring with no central galaxy
ORC 3	0.31	3,540	1.8	ASKAP/EMU	$20^h 58^m$	−57° 36′	Diffuse emission
ORC 4	0.45	4,720	1.3	GMRT	$15^h 55^m$	−27° 26′	ORC
ORC 5	0.26	3,160	1.0	ASKAP	$01^h 02^m$	−24° 50′	ORC
ORC 6	0.125	1,610	3.3	ASKAP	—	—	Double ring
ORC 7	0.3	3,450	1.3	MeerKAT	$10^h 27^m$	−44° 22′	ORC
Physalis	0.017	240	(multiple rings)	ASKAP	$19^h 14^m$	−54° 33′	Radio-shell system
Cloverleaf	0.05	680	(multiple rings)	ASKAP	$11^h 37^m$	−00° 50′	Radio-shell system
SAURON	0.55	5,440	0.6	MeerKAT	$01^h 31^m$	−13° 34′	ORC candidate*
J0849−0457	0.34	3,810	0.2	ASKAP	$08^h 49^m$	−04° 57′	ORC candidate*
J2223−4834	0.27	3,160	1.2	ASKAP	$22^h 23^m$	−48° 34′	ORC candidate*
J1507+3013	0.08	1,100	0.2	VLA/FIRST	$15^h 07^m$	+30° 13′	ORC candidate

*Discovered via machine learning

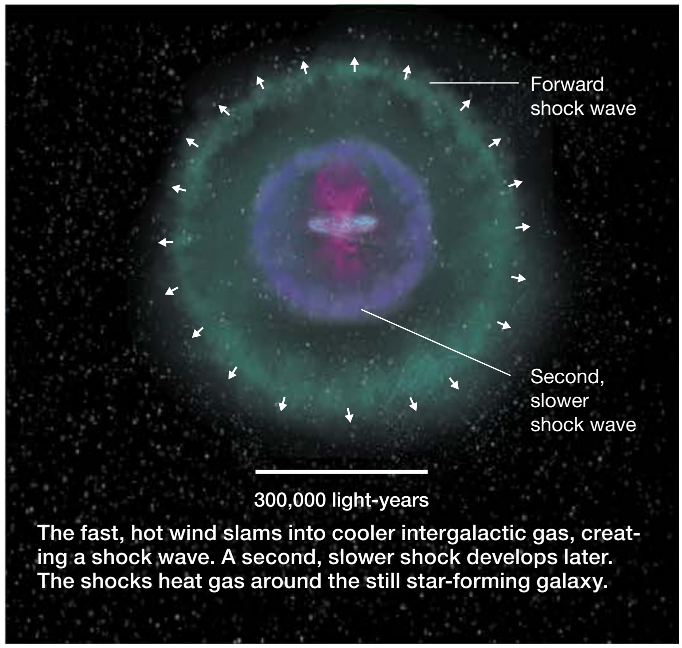
Right ascension and declination are for equinox 2000.0. Note that ORC 6's position on the sky is not yet published.

JURIK PETER / SHUTTERSTOCK.COM

STARBURST SCENARIO

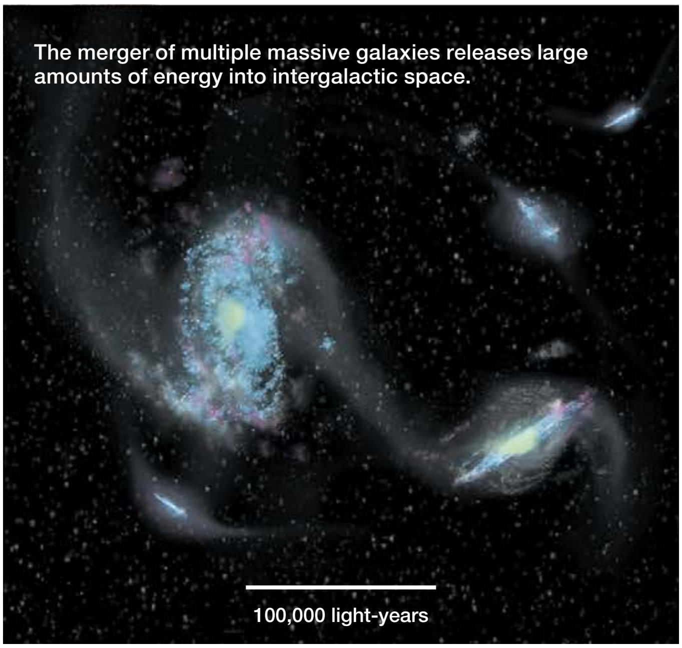


Bursts of star formation drive a "wind" of gas out of the galaxy.

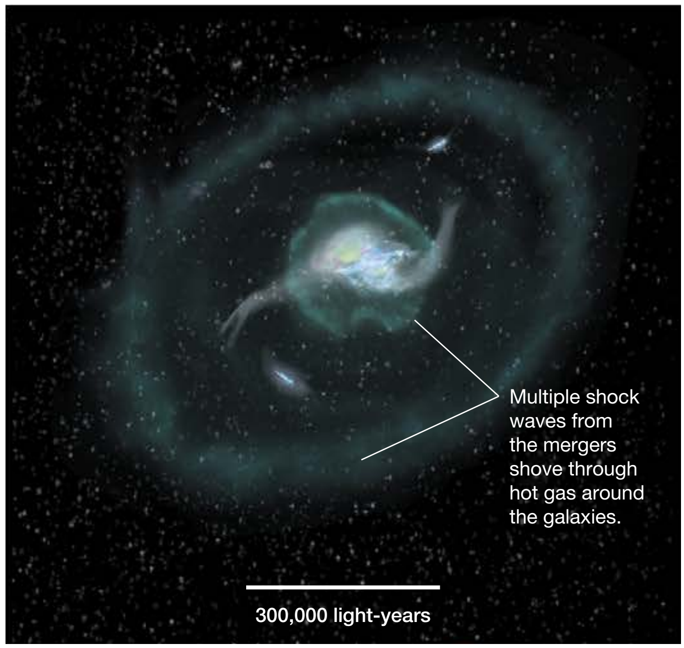


The fast, hot wind slams into cooler intergalactic gas, creating a shock wave. A second, slower shock develops later. The shocks heat gas around the still star-forming galaxy.

GALAXY MERGER SCENARIO



The merger of multiple massive galaxies releases large amounts of energy into intergalactic space.



Multiple shock waves from the mergers shove through hot gas around the galaxies.

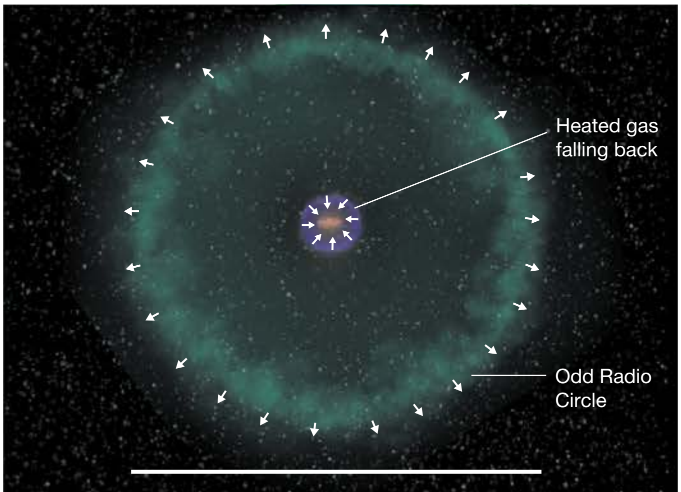
BEATRIZ INGLESSIS / *S&T* (2)

Cosmic Web Imager, an instrument designed to take spectroscopy of extremely faint things, just to check whether they could see something. "And then we saw this *booming* amount of gas," she says.

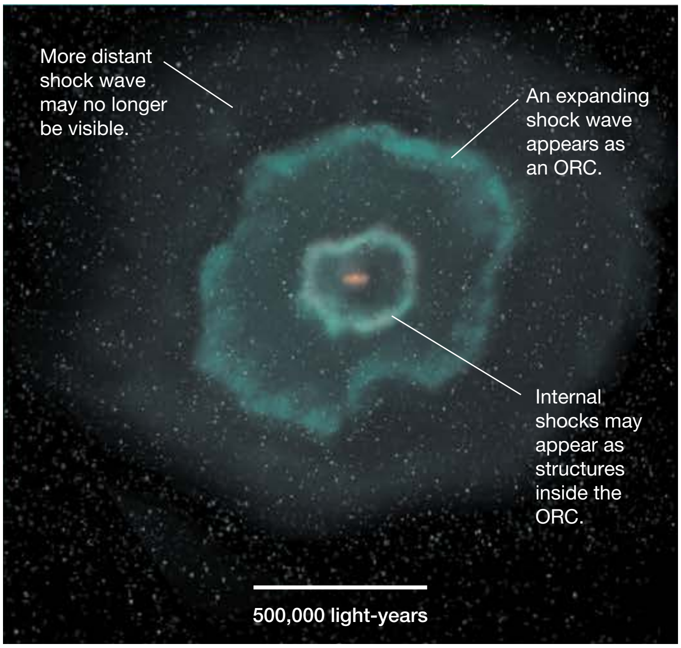
The gas they observed was oxygen, and it was ionized, meaning that an electron had been ripped from each atom during some energetic event — such as a passing shock wave. But the ions, though they spread well beyond the galaxy itself, extend out to just over 100,000 light-years — well within the 1 million-light-year-wide outer ring.

This finding, too, fits with the starburst scenario: A multitude of exploding stars and stellar winds push out a pressure wave, known as the *forward shock*, which plows into material around the galaxy. That shock wave, Coil's team suggests, spurs ambient electrons into generating the radio waves that we see as the outer ORC ring. The shock wave, and its associated ring of radio emission, keeps expanding long after the central galaxy has finished forming stars.

Meanwhile, as cooler, denser material piles up along the bubble's inner edge, a second, slower shock wave forms. Once the star-fed wind stops, the gas this second shock has heated up falls slowly backward, filling in the now largely empty space nearer the galaxy. This hot, sparse gas creates the ionized emission that Coil's team saw.



The burst of star formation has ended. The forward shock wave continues traveling into intergalactic space, resulting in an ORC. Gas heated by the second shock slowly falls back toward the galaxy.



If this scenario pans out, then ORCs provide a pathway to understanding galaxy evolution. "They'll help us understand how common these extreme outflows are," Coil notes.

Not Yet at Journey's End

Bursts of starbirth (and star death) might explain ORC origins, but the matter is far from settled. Other events besides starbursts can push out spherical shock waves. Perhaps the supermassive black hole in the central galaxies is responsible for the explosive action instead.

The histories of a galaxy's star formation and its supermassive black hole tend to evolve hand-in-hand, as both rely on gas supply and the propensity of the galaxy to merge with others. It can be difficult to tease the two histories apart. But it does seem indicative that the galaxies at the center of most ORCs are elliptical: These fuzzy, football-shape galaxies have probably merged with many galaxies in the past and tend to host behemoth black holes in their cores. It's possible that each galaxy's black hole is in fact the outcome of an ancient merger between two smaller black holes — and such a merger might be able to power a spherical shock.

Galaxy collisions can also set off shock waves. In cosmological simulations, investigated by Klaus Dolag (Ludwig Maximilian University, Germany) and colleagues, major galaxy mergers result in a central, massive galaxy surrounded by shock waves of the same size, shape, and relative speed as ORCs. Also, such powerful mergers shouldn't happen that often, explaining ORCs' rarity. Only the predicted brightness comes up short, unless bolstered by further interactions.

"It's a great scenario," says Koribalski, "and testable."

Also under serious consideration is the resurrection of "old" intergalactic particles, an idea proposed by Stas Shabala (University of Tasmania, Australia) and colleagues. Under this scenario, an elliptical galaxy hosts a supermassive black hole that shoots out twin jets of speedy plasma, each of which plows through the thin gas around the galaxy and produces radio waves. Over time, those jets turn off, the now-intergalactic particles slow down, and their radio emission fades. But when a shock wave passes through the area — not necessarily from the galaxy itself — what's left of the jets lights up.

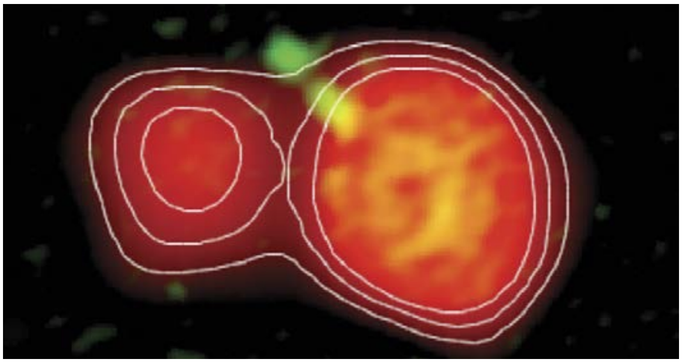
Norris initially disagreed with the idea and discussed it at length with Shabala. Now he's a coauthor on the published study. He currently thinks that the relighting of gas around old radio galaxies could explain some ORC-like systems.

"It's possible that not one formation scenario explains all ORCs," Koribalski notes.

Even the first handful of discoveries demonstrate that not all ORCs look alike. ORC 1 is isolated, with its galaxy smack in the center, but ORCs 2 and 3 lie close together on

Naming Odd Radio Circles

Koribalski and Norris came up with the ORC acronym together, in a brainstorming session that focused on J. R. R. Tolkien's *Lord of the Rings*. (Orcs are the monstrous foot soldiers of the enemy in Tolkien's fantasy world.) "I wanted to make ORC work, but I only got as far as O for their round/circular nature and RC for radio circle," Koribalski says. "I am quite sure Ray came up with O for 'Odd.'"



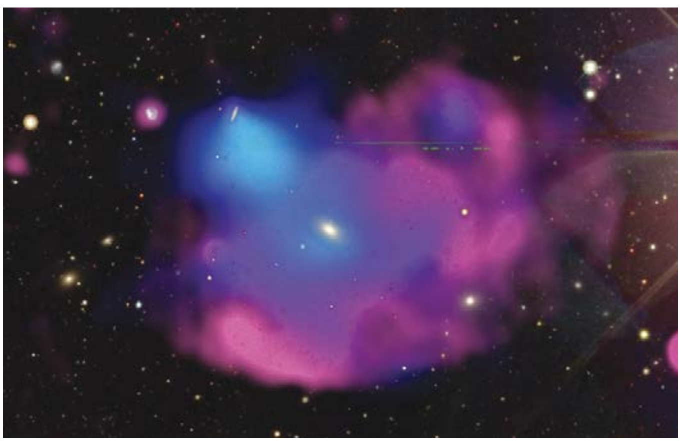
▲ **DOUBLE ORC** Unlike ORC 1, ORCs 2 and 3 appear close together on the sky and, as later work showed, share a host galaxy, which is offset to one side of both circles (not visible in this radio image).

the sky and are probably related. They only have one associated galaxy, and instead of lying in the middle of either ring or even between the two, it lies off to one side of both rings. Koribalski and Norris now think that these two formed in a way distinct from single ORCs, perhaps by the resurrection mechanism Shabala proposed.

Other teams have since found a couple of relatively nearby, multiply ringed systems. “These are very likely related to ORCs, in my opinion,” Koribalski says. But she cautions against reaching firm conclusions just yet. “We need more data (always) and more simulations.”

The Road Goes Ever On

Astronomers continue to study the known complement of ORCs. Coil is doing so with an upgraded Keck instrument, called the Keck Cosmic Reionization Mapper. By taking longer exposures at longer wavelengths of ORC 4, she hopes to better understand the extent and state of the gas flow around its galaxy. She’s using a similar instrument, the Multi-Unit Spectroscopic Explorer on the Very Large Telescope in Chile, to explore gas flows around the other ORCs that are only visible from the Southern Hemisphere.



▲ **THE CLOVERLEAF** This system of giant, overlapping radio rings (pink) also emits X-rays (blue). Visible light is shown as white to yellow. Some of the X-ray-emitting regions are associated with the central elliptical galaxy; others aren’t associated with any source of radio or visible light and might instead come from ionized gas in between galaxies.

Others, too, are turning to different instruments. While the original ORCs evaded X-ray detection, Esra Bulbul (Max Planck Institute for Extraterrestrial Physics, Germany) did manage to collect high-energy photons coming from hot gas in a nearer ORC-like system, dubbed the Cloverleaf for its overlapping circles around a single elliptical galaxy. Using the European Space Agency’s XMM-Newton Observatory, she and colleagues saw two bright dollops of X-ray emission: one around the central galaxy itself and one off to the side, unrelated to any radio or visible light. Combined with the lopsided shapes of nearby galaxies, as seen in visible light, the X-ray data suggest an ongoing maelstrom as two galaxy groups come together. The overlapping radio circles might again represent Shabala’s idea, with shock waves lighting up remnants of ancient jets sent out from the central galaxy’s black hole.

Primarily, though, the focus is on simply finding more ORCs. “We really need to get more examples,” Norris says. “We’re really hampered.”

He notes that searches at longer wavelengths using the Low Frequency Array (LOFAR) based in the Netherlands haven’t found anything yet, which is something of a mystery. If ORCs are emitting synchrotron emission, then they should emit more radiation at LOFAR’s longer wavelengths than at the shorter radio wavelengths collected by ASKAP. “They can see the ones we know about,” he says, “but they haven’t seen any new ones, and that surprises me.”

Machine-learning searches of EMU data haven’t turned up any classical, one-ring ORCs, either, although they have found some of the nearer multiple-ring systems. “So far, all the classical ORCs have been found by eye,” Norris says. “But I think that’s about to change, as machine-learning algorithms become increasingly powerful.”

Citizen-science projects are also an obvious, albeit laborious, next step. Eleni Vardoulaki (National Observatory of Athens, Greece) and Hongming Tang (Tsinghua University, China) announced in mid-2024 that Radio Galaxy Zoo: EMU (**https://is.gd/GalaxyZooEMU**) is up and running. Just a month after the project’s launch, users have already classified more than 12,500 radio sources; they can also note any distinctly odd shapes in the project’s online forum.

In the meantime, most of the ORCs currently known owe their discovery to a single individual: Koribalski. Even now, she still looks for the giant circles on a regular basis, downloading each ASKAP field as it comes in and scanning through some 20,000 radio sources by eye. She’s also working with Norris to compile current observations and ideas into a review article for a scientific journal.

“It would be great to discover these things when you’re at the start of your career — I could have built an entire career on them,” says Norris, who has semi-retired. “But I will leave that to my younger colleagues.”

■ News Editor **MONICA YOUNG** relishes the fictional astromythology in Tolkien’s *Lord of the Rings* and *Silmarillion*.

ORCS 2 AND 3: R. NORRIS ET AL. / *PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF AUSTRALIA* 2021; CLOVERLEAF: XIAOYUAN ZHANG & MATTHIAS KLUGE (MPE), BÄRBEL KORIBALSKI (CSIRO)

SKY AT A GLANCE
January 2025

1 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 11:53 p.m. PST (see page 50).

2–3 **ALL NIGHT:** The brief but intense Quadrantid meteor shower is expected to peak. The waxing crescent Moon sets in the evening and won't hamper viewing. Page 50 has further details.

3 **DUSK:** Face southwest to see the lunar crescent around 3° upper left of brilliant Venus. Turn to page 46 for more on this and other events listed here.

4 **EARTH** passes through perihelion, its closest point to the Sun for 2025, at around 8:30 a.m. EST.

4 **DUSK:** High in the south-southwest, the waxing crescent hangs some 3° upper left of Saturn.

4 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 11:42 p.m. EST (8:42 p.m. PST).

7 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:31 p.m. EST.

9 **EVENING:** The waxing gibbous Moon visits the Pleiades in Taurus. Binoculars should tease out the cluster stars from the dazzle of the Moon. Look high in the south-southeast to take in this sight.

13 **EVENING:** In the east, the full Moon anchors the bottom end of a line with Castor and Pollux, Gemini's bright lights. Ruddy Mars completes the picture lower left of the lunar limb. Later, viewers in most of North America will see the Moon eclipse the planet.

15–16 **ALL NIGHT:** Mars arrives at opposition. See pages 48–49 and 52 for full details on Mars this month.

16 **EVENING:** The waning gibbous Moon follows Regulus, in Leo, by some 6° as they climb in the east.

17, 18 **DUSK:** Venus blazes in the southwest with Saturn a bit more than 2° left or lower left both evenings.

21 **MORNING:** The Moon, just shy of last quarter, sits around 3½° lower left of Spica in Virgo. Face south before dawn to take in this view.

23 **EVENING:** A scene with Mars, in Gemini, pleasingly placed some 2½° right of Pollux graces the eastern sky.

24 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:27 p.m. PST.

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

30 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 7:06 p.m. EST.

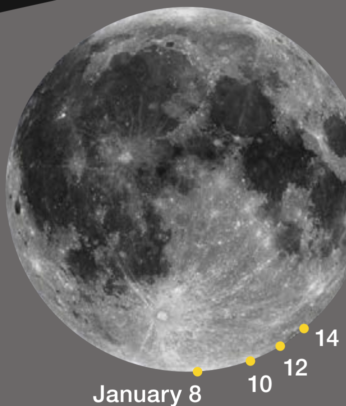
31 **DUSK:** Face west-southwest after sunset to see the waxing crescent Moon around 3° lower right of Saturn. Venus guards the pair from above. The view will intensify as twilight deepens.
—DIANA HANNIKAINEN

Mars arrives at opposition this month. Instruments onboard NASA's Perseverance rover obtained this image of features in the nearly 1-kilometer-wide Belva Crater on April 22, 2023. NASA / JPL-CALTECH / ASU / MSSS

JANUARY 2025 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



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

NASA / LRO

MOON PHASES

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

FIRST QUARTER
January 6
23:56 UT

FULL MOON
January 13
22:27 UT

LAST QUARTER
January 21
20:31 UT

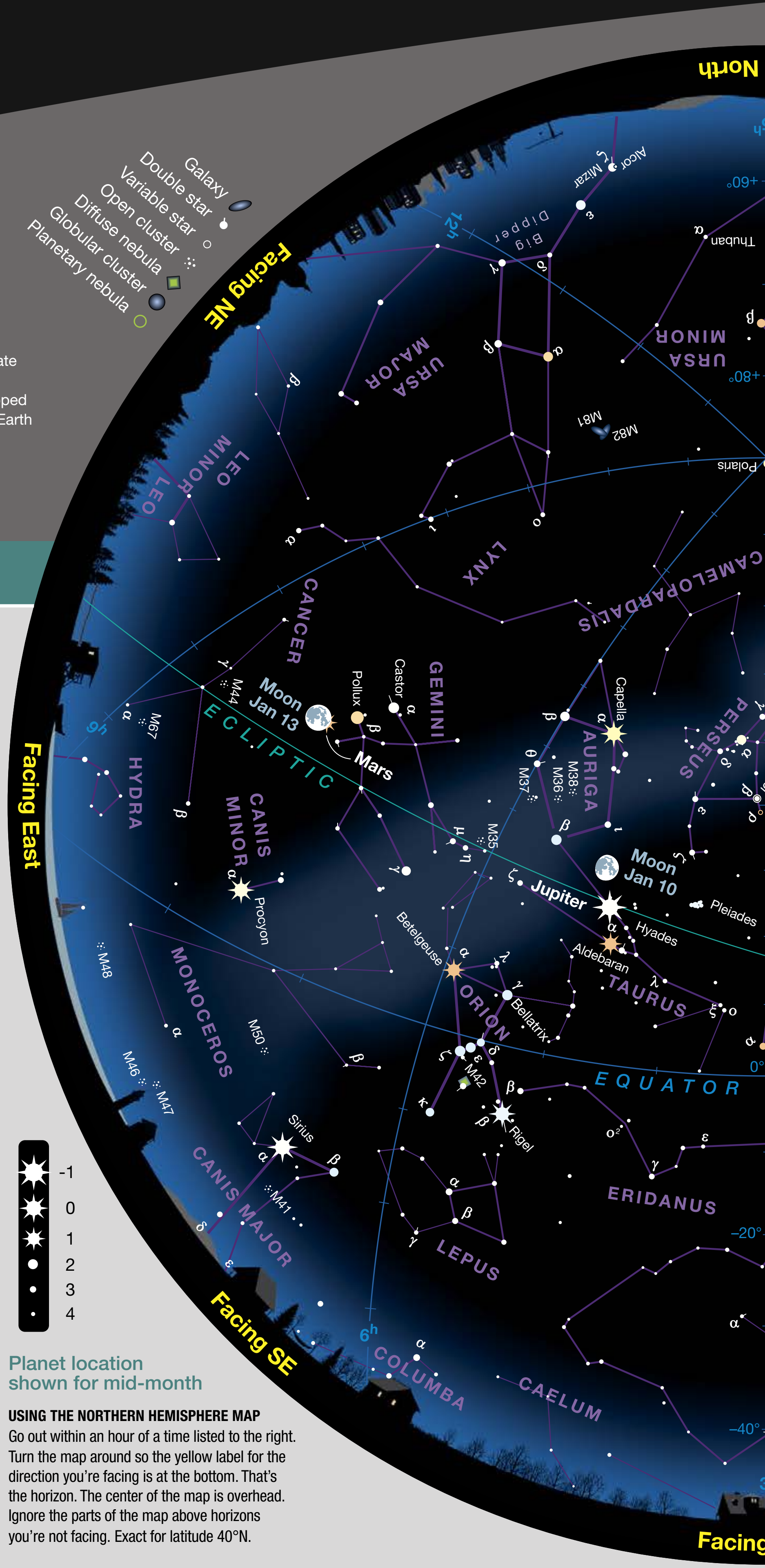
NEW MOON
January 29
12:36 UT

DISTANCES

Perigee	January 8, 0^h UT
370,171 km	Diameter 32′ 17″
Apogee	January 21, 5^h UT
404,298 km	Diameter 29′ 34″

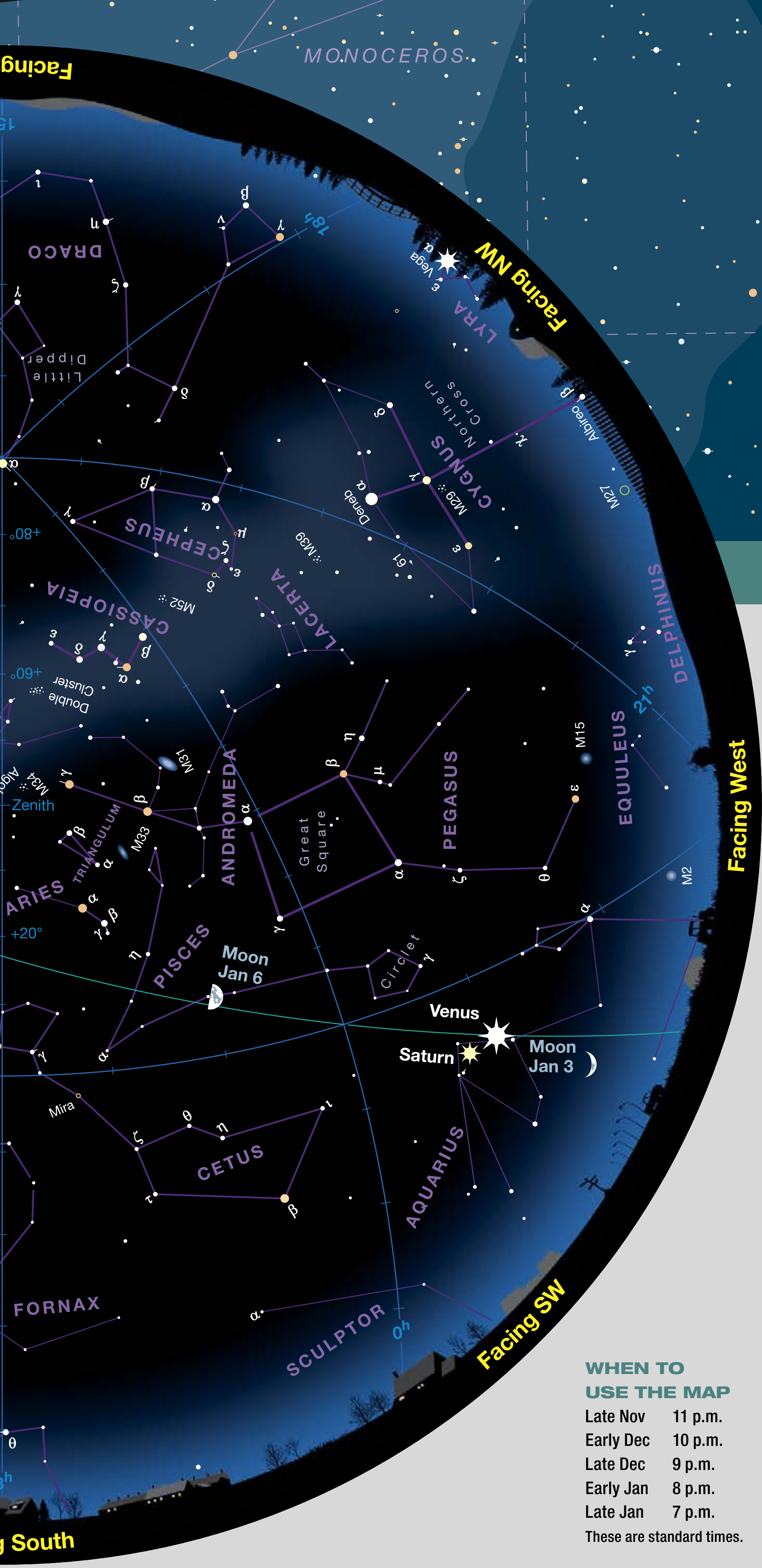
FAVORABLE LIBRATIONS

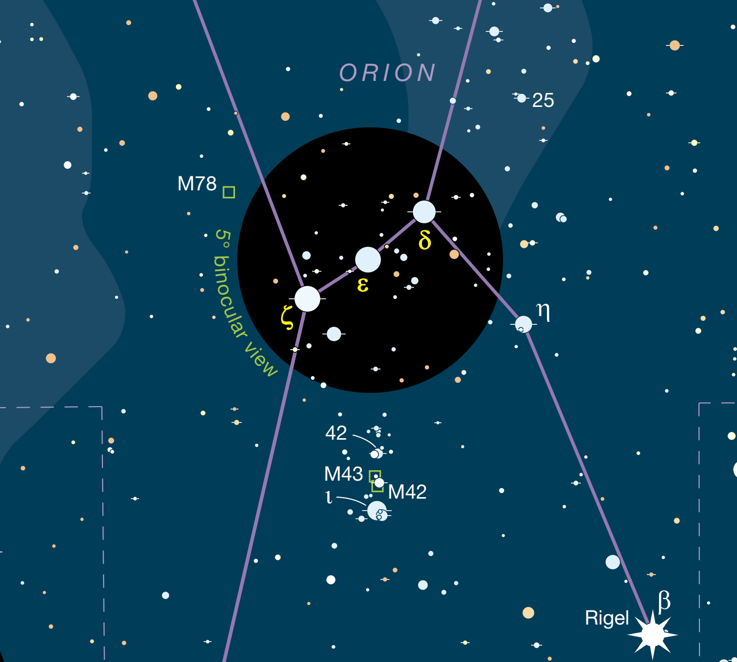
• Schomberger Crater	January 8
• Helmholtz Crater	January 10
• Pontécoulant Crater	January 12
• Lyot Crater	January 14



Planet location shown for mid-month

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





Binocular Highlight by Mathew Wedel

The Hot New Thing

Among my favorite observing targets are familiar objects that deserve a second look. Top in that category — possibly the Platonic ideal — is **Orion's Belt**, the line of three stars that marks the waist of the celestial Hunter.

From east to west, the Belt stars are 1.8-magnitude **Zeta (ζ) Orionis**, or Alnitak; 1.7-magnitude **Epsilon (ε) Orionis**, or Alnilam; and 2.4-magnitude **Delta (δ) Orionis**, or Mintaka. The trio collectively spans 2.7°, so they're well-framed in virtually any binoculars — I prefer the expansive view in my 7×50s.

Alnitak, Alnilam, and Mintaka are all members of Orion OB1, an association of young, hot stars. Specifically, the portion that encompasses the Belt is Orion OB1b. A long chain of 5th- to 8th-magnitude stars winds like a letter S between Alnilam and Mintaka. Two chains surround Alnitak and Alnilam: One, fainter and more ragged, runs north between the two stars, while a second, straight line stretches southeast to northwest north of the stellar pair. If you get a chance, sketch these chains of stars from a dark site — they'll later give you a handle on your sky quality under other conditions.

After you've had an eyeful (or two!) of Orion OB1b, try to view this stellar association in context. To the northwest, the rich field of stars around 5th-magnitude 25 Orionis comprises Orion OB1a, and to the south the stars of the Sword make up Orion OB1c. Of these, OB1a is the oldest, OB1b — the Belt — is intermediate, and OB1c is the youngest. Collectively, these subgroups are the products of sustained star formation over the past few million years — observing them lets us see the machinery of our galaxy in action.

■ **MATT WEDEL** is humbled that we can observe such momentous events as the births of stars with handheld optics.

WHEN TO USE THE MAP

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

These are standard times.

JANUARY 2025 OBSERVING

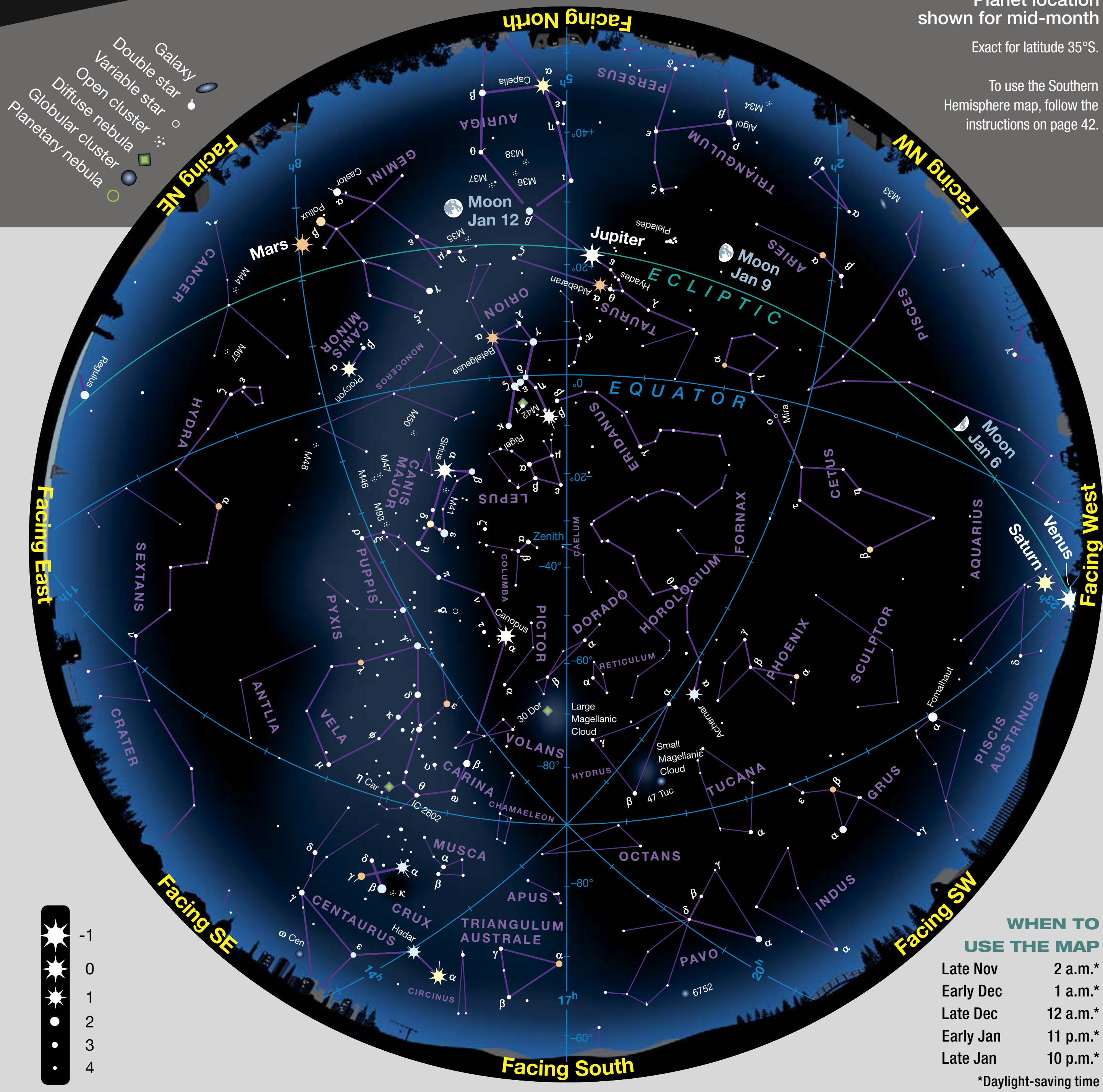
Southern Hemisphere Sky Chart

by Jonathan Nally

Planet location shown for mid-month

Exact for latitude 35°S.

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



WHEN TO USE THE MAP

Late Nov	2 a.m.*
Early Dec	1 a.m.*
Late Dec	12 a.m.*
Early Jan	11 p.m.*
Late Jan	10 p.m.*

*Daylight-saving time

THE SMALL CONSTELLATION Dorado is named after the mahi-mahi, or dolphinfish, though on the chart above it more closely resembles its official guise as the celestial Swordfish. Dorado's main claim to fame is that it's home to most of the magnificent Large Magellanic Cloud (LMC), one of the largest of the Milky Way's satellite galaxies. Also marked on the chart is 30 Dor, which is another name for the famous Tarantula Nebula — a particularly large and prominent region of nebulosity within the LMC.

Dorado's two most conspicuous stars are of contrasting colors: bluish Alpha (α) Doradus, a binary system with a combined magnitude of 3.3, and yellowish-white Beta (β), a Cepheid variable that ranges from magnitude 3.4 to 4.1 in just under 10 days. ■

A Parade of Colors

Several pairings of planets and stars offer a chance to test your color perception.

January's night sky contains three playful pairings that include some of the most brilliant stars and planets in the heavens. They're strung out across the sky like colorful gems adorning the necklace of the *ecliptic* — the teal line that indicates the path of the Moon and planets across the sky on our all-sky charts (pages 42–43 and page 44). As the month progresses, Venus joins Saturn low in the west while Jupiter keeps watch over Aldebaran, in Taurus, high overhead. And in the eastern sky, Mars dances with the celestial Twins, Castor and Pollux, in Gemini. More than just interesting interplay, these pairings provide opportunities to seek out delicate hues.

A star's color is a direct indicator of its surface temperature. The hottest stars we can see with our unaided eyes are blue-white, while the coolest ones are reddish; those with temperatures similar to our Sun's appear yellowish. The stars we're focusing on this month have an array of hues: Aldebaran is an orange giant; Betelgeuse, in Orion, is a red giant; and Capella, in Auriga, is a yellow, Sun-like star. Castor appears blue-white, while Pollux is another orange giant.

Planets, on the other hand, shine by reflected sunlight, so their colors mainly depend on the specific planet's characteristics and on the effects of Earth's atmosphere. For instance, when Venus is highest it shines brilliantly white, but when it's near the horizon — as it is this month — its color appears warmer due to the same atmospheric effect that gives us red sunsets. Saturn usually looks golden-hued, but it too is low in the sky, where it may appear more orange. Jupiter is much higher and under ideal atmospheric conditions displays an untainted creamy luster. But don't be fooled by Mars's nickname — the Red Planet usually isn't red. Instead, it appears more golden than red when it glows brightly around the time of opposition, which occurs this month on the 16th.

▲ This photo of the conjunction between Jupiter and Mars captures the naked-eye view on the morning of August 14, 2024. At the time, the planets were just 19′ apart.

BOB KING

No matter a star or planet's true color, how it looks to each of us is never clear-cut. Everyone has slightly different color perception, so what each of us sees is subjective at best. And there's also a phenomenon called *simultaneous contrast*, which affects how we perceive two adjacent colors — each influencing how the other looks. This includes stars and planets seen against the background sky, which can be velvety black, twilight blue, dusty red, or tinted orange by the glow of sodium-vapor lamps. Have a look at Jupiter in twilight when the sky is still deep blue — will it have the same color later at night?

Returning to this month's celestial pairings, let's first nab Venus and Saturn before they set. As noted on page 46, the best date to catch them is January 3rd, when a waxing crescent Moon lies between them. All three objects will be very low in the southwest and subject to atmospheric reddening. With each passing night in January, Venus and Saturn inch closer to each other. Does their proximity have an effect on the hues you see?

Jupiter, on the other hand, reigns supreme high overhead near Aldebaran, offering a wonderful opportunity to contrast their colors. Does Jupiter's presence near Aldebaran affect what you see? Block the star with your hand. Does Jupiter's color change when the star is absent? In August 2024, Mars, Aldebaran, and Betelgeuse were roughly the same brightness and appeared to share the same orange hue. It was a captivating sight, as shown in the photo above. Since then, the scene has changed. Mars has moved on, and even Betelgeuse might look a little different. It's a variable star whose brightness typically fluctuates by only a couple of tenths of a magnitude, though in 2019 it dimmed dramatically by more than a full magnitude (*S&T:* Mar. 2021, p. 14)!

As January progresses, Mars is zeroing in on pale-orange Pollux. Be sure to compare both Mars and Pollux to blue-white Castor and with yellow Procyon, in Canis Minor. Mars outshines all three stars, but will its proximity to Pollux enhance or diminish its redness? You be the judge.

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

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

Venus and Saturn Meet at Dusk

The month features several eye-catching conjunctions and a full Moon occultation.

FRIDAY, JANUARY 3

The new year kicks off with a lovely conjunction between the **Moon** and **Venus**. These pairings occur once a month (sometimes twice), whenever Venus is visible — which is most of the time. It's always a highlight when the night sky's two brightest objects meet, as they do at dusk today high above the southwestern horizon. The reigning Evening Star gleams brilliantly at magnitude –4.5, a bit more than 3° lower right of the four-day-old lunar crescent. That's close enough that you can view them together in binoculars.

Indeed, this proximity presents a good opportunity to spot Venus in broad daylight. At around 3:30 p.m. local time, the Moon is due south and on the *meridian* (the imaginary line that connects north to south and passes directly overhead). Once you've spotted the Moon, train your binoculars on it to get a sharp focus. Now, move the pale crescent to the left side of your field of view — Venus should pop into view near the right edge. If you have very transparent skies, you might even be able to sight Venus without optical aid. Give it a try — the planet is surprisingly easy to see once your eyes lock onto it.

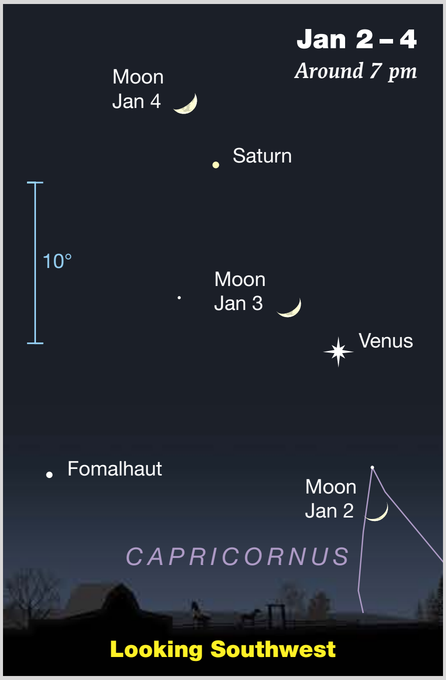
Venus is in the latter stages of its current evening apparition. As such, after today's meeting, it greets the Moon just two more times before disappearing into the sunset glare on its way to a late-March solar conjunction.

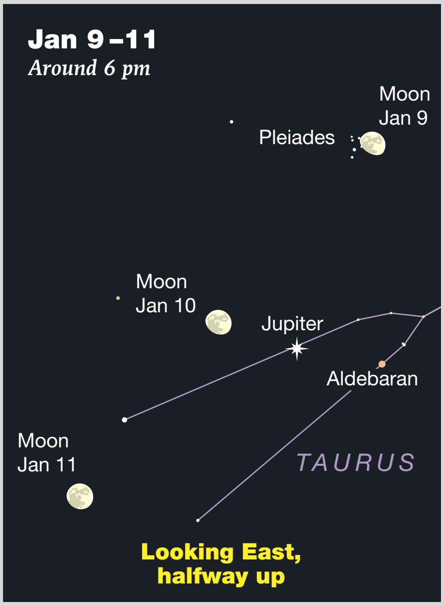
SATURDAY, JANUARY 4

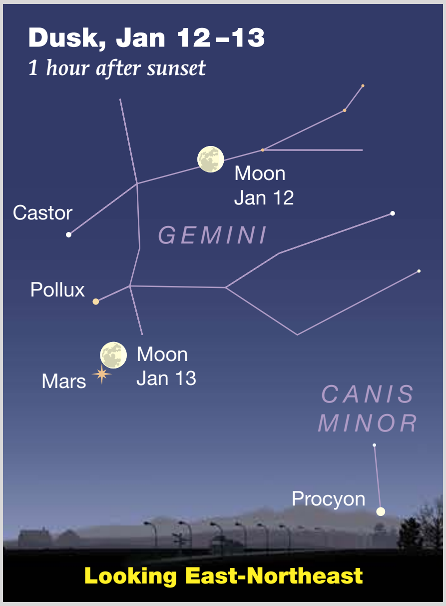
One day after its meet-up with Venus, the **Moon** has shifted 14° eastward along the ecliptic and now sits 3° above left of **Saturn**. As it does with Venus, the Moon gets close to the Ringed Planet usually once a month. However, this evening's event is the first of two meetings in January — they pair up again on the 31st, when they're only marginally farther apart than tonight, and with the Moon positioned below right of Saturn. That second encounter will be their final evening one this apparition as Saturn drifts towards its mid-March conjunction with the Sun.

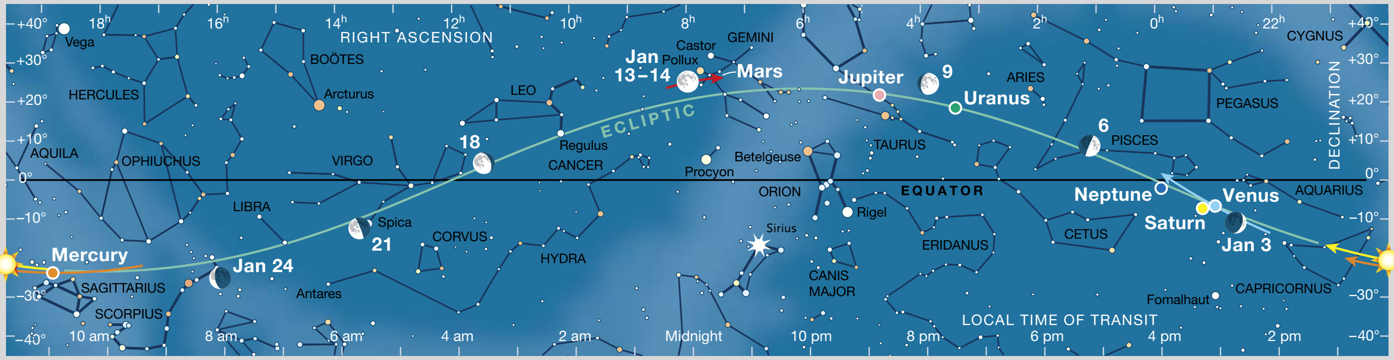
FRIDAY, JANUARY 17

Without doubt, the highlight of highlights for this month is the Moon occulting Mars on the 13th — an event discussed in detail on page 49. But when it comes to naked-eye appeal, this evening's conjunction featuring **Venus** and **Saturn** is a close second. As twilight fades, both planets are high above the southwestern horizon with just 2¼° separating them (they're similarly close on the 18th). However, they're worlds







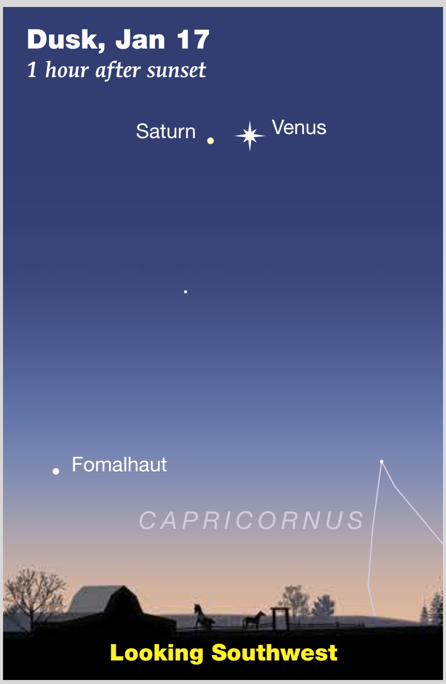


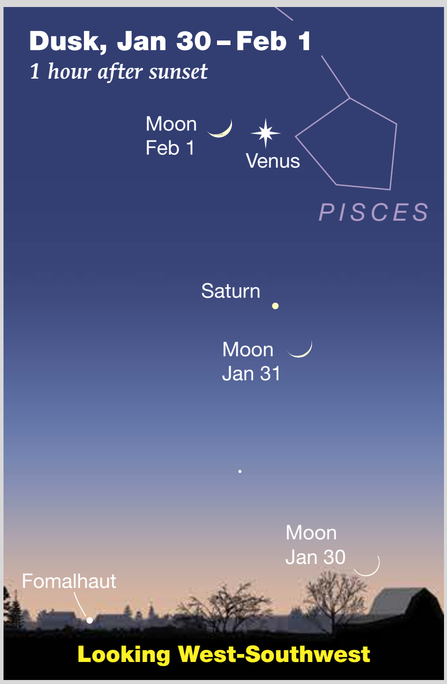
▲ The Sun and planets are positioned for mid-January; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

apart when it comes to brightness. Saturn is a respectable magnitude 1.1, but Venus is an absolute beacon gleaming at magnitude –4.6 — nearly 200× brighter! Since both objects easily fit into a binocular field, there's a fun experiment you can try. Go outside soon after sunset and locate Venus in your binos. Now keep watching and see how long it takes before you can perceive Saturn to its left. How about with your eyes alone? Knowing exactly where to look will make Saturn much easier to find.

Our second evening event is the culmination of an alignment featuring **Mars** and Gemini's two brightest stars, **Castor** and **Pollux**. The trio form an eye-catching, three-in-a-row line as they rise in the east-northeast in fading twilight. After a lead-up spanning several nights, the configuration is at last tantalizingly close to perfect — Mars is ever so slightly to the right of a line passing through Castor and Pollux. (True perfection occurs a few hours before the threesome rise.)

Post-opposition Mars is currently traveling westward in retrograde motion — something it will continue to do until late February, when it reverses direction and begins trekking eastward. Over the next few nights, Mars angles a little bit closer to Pollux and passes within 2½° of the star on January 22nd.





Finally, on the evening of the 31st, the Red Planet forms a striking right triangle with Castor and Pollux.

TUESDAY, JANUARY 21

The best encounter between the **Moon** and a bright star this month happens in the predawn hours today. That's when a waning gibbous Moon trails behind 1st-magnitude **Spica** as they rise in the east-southeast. The star is a touch more than 1½° from the Moon. As the morning progresses, the gap between the two objects increases and will have more than doubled by the time twilight lights the dawn sky. And though I said the Moon's phase is gibbous, it actually rises 55%-illuminated and very nearly at last-quarter phase — a mark it will hit later in the afternoon.

The Moon passes Spica once every *sidereal month*, which is 27.3 days long. That's why it can encounter the same star (or planet) twice in a calendar month. But because each return has a slightly different set of circumstances, sometimes the Moon passes above or below Spica, while other times it passes directly in front of it and we get an occultation, as we did last November. Indeed, this morning's conjunction unfolds as an occultation for observers in western Africa, but the event ends before the pair rise in the Americas.

■ Consulting Editor **GARY SERONIK** tracks the interactions of the Moon and planets from his home in British Columbia's Okanagan Valley.

◀ This May 2014 image by the European Space Agency's Mars Express orbiter captures a mid-summer view of the shrinking North Polar Cap (right). Vaporizing ice generated strong winds that spawned a low-pressure system rich with water-ice cirrus clouds (left). Dust raised by seasonal storms helped create the Cap's characteristic laminated ice-and-dust deposits.

Mars in Fine Form

The Red Planet's draw is irresistible even during a relatively distant opposition.

Mars doles out face time like Charles Dickens's penny-pinching Scrooge parts with money. Observers feel an urgency to get their scopes out on good nights for the few months every two years when the planet is closest and at its best.

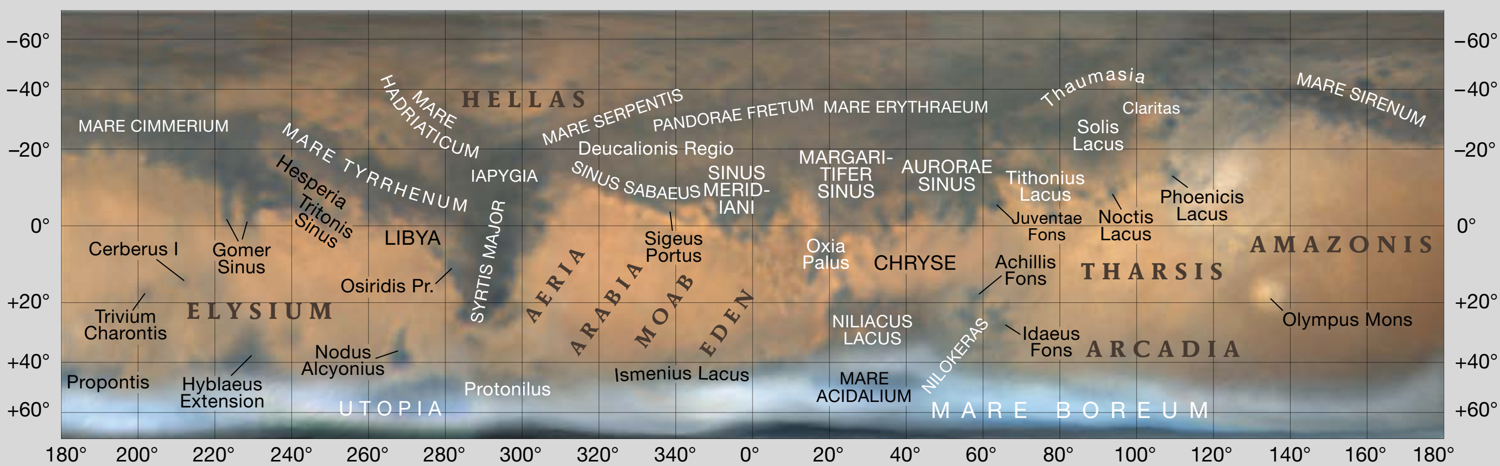
Mars equals Sirius, the brightest nighttime star, when it reaches opposition on January 16th and shines at magnitude –1.4. That night the Red Planet forms a nearly straight line with Castor and Pollux in Gemini and stands in stark color contrast to blue-white Sirius. Closest approach to Earth occurs on January 12th, when the two planets are 96.1 million kilometers (59.7 million miles) apart.

The Red Planet can be frustrating to observe with a telescope and tests our resolve like no other target. The cold, desert world is big enough to allow glimpses of dark surface markings and patchy, bright atmospheric features, but clearly discerning such details requires high magnification, which unfortunately exaggerates the effect of sub-par seeing conditions. If your observing site is like mine, better than half the nights in a year are challenging for planet observing. Fortunately, most amateurs possess the requisite attention span and patience to net those rock-steady seconds of perfect calm when all is revealed.

During its closest recent opposition, in July 2018, the Martian disk grew to 24.3″ in apparent diameter. This time it maxes out at 14.6″. While its smaller size is disadvantageous, the current apparition's northern declination provides significant compensation for observers at mid-northern latitudes, who will get to enjoy the planet's improved altitude.

If the orbit of Mars were more circular, it would always remain about 78 million kilometers away at opposition and have an apparent diameter that would vary little. But our rusty-dusty neighbor's orbit is eccentric, which causes its distance from the Sun to vary considerably over its 687-day period. As a result, we see the planet best at oppositions that occur at or near Martian *perihelion*, when the planet is closest to the Sun; those that happen around *aphelion* (farthest from the Sun) are less favorable. Oppositions follow an approximately 15.8-year cycle from one perihelion to the next. The most distant opposition in the current series takes place in February 2027, when the planet's disk spans 13.8″.

But even during a middling opposition like this year's, Mars is an intriguing telescopic sight. The North Polar Cap (NPC) features prominently this time and should be easily visible in a 3-inch telescope as a gleaming, lens-shaped dab of bright white. Northern-



hemisphere spring began on Mars last November, when the clouds of the North Polar Hood slowly began to part and reveal the polar cap. As the season progresses, the NPC's carbon-dioxide ice sublimates and exposes the permanent water-ice lying beneath. A dark collar of basaltic sand dunes, part of which comprises Mare Boreum (see map), encircles the NPC and helps define its boundaries. The dunes typically become more prominent as spring deepens and the cap shrinks.

Prominent dark albedo features in the northern hemisphere include the vast, low-lying plain of Mare Acidalium, which looks like a truncated version of Syrtis Major, the enormous, thumb-shaped shield volcano in the planet's southern hemisphere. Niliacus Lacus and Oxia Palus appear as dark, southward extensions of Mare Acidalium. See if you can also spot the dark hump of Utopia — another northern-hemisphere albedo feature, located at about the same latitude as Mare Acidalium but north of Syrtis Major. To Utopia's south you'll see a large, pale expanse dubbed Utopia Planitia. With a diameter of about 3,300 km, it's the largest known impact basin in the solar system. It's also where NASA's Viking 2 lander touched down in September 1976.

On nights of very steady seeing, additional dark markings materialize from the Martian glare. Some of the easier ones include Sinus Sabaeus, Sinus Meridiani, Mare Tyrrhenum, Mare Cimmerium, Aurorae Sinus, and Mare Erythraeum — all located in the southern hemisphere. South of Syrtis Major, look for Hellas, a large, circular impact basin with a pale floor. When it's covered in frost or overtopped by clouds, it mimics the appearance of the South Polar Cap.

If you manage to see these, try for subtler features such as Solis Lacus, Idaeus Fons, and the towering extinct volcano Olympus Mons. Every opposition I look for orographic clouds hugging its slopes. I succeeded once!

Color eyepiece filters work wonders on Mars. A light-red Wratten 23A for smaller scopes and deep-red Wratten 25 for larger instruments will show dark albedo markings more clearly. For clouds and limb haze, a blue Wratten 80A or 38A improves the contrast. A magenta filter (Wratten 30) enhances both surface and atmospheric details, while an orange Wratten 21 can help identify and enhance the visibility of dust storms. Although most major storms occur during southern-hemisphere summer, they can appear anytime, so remain vigilant. As the NPC continues to shrink during Martian spring, powerful seasonal winds can whip up a dust storm in a hurry.

A day on Mars lasts approximately 39 minutes longer than one on Earth, so a feature on the Martian central meridian will reappear there 39 minutes later on the following night. If you view Mars at the same time on successive nights, the planet will seem to slowly rotate backwards.

To find out which face of Mars you're observing, use our online Mars Profiler Tool at **https://is.gd/marsprofiler**.

◀ Associate Editor Sean Walker captured this Mars occultation sequence on December 8, 2022. "Mars drifted behind many craters for about 12 minutes or so before finally lifting away from the Moon's edge," he wrote. The Moon covers the Red Planet again this month on the night of January 13–14.

The Moon Occults Mars

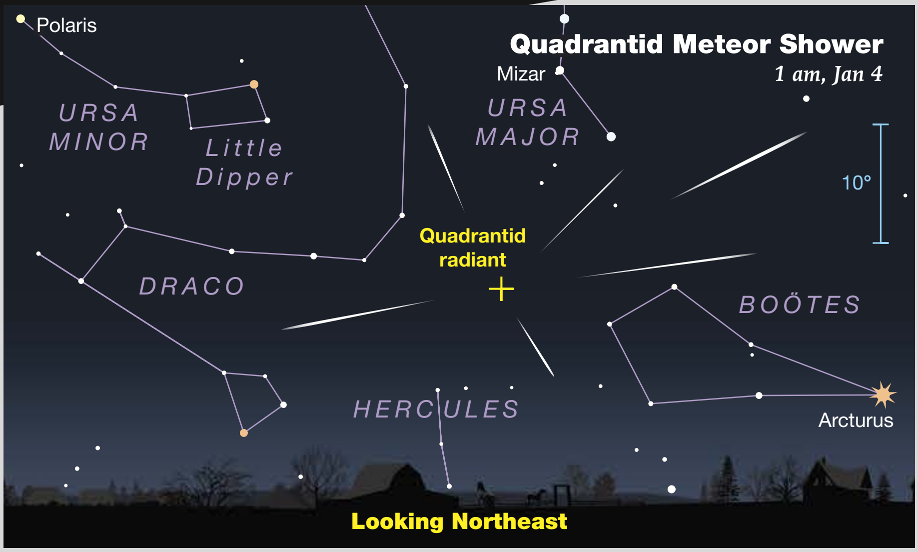
MARS HAS MORE in store. On the night of January 13–14, the full Moon occults the planet for observers in the contiguous United States, much of southern and eastern Canada, Mexico, and West Africa. Use your favorite planetarium software or google "International Occultation Timing Association Mars occultation 2025" for disappearance and reappearance times for your location.

From Chicago, Illinois, for example, the Moon and Mars are less than 2° apart as they rise together in evening twilight. At 8:07 p.m. CST, the Moon encroaches on the planet, taking about 29 seconds to completely cover it. More than an hour later, at 9:16 p.m., Mars slowly returns to view on the opposite limb.

During the December 2022 Mars occultation, I tried to keep sight of Mars right up to the lunar limb with just my eyes. I failed miserably, losing the planet in the full Moon's glare nine minutes before it disappeared. However, it was clearly visible in binoculars right up to the moment of occultation. Viewed with my telescope, what struck me most was the compelling color contrast between the Red Planet and the gray Moon. I also vividly recall the wonder I felt watching Mars seemingly rise above the lunar horizon as the Moon inexorably drifted away.

Both objects are bright and show up well in photos taken with a telephoto lens on a tripod. Smartphone users can get excellent images when the device is aimed at the eyepiece of even a modest telescope. This method works best with a dedicated mounting bracket.

Good luck and take care not to let your fingers freeze!



Moonless Quadrantids

ONCE A YEAR, Quadrans Muralis, the obsolete constellation that once resided among the dim stars of northern Boötes, reminds us that it's not dead yet. The Quadrantid meteor shower streams from the defunct Mural Quadrant every January and blitzes Earth with scraps of asteroid 2003 EH_1.

The Quads peak this year at around 15:00 UT (10 a.m. EST) on Friday, January 3rd — nearly ideal for observers in Alaska, but rather less so for the rest of North America. Timing is more of a concern with this shower than most because its peak is so brief, lasting only about six hours. If you happen to live where the radiant is well placed in a dark sky, you could witness more than 100 meteors per hour. Less ideal locations will see closer to 25 per hour.

Quads are swift, pinging the atmosphere at more than 147,000 kilometers per hour (91 miles per hour), and they often produce bright fireballs.

Minima of Algol

Dec.	UT	Jan.	UT
1	18:52	2	7:53
4	15:41	5	4:42
7	12:30	8	1:31
10	9:19	10	22:21
13	6:08	13	19:10
16	2:58	16	15:59
18	23:47	19	12:49
21	20:36	22	9:38
24	17:25	25	6:27
27	14:14	28	3:17
30	11:04	31	0:06

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

▲ Perseus is conveniently positioned at the zenith during evening hours in January. 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

JANUARY IS PRIMETIME for Jupiter. The giant planet reached opposition on December 7th and currently is visible most of the night, gleaming at magnitude –2.7 from its perch high up in Taurus. By the time twilight ends mid-month, Jupiter is already more than 50° above the southeastern horizon and crosses the meridian at roughly 10 p.m. local time. The Jovian disk spans a generous 45″, which means even a small telescope working at moderate magnification will reveal the two main equatorial belts and a healthy serving of other features.

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

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.)

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

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

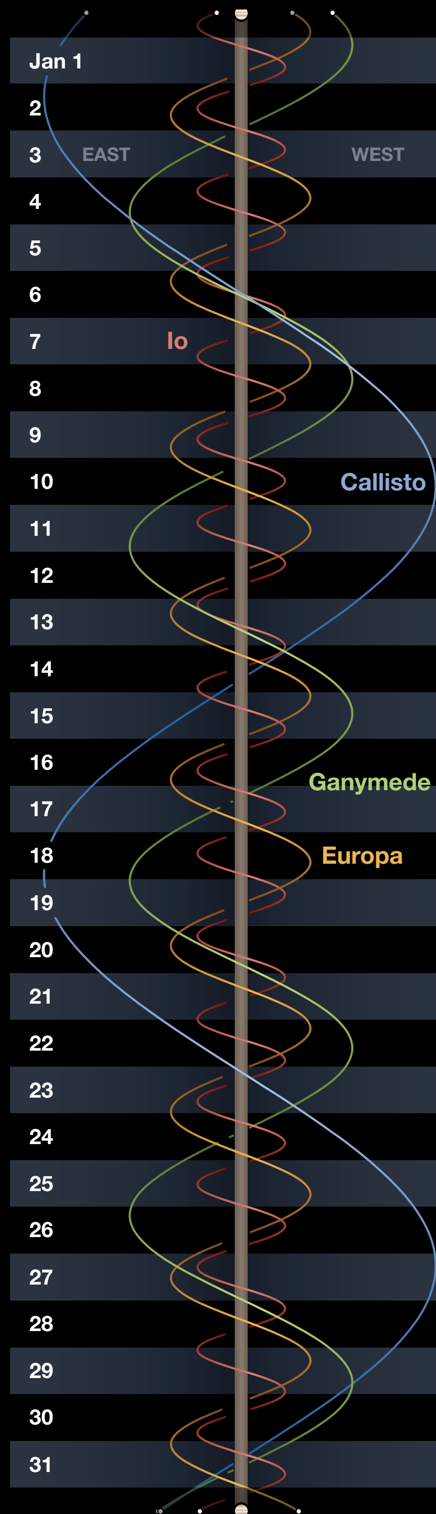
These times assume that the spot will be centered at System II longitude 68° on January 1st. If the Red Spot has moved elsewhere, it will transit 1²⁄₃ minutes earlier for each degree less than 68° and 1²⁄₃ minutes later for each degree more than 68°.

Phenomena of Jupiter's Moons, January 2025

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

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

Jupiter's Moons



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

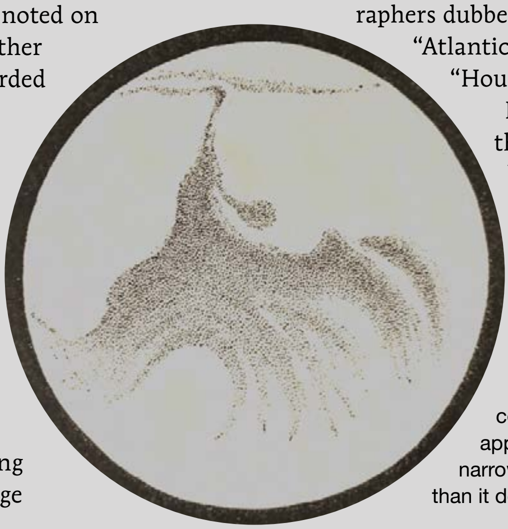
The Shifting Sands of Mars

Syrtis Major is an iconic Martian feature that has changed dramatically over the years.

▲ Syrtis Major is the centerpiece of this 1999 Hubble Space Telescope image.

In 1877, Italian astronomer Giovanni Schiaparelli introduced a naming system for surface features on Mars based on geographical names from classical antiquity. This nomenclature is still in use today. He named the Red Planet's most conspicuous dark marking **Syrtis Major** after the Roman name for the body of water on the coast of Libya that's known today as the Gulf of Sidra.

Centered near 290° longitude and 10° north latitude, Syrtis Major is a dusky, wedge-shaped *albedo feature* (a region that differs in reflectivity from adjacent areas) that extends some 1,500 kilometers (930 miles) northward from the Martian equator and spans 1,000 km from west to east. The first permanent feature to be noted on the surface of another planet, it was recorded in a series of 1659 sketches of Mars by the Dutch astronomer Christiaan Huygens. He was able to glean that the length of a day on Mars is slightly longer than a day on Earth by monitoring the feature's passage across the face of Mars from night to night through a primitive 2.7-inch refractor that magnified only 87×.



◀ As this 1864 sketch by English observer William Rutter Dawes depicts, during the 19th century Syrtis Major appeared considerably narrower and more pointed than it does today.

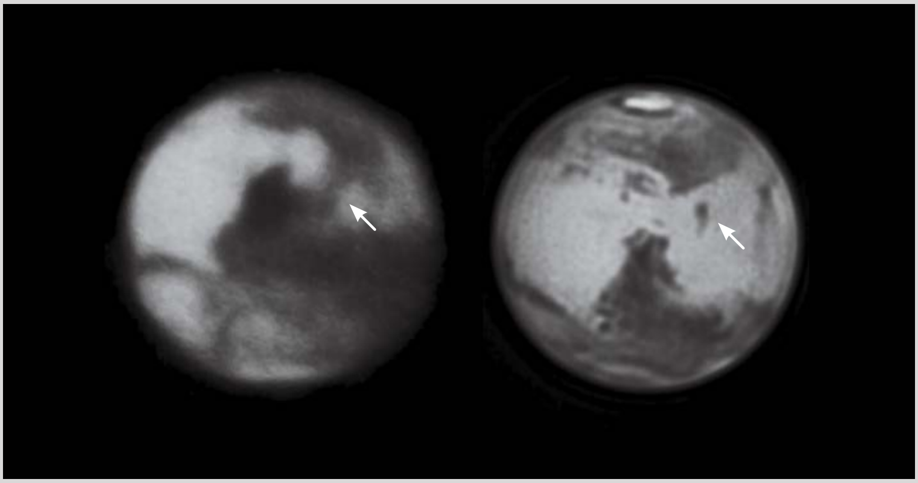
A native of water-logged Holland, Huygens compared the prominent smudge to a bog. By the mid-19th century, the numerous dark features that cover about three-eighths of the Martian surface came to be widely regarded as bodies of water. Before the adoption of Schiaparelli's nomenclature, cartographers dubbed Syrtis Major the "Atlantic Channel" or the "Hourglass Sea."

By the dawn of the 20th century, it became clear that these markings couldn't be bodies of water because they never produced visible specular reflections of sunlight. In addition, steady seeing revealed that they weren't uniformly dark, but rather complex patchworks of spots and streaks. A new consensus emerged that the markings were the dried-up beds of ancient seas surrounded by bleak ochre deserts — a notion that persisted until NASA's three Mariner spacecraft surveyed the planet at close range in the 1960s.

In 1873 British astronomer Richard Anthony Proctor wrote: "The principal charm of astronomy, as indeed of all observational science, lies in the study of change — of progress, development, and decay, and especially of systematic variations taking place in regularly-recurring cycles."

Changes on Mars have captivated generations of observers. While the overall pattern of its markings has remained recognizable over the centuries, the planet's albedo features vary in outline, intensity, and coloration both seasonally and from year to year. On a timescale of

MARS: NASA / ESA, S. LEE (U. COLORADO) J. BELL (CORNELL U.) AND M. WOLFF (SSI); SKETCH: WILLIAM R. DAWES



▲ In 1954 the Martian albedo feature Nepenthes-Thoth was unusually dark and eye-catching, but in 2012 the only remaining trace was a spot known as Nodus Alcyonius.

decades, Syrtis Major and its surroundings have undergone extensive changes.

During the 19th century, Syrtis Major appeared considerably narrower than it does today and tapered into a long, curving tail-like appendage known for a time as Nilosyrtis. The Italian astronomer Angelo Secchi compared its shape to a scorpion. Nilosyrtis faded from view early in the 20th century as Syrtis Major gradually broadened to take on the appearance of a shark's fin. Its pointed northern tip grew blunt during the 1970s and today resembles the rounded southern end of Africa.

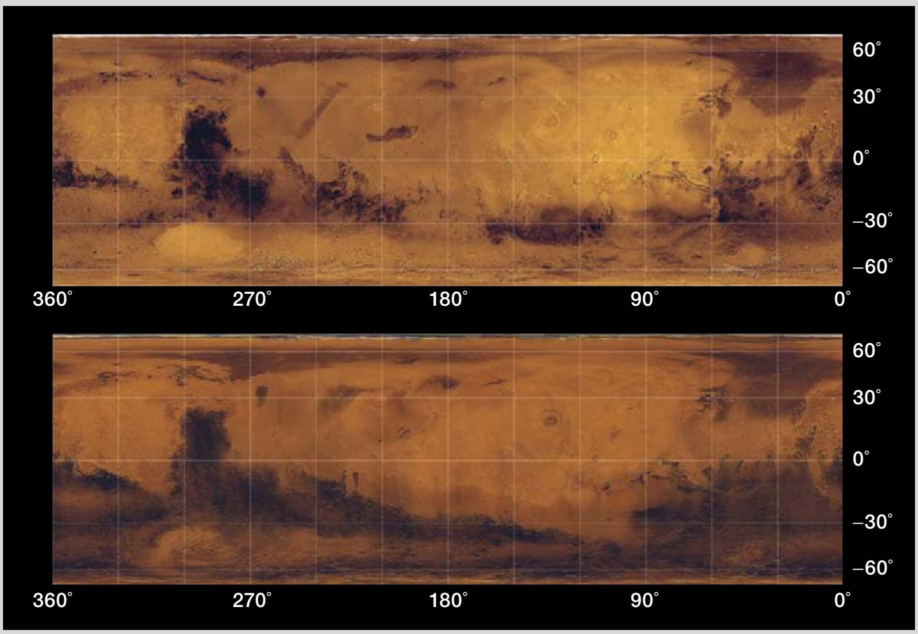
A broad, dark arc formerly known as Nepenthes-Thoth protruded from the eastern flank of Syrtis Major during the first half of the 20th century. Prominent in 1954, it faded abruptly in the late 1960s. Today only a small remnant known as Nodus Alcyonius survives.

These transformations were widely attributed to the growth and decay of tracts of vegetation until the late 1950s, when two leading scientists — Gerard Kuiper in the United States and Vsevolod Sharonov in the Soviet Union — independently surmised that the seasonal and cyclical changes on Mars are caused by winds that alternately deposit and remove bright dust and sand from darker underlying terrain. They were vindicated when spacecraft in Martian orbit revealed Syrtis Major to be an immense, low-relief shield volcano covered with dark gray basalt from ancient lava flows. Its intensity and extent wax and wane as windblown particles accumulate and then are scoured away.

Although the apparent size of the Martian disc will only be a paltry 14.6 arcseconds at closest approach this year (see page 48), the planet's northern hemisphere will be tilted toward Earth, providing excellent opportunities to scrutinize Syrtis Major. But be prepared for surprises when you train your scope on Mars . . .

Sketches of Mars made during the closing years of the 18th century by the era's leading Mars observers — Johann Hieronymus Schröter in Germany and William Herschel in Britain — depict a prominent, wedge-shaped marking rivalling Syrtis Major in size. The base of this large triangular feature was located near Martian longitude 225° and latitude –15° along the edge of the rugged highlands of Mare Cimmerium, and it extended northward into the adjacent Amenthes basin to a latitude of about +10°. Joseph Ashbrook, who authored the "Astronomical Scrapbook" column in this magazine from 1954 until his death in 1980, dubbed this Texas-sized feature the "Arrowhead."

By 1830, when German astronomers Wilhelm Beer and Johann Mädler began to compile the first map of Mars to employ latitude and longitude coordinates, the Arrowhead had vanished. Ashbrook wrote: "The disappearance of this vast tract — for two decades one of the most easily seen features on Mars — is the most striking change yet recorded on the surface of the Red Planet. Its explanation remains an intriguing puzzle."

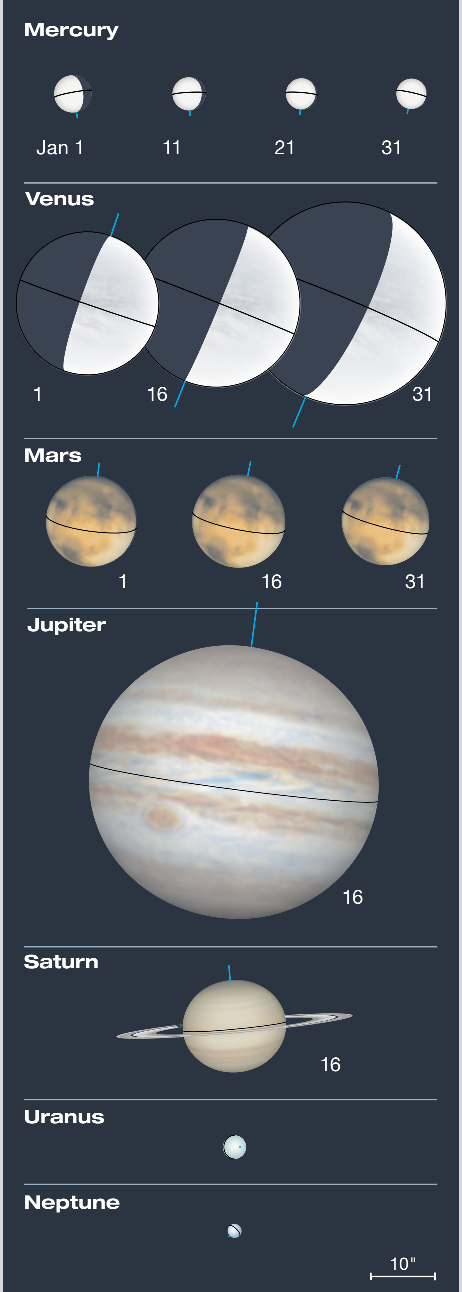


▲ These global mosaics of Mars were assembled from images taken by NASA's Viking Orbiter between 1976 and 1980 (top) and by the Mars Global Surveyor between 1999 and 2002 (bottom). Dramatic changes in the planet's markings are apparent, especially in the southern hemisphere.

MARS PHOTO: E. C. SLIPHER; MODERN IMAGE: SEAN WALKER; MARS GLOBAL MAPS: USGS / P. GEISSLER

■ Contributing Editor **TOM DOBBINS** co-authored *Epic Moon: A History of Lunar Exploration in the Age of the Telescope*, available at **shopatsky.com**.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn to the 12th • **Venus** visible at dusk all month • **Mars** rises at dusk and is visible to dawn • **Jupiter** visible at dusk and sets before morning twilight • **Saturn** high in southwest at dusk and sets in the evening.



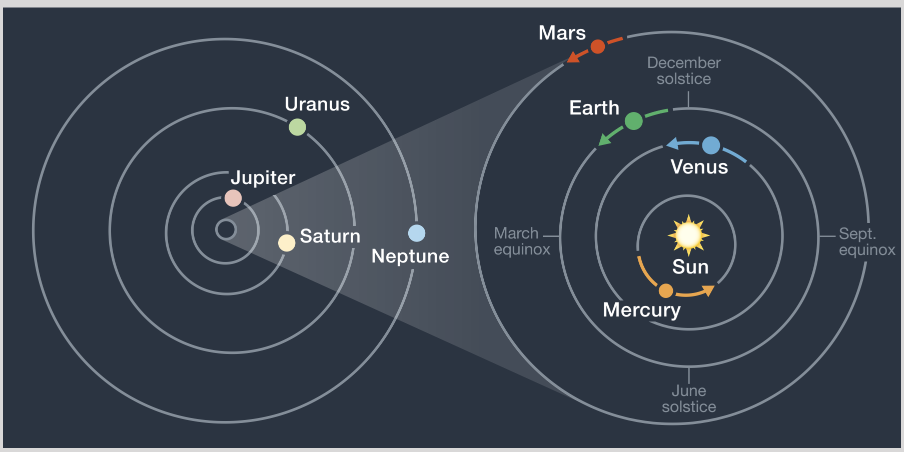
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

January Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$18^h\ 45.5^m$	–23° 01′	—	–26.8	32′ 32″	—	0.983
	31	$20^h\ 53.9^m$	–17° 28′	—	–26.8	32′ 28″	—	0.985
Mercury	1	$17^h\ 14.8^m$	–21° 55′	21° Mo	–0.4	5.9″	77%	1.148
	11	$18^h\ 14.6^m$	–23° 37′	17° Mo	–0.3	5.2″	88%	1.289
	21	$19^h\ 20.3^m$	–23° 28′	13° Mo	–0.5	4.9″	94%	1.375
	31	$20^h\ 28.8^m$	–21° 04′	7° Mo	–0.9	4.8″	98%	1.411
Venus	1	$22^h\ 00.2^m$	–13° 42′	47° Ev	–4.5	22.2″	55%	0.751
	11	$22^h\ 38.9^m$	–9° 11′	47° Ev	–4.6	24.6″	51%	0.677
	21	$23^h\ 13.5^m$	–4° 29′	47° Ev	–4.7	27.7″	45%	0.603
	31	$23^h\ 43.6^m$	+0° 10′	45° Ev	–4.8	31.5″	39%	0.530
Mars	1	$8^h\ 19.0^m$	+23° 37′	159° Mo	–1.2	14.3″	99%	0.657
	16	$7^h\ 55.1^m$	+25° 10′	176° Mo	–1.4	14.5″	100%	0.644
	31	$7^h\ 31.1^m$	+26° 06′	159° Ev	–1.1	13.8″	99%	0.680
Jupiter	1	$4^h\ 46.0^m$	+21° 44′	152° Ev	–2.7	47.0″	100%	4.191
	31	$4^h\ 37.8^m$	+21° 36′	120° Ev	–2.5	43.5″	99%	4.529
Saturn	1	$23^h\ 04.8^m$	–8° 03′	64° Ev	+1.1	16.6″	100%	10.025
	31	$23^h\ 15.1^m$	–6° 55′	36° Ev	+1.1	16.0″	100%	10.401
Uranus	16	$3^h\ 22.7^m$	+18° 17′	117° Ev	+5.7	3.7″	100%	19.081
Neptune	16	$23^h\ 51.8^m$	–2° 17′	61° Ev	+7.9	2.2″	100%	30.351

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

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



A Collection of Clusters

These modest deep-sky treasures in eastern Taurus are within range of backyard telescopes.

Taurus ain't no slouch. The big bad Bull is home to the Pleiades and Hyades clusters, the famous Crab Nebula supernova remnant, and the red giant Aldebaran. Gleaming at magnitude +0.9, Aldebaran is the ninth-brightest star visible to mid-northern observers.

There's subtler stuff, too. For example, the region east of Aldebaran holds a quartet of relatively obscure yet enjoyable open clusters. On a windy evening last January, I looped around the area using an 8-inch f/6 Newtonian reflector on a Dobsonian mount. Although my suburban night sky is the color of neglected dishwater, all four clusters — and more — showed in my trusty Dob. Join me on a wind-chilled tour.

Ugly Ducklings

My Taurus loop begins at **Aldebaran**, Alpha (α) Tauri. Aldebaran dominates the Hyades Cluster, whose loosely bound members are about 150 light-years from Earth. One caveat: Aldebaran isn't a member. Only 67 light-years away, the red giant is an older sun that lies in the same line-of-sight as the mostly youthful Hyades. But don't let the details of distance blunt your appreciation of this gorgeous star's fiery gleam.

Next, I examined **NGC 1807** and **NGC 1817**, side-by-side clusters aligned northeast-southwest. The sparse specimens reside 8½° east of Aldebaran, on the western flank of the Milky Way, just north of Taurus's border with Orion. If my 8-inch reflector had been on an equatorial mount, I could've shifted the scope directly eastward from Aldebaran to the clusters. Instead, my star-hop isn't quite so direct — the route from the star dips briefly into Orion before returning to Taurus — but the circuitous path is illuminated by finderscope-friendly 4th- and 5th-magnitude stellar stepping-stones.

The first two are Sigma^1 (σ^1) and Sigma^2 (σ^2) Tauri, which stand 7.3′ apart, 1° southeast of Aldebaran. After the Sigma set, I continued southeastward 3½° to Omicron^1 (o^1) Orionis, then a bit more than 1° to Omicron^2 (o^2). At o^2, I turned northeastward for 2¾° to 11 Orionis — "11" being the star's identification in the *Historia Coelestis Britannica* compiled in the early 1700s by British astronomer John Flamsteed. Veering east-northeastward from there, a 1¼° hop landed me on another Flamsteed, 15 Orionis. Then it's a ⅔° hop northeastward to a 5.2-magnitude, deep-orange dot cataloged as HD 33554 (oddly, no Flamsteed designation for this star). One further step northward took me across the Orion/Taurus border to the clusters.

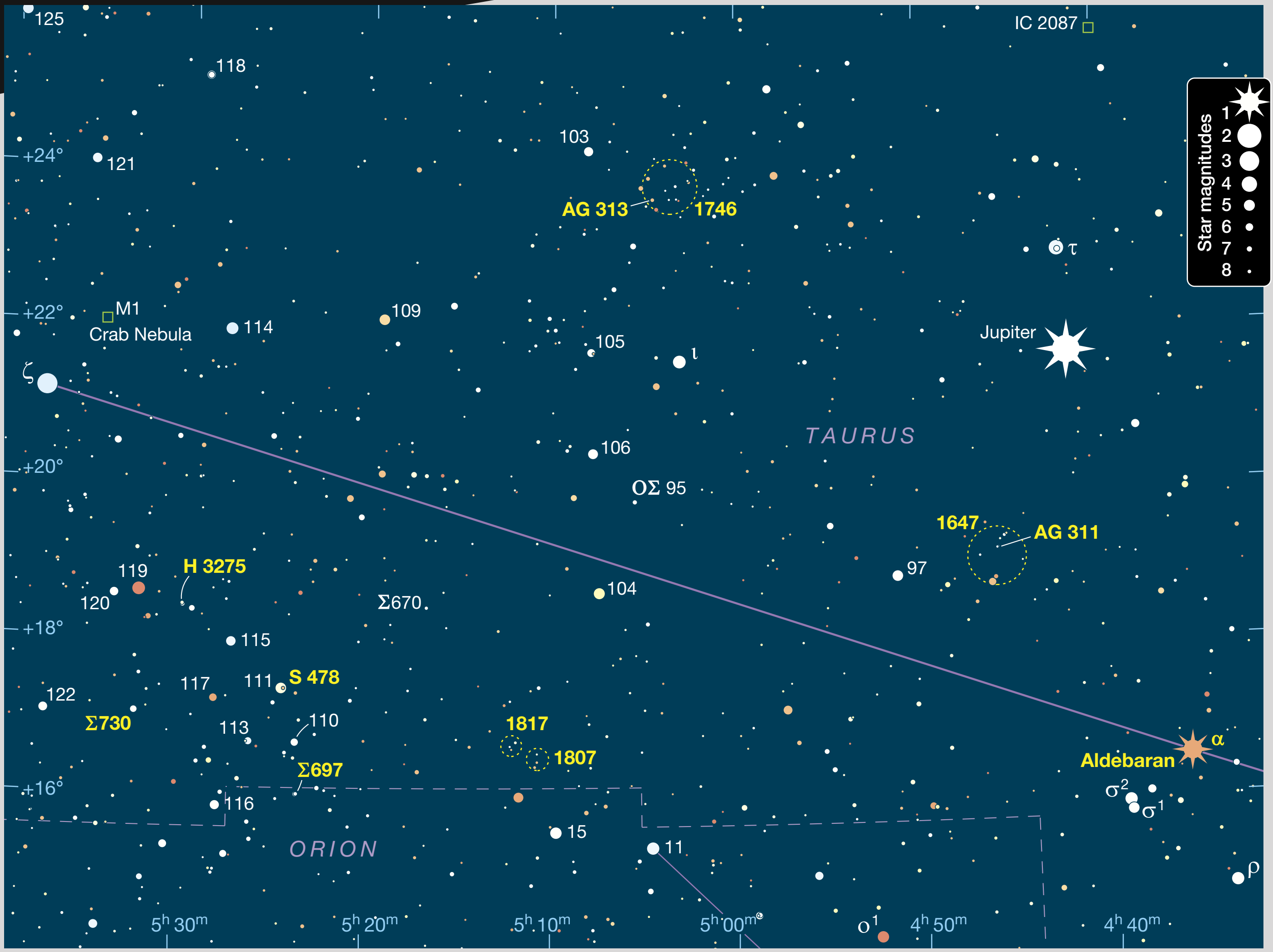
Admittedly, NGC 1807 and NGC 1817 are ugly ducklings. The former is listed at magnitude 7.0, while the latter is magnitude 7.7. They're 12′ and 20′ in diameter, respectively, and together span less than ⅔° of sky. My Dobsonian at 41× captured both uglies in a single view, each cluster defined by a north-south row of stars. The row in NGC 1807 is a zigzag of six 9th- and 10th-magnitude stars. Upping to 76× added a similar number of fainter pinpoints all around. NGC 1817 managed a zigzag of just four stars. However, I noticed *something* pooled east of the row. At 135× my averted vision sensed a pale puddle of stars at the threshold of visibility. Hey, not so ugly after all.

A Flock of Flamsteeds

A celestial atlas is a wonderful thing. As I examined various charts of eastern Taurus for easy routes to the clusters, I "discovered" a large pattern of stars — not visible to my bare suburban eyes but bright in my 8×50 finderscope — a few

▲ **BULLISH ON CLUSTERS** The constellation Taurus, the Bull, offers backyard astronomers lots of open star clusters. Although the brilliant Pleiades (M45) and Hyades clusters are fan favorites, several smaller starry collections in eastern Taurus are also worth a look. The brightest object in this photo is the planet Jupiter, which visits Taurus in roughly 12-year intervals. This month, the planet is slightly farther east than it was when captured in this photo from January 2013.

ALAN DYER



▲ **TAURUS TARGETS** Numerous 4th-, 5th-, and 6th-magnitude stars lie along the route to four modest star clusters in eastern Taurus. Observers whose telescopes are equipped with red-dot finders can, with care, follow the star-hop described in the text by using a low-power, wide-field eyepiece. Those using a conventional optical finder will have no difficulty finding their way, even under suburban skies.

degrees east of NGC 1807/1817. This eye-catching asterism turns out to be a very loose cluster called **Collinder 65** (Cr 65). I've dubbed it the Geese.

The honking high-flyers are seemingly winging their way westward in a ragged arrow formation outlined by 5th- and 6th-magnitude stars scattered across four degrees of sky. The flock is led by seven Flamsteed stars labelled 110, 111, 113, 115, 116, 119, and 120 Tauri. Trailing them are three more Flamsteeds: 117, 122, and 126 Tauri. Between 117 and 122 Tauri is HD 36408, a 6.1-magnitude star that, like HD 33554 mentioned earlier, isn't blessed with a Flamsteed number. Numerous dimmer stars fill out the field.

The Geese are freighted with double stars. Near the front of the Flamsteed flock is 5.1-magnitude 111 Tauri, which sports an 8.8-magnitude companion 106.7″ westward. This wide pairing is called **S 478**. HD 36408, the non-Flamsteed star noted above, is **Σ730** — a superb binary featuring 6.1- and 6.4-magnitude stars 9.7″ apart. Just over ½° west-southwest of 4.3-magnitude 119 Tauri (the brightest "bird" here) is a double named **H 3275**, which comprises 7.7- and 8.2-magnitude components separated by 56.1″. About 40′ south of 6th-magnitude 110 Tauri is **Σ697**, which consists of 7.3- and 8.1-magnitude stars 25.4″ apart. My 8-inch resolved all of these dim doubles at 41×.

Some of the Geese exhibit appealingly warm hues. For example, 119 Tauri is a stoplight-red variable star listed as CE Tauri. Nearly ¼° west of CE is 8.7-magnitude DV Tauri, which yields a golden glow. Approximately ⅓° south-southwest of CE is 6.8-magnitude HD 36320, another distinctly red star. Less than 3′ east-southeast of HD 36320 is 9.2-magnitude HD 244538, whose redness is real but didn't become strongly evident to my eye until I applied high power. Delightfully obvious at any magnification was the beautifully deep orange sheen of 5.8-magnitude 117 Tauri.

Done with the Geese, I returned to NGC 1807 and charged northward 7¾°, following a string of four 5th-

▲ **STELLAR CLUSTERS** *Left:* The side-by-side clusters NGC 1807 (right) and 1817 (left) are loose collections of mostly dim stars. However, each one features a colorful mixture of blue-white and yellow-white suns, with a distinctly orange star lying near the south edge of NGC 1817. The blue star at the north end is a binary named HJ 3269. It consists of 8.7- and 10.8-magnitude components 20.0″ apart. *Right:* The cluster identified as NGC 1746 is likely two clusters located at different distances. The western portion is designated NGC 1750, while the eastern section is called NGC 1758.

DSS2 (2)

and 6th-magnitude stars. From south to north, the Flamsteed four are 104, 106, 105, and 103 Tauri (I almost got drawn off-course by 4.6-magnitude Iota Tauri, 1° west of 105 Tauri). Finally, a gentle nudge of the Dob 1° west-southwestward from 103 Tauri grabbed **NGC 1746**, a cluster that easily outclassed the previously observed ugly ducklings.

NGC 1746 weighs in at magnitude 6.1 and is about 40′ across. The 8-inch Newtonian captured upwards of five dozen blue-white stars, all except one under magnitude 8.5. The coarse bunch includes **AG 313**, a delicate duo southwest of center. Its 9.4- and 10.0-magnitude components are 19.8″ apart. In addition, NGC 1746 is bordered along its eastern side by a sharply bent fence of five 7th- and 8th-magnitude orange stars. Bumping up to 135×, then concentrating on where the fence bends, I glimpsed a 10′-wide clump of at least 20 exceedingly faint pinpoints. This pallid bunch is possibly an unrelated cluster far beyond NGC 1746.

Shifting the telescope 6¼° southwestward toward Aldebaran swept up 6.4-magnitude **NGC 1647** (it's 3½° northeast of Aldebaran). The finderscope couldn't detect the cluster but it netted two neighbors just to its south — 6.0- and 7.5-magnitude yellow-orange stars, 5′ apart, oriented southeast-northwest. Together they act as a signpost for the thin glitter lying ¼° northward. Working at 41× again, the 8-inch corralled perhaps 60 stars, all below magnitude 8.0, covering 40′ of sky. The jewel in the NGC 1647 crown is **AG 311**, a quickly spotted double consisting of 8.9- and 9.3-magnitude stars separated by 33″.

From NGC 1647, I headed home to Aldebaran. Jupiter, beaming at magnitude –2.6, adds luster to the scene as it plies a retrograde course slowly westward, just north of our modest targets. Brave the January chill and go get 'em!

■ Contributing Editor **KEN HEWITT-WHITE** is a seasoned connoisseur of clusters, bright and dim.

Treasures in Eastern Taurus

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Aldebaran	Star	+0.9	—	$4^h\ 35^m$	+16° 31′
NGC 1807	Open cluster	7.0	12.0′	$5^h\ 10.8^m$	+16° 31′
NGC 1817	Open cluster	7.7	20.0′	$5^h\ 12.5^m$	+16° 41′
Cr 65	Open cluster	—	220′	$5^h\ 26.1^m$	+15° 42′
S 478	Double star	5.1, 8.8	106.7″	$5^h\ 24.4^m$	+17° 23′
Σ730	Double star	6.1, 6.4	9.7″	$5^h\ 32.2^m$	+17° 03′
H 3275	Double star	7.7, 8.2	56.1″	$5^h\ 29.8^m$	+18° 25′
Σ697	Double star	7.3, 8.1	25.4″	$5^h\ 23.5^m$	+16° 02′
NGC 1746	Open cluster	6.1	40.0′	$5^h\ 03.8^m$	+23° 46′
AG 313	Double star	9.4, 10.0	19.8″	$5^h\ 03.6^m$	+23° 39′
NGC 1647	Open cluster	6.4	40.0′	$4^h\ 45.7^m$	+19° 07′
AG 311	Double star	8.9, 9.3	33.0″	$4^h\ 45.9^m$	+19° 11′

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.

Goodbye to Gaia

Catch a last glimpse of a successful spacecraft.

All good things must come to an end. And so it is with the European Space Agency's Gaia space observatory. Gaia has carried the mantle of the ancient and time-honored tradition of *astrometry*, or measuring the positions and motions of celestial objects. And it has done so with unprecedented accuracy, precisely recording the positions of more than 1.8 *billion* targets since the start of nominal operations shortly after its launch in December 2013. The mission has been extraordinarily successful — you'd be hard-pressed to find an issue of this magazine from the past decade that doesn't mention Gaia somewhere in its pages (see, e.g., *S&T:* Feb. 2023, p. 34 and *S&T:* Apr. 2024, p. 12).

The spacecraft will have used up all its fuel by mid-January 2025, signaling the end of the space-based phase of the mission. But before that, we'll have a chance to say farewell.

Missing magnitudes. In order to ensure accurate measurements of the positions of celestial objects, Gaia scientists have to calculate the spacecraft's orbital parameters with high precision. To do so, they established the Ground Based Optical Tracking, or GBOT, program to monitor Gaia's position on the sky from Earth — a crucial parameter for this task. Gaia doesn't glow per se, but it does reflect sunlight back at us from its position far beyond Earth's nightside, the light bouncing off its 11-meter-wide (36-foot-wide) sunshield. Initially, engineers estimated the spacecraft's magnitude would be around 18. As the mission got under way, a fleet of 1- to 2-meter-class telescopes across the globe was poised to record the spacecraft's celestial position daily.

As preliminary data rolled in, Gaia kept clocking in at around magnitude 21 instead of the predicted 18. Bewildered, the GBOT team had to rethink their strategy — the diminished magnitude forced them to limit their data acquisition to telescopes 2 meters or larger in aperture. But that compromised coverage, as bigger instruments are fewer and farther between and have less flexibility in their scheduling.

After a decade of poring over the data, engineers are still puzzled as to why Gaia's apparent magnitude never reached the pre-launch prediction. In order to solve this mystery and also to find out just how the deep-space environment has affected the spacecraft, the GBOT team plans to run a battery of technical tests and experiments to help them better understand this discrepancy.

Goodbye to Gaia. Space engineers conduct procedures known as "end-of-life" tests on spacecraft before decommissioning so that they can anticipate problems that might arise in future missions and offer potential solutions. And so, Gaia will undergo the same process, which will, among other things, shed light on the effects of the harsh atmosphere of space on the craft's sunshield.

GBOT team leader Martin Altmann (Heidelberg University, Germany) outlines that one of these tests will be to slew the satellite from its normal inclination to the Sun to angles more favorable to making it light up for ground-based observers. Starting in mid-January, operators will guide the spacecraft through a series of maneuvers that will change the angle of the sunshield from 45° to 90° and back again over a period of several weeks. During this time, Gaia's apparent magnitude should leap to 14 or so, well within the reach of amateur telescopes.

▲ Engineers inspect Gaia's 11-meter sunshield before launch from Kourou, French Guiana.

Altmann and his team are calling on the amateur community to participate in the end-of-life testing period, requesting magnitude and color measurements. For this, even an 8-inch scope should suffice — and an astronomical camera and filters are desirable for color estimates. Head over to **https://is.gd/Gaia_EOL** for information on how and when to observe Gaia as it approaches the close of its space operations. The GBOT team is eager to hear from you — but note that you'll have to reduce all the data yourself before you upload your measurements.

As you point your telescope at Gaia and gather data that will help the GBOT team unravel the mystery of the missing magnitudes, see this as a fitting farewell to an extraordinarily successful spacecraft. Join Altmann and his colleagues in what he calls "the time to say goodbye."

■ Observing Editor **DIANA HANNIKAINEN** plans to wave farewell to Gaia in January.

ESA / CNES / ARIANESPACE

Pixel Scale for Deep-Sky Imaging

Here's how you can get all the fine details your gear can deliver.

Astrophotographers typically try to get the most they can out of their equipment, whether it's capturing the most exposures or resolving the tiniest details possible with their telescope and camera combination. To do that, we must become very familiar with all aspects of our gear so that we can use it to its fullest potential. That means, for example, mastering polar alignment, consistently nailing focus, and learning the nuances of autoguiding. But one of the most important details that beginners frequently overlook is matching your camera's pixel size to your optics to achieve consistently sharp results. Doing so is particularly important if your desire is to record high-magnification images of galaxies, nebulae, and star clusters. Here's how it works.

Pixels and Resolution

Most of us are content to produce beautiful astrophotos and don't concern ourselves with the mechanical and electronic wizardry that makes modern digital cameras work. But these devices are doing something quite remarkable: They record analog signals and convert them to digital. Your camera has an array of millions of light-sensitive picture elements, better known as *pixels*. The size of these pixels, combined with the focal length of your telescope, determines the spatial resolution of your image.

In astrophotography, *pixel scale* refers to the angular width of the area of sky (measured in arcseconds) falling on a single pixel, typically stated as arcseconds per pixel. This

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measure depends on the focal length of your telescope or lens, and the size of the pixels of your camera. To calculate pixel scale, plug your telescope's focal length (in millimeters) and your camera's pixel size (in microns) into this equation:

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

where P is the size of the pixels in your camera, and F is the focal length of your telescope. For example, let's say I have a telescope with a focal length of 1,000 mm paired with a camera having 3-micron-square pixels. My pixel scale is 0.6 arcsecond.

You can think of pixel scale as the imaging equivalent to visual magnification, with low-pixel-scale values (less sky per pixel) being similar to higher magnification, and high-pixel-scale values (more sky per pixel) corresponding to lower magnification. Pixel scale also sets an upper limit on the angular size of the tiniest details that your images can reveal — its *resolution*.

This is where the aperture of your telescope comes into play, since it sets an upper limit on resolving power. For example, you might be tempted to pair a camera with tiny pixels to a short-focal-length optic to increase image resolution. You'll find that resolution is limited by the resolving power of the telescope, and you'll fall short of the calculated pixel scale. As a result, you'll just produce an image with larger, fuzzier details.

▲ **SCALE MATTERS** Proper sampling can reveal detail that is muted or invisible in undersampled images. The above photos of M27, the Dumbbell Nebula, were recorded with two different telescopes and cameras. The version at left was taken through a 10-inch f/3.6 reflector at a scale of 1.36 arcseconds per pixel, while the other was captured through a 14-inch SCT at 0.4 arcsecond per pixel. Note the smaller stars and additional detail in the right image.

The resolution of your images, particularly when taken at long focal lengths, also varies from night to night due to atmospheric conditions, the most important of which is *seeing*, which refers to the turbulence in the atmosphere. Seeing doesn't affect all imaging systems equally: The smaller the pixel scale you're shooting at, the more severely resolution is affected by poor seeing. In general, wide-field imaging rigs typically produce large image scales that are relatively tolerant of turbulent conditions. However, the performance of long-focal-length systems with the same cameras may be very sensitive to resolution-degrading atmospheric effects.

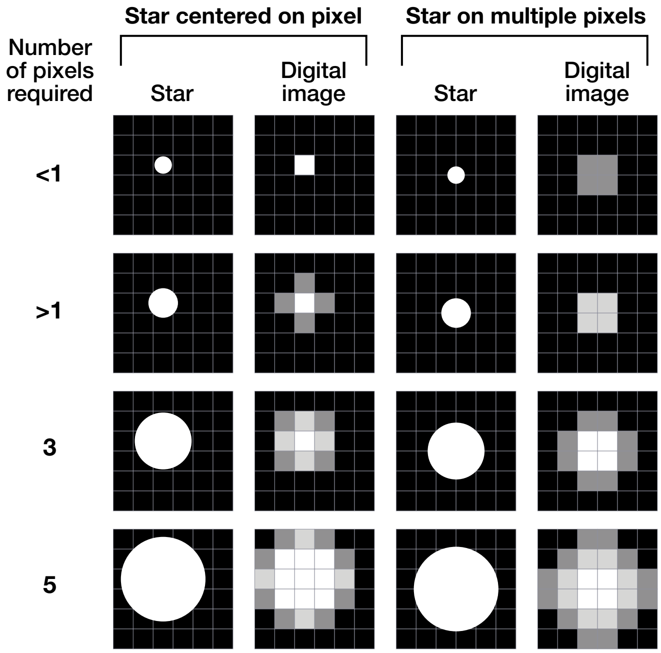
You can evaluate the quality of seeing and the resolution in your photos by analyzing the stars. The *full width at half maximum* (FWHM) is a measure of the curve of a star's brightness profile at half its maximum brightness and is the standard measure used in most imaging software. The better the conditions, the smaller the FWHM value will be. Some programs report the FWHM in pixels rather than arcseconds. Here's a helpful formula used to convert to the FWHM value to arcseconds:

FWHM (arcseconds) = pixel scale × FWHM (pixels)

A related measure, the *Half-Flux Diameter* (HFD) is another way to quantify seeing and is more tolerant of slightly out-of-focus data than FWHM is. HFD is determined by summing the brightness values and measuring the diameter of a circle where 50% of the signal resides. HFD can be used interchangeably with FWHM.

Enter Nyquist

So how do you know what the right pixel scale for your telescope is? How many pixels are needed to make stars look round in an image composed of square pixels? Obviously, one pixel is not enough because if a faint star falls on only one pixel, it will look square upon close inspection. At the other extreme, a million pixels is intuitively too many. You don't need a 1,000 × 1,000 grid of pixels to represent a single star. So how many pixels do you need?

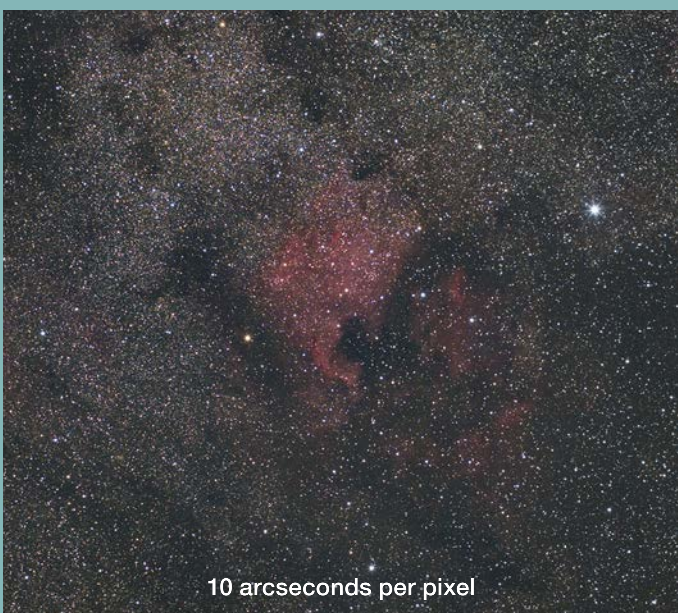


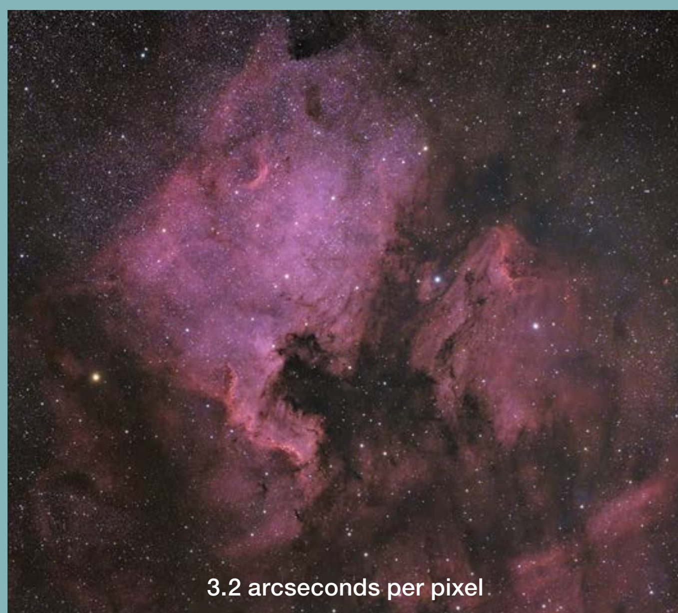
▲ **ROUND STARS, SQUARE PIXELS** Several pixels are required for stars to appear round in digital images. This is true whether a star falls in the center of a pixel or between them. The Nyquist theorem suggests that the optimum image scale to maximize detail in deep-sky images is about ¼ to ⅓ of the seeing limit.

SPATIAL-RESOLUTION DIAGRAM: LEAH TISCIONE / *S&T*

The *Nyquist theorem* answers that question. This is also known as the *sampling rate* of your system. If you would like to dive into the mathematical details, you can find plenty of information about the theory online. But in short, the Nyquist theorem advises that we need to sample at twice the

▼ **ZOOM WITH A VIEW** This series of images shows the region of NGC 7000, the North America Nebula, at four different pixel scales. Notice how the amount of detail increases as the image scale decreases from 10 arcseconds per pixel (far left) to 0.4 arcsecond per pixel (far right).

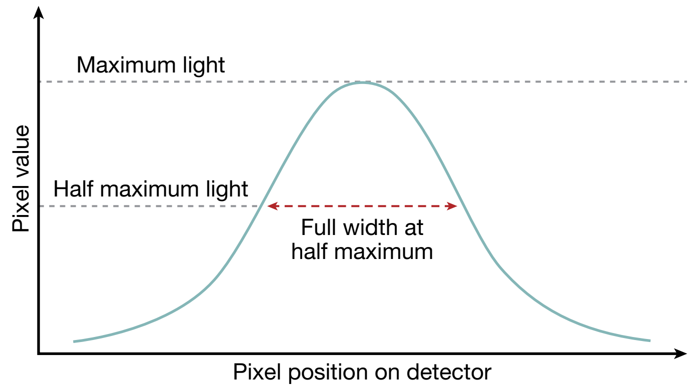




resolution that the seeing will support, assuming everything else is optimal.

In my experience, a higher sampling rate — more like ⅓ to ⅕ of the seeing — is needed to ensure that even the tiniest stars fall on more than one pixel and appear round. For instance, if the seeing hovers around 3 arcseconds (fairly typical conditions), an image scale of 0.75 to 1 arcsecond per pixel will capture all the resolution the seeing allows. Are you one of the lucky few who enjoys seeing in the 1-arcsecond range? You'll be able to take advantage of a higher-resolution system providing a pixel scale of 0.25 to 0.3 arcsecond. My current setup (3,940-mm focal length and 7.52-µm pixels) produces 0.4 arcsecond per pixel, allowing me to take advantage of those rare nights of excellent seeing conditions when my FWHM is below 2 arcseconds.

When considering how these numbers might apply to your equipment, it helps to calculate combinations of focal length and pixel size that produce an image scale of 1 arcsecond per pixel. For example, a camera with 3.76 µm pixels paired with a focal length of 775 mm yields precisely 1 arcsecond per pixel. My QHY367 Pro camera's 4.88-micron pixels produce the same 1-arcsecond pixel scale with a focal length of 1,000 mm. Systems with larger pixels require long focal lengths to achieve that same image scale.



▲ **"SEEING" STARS** Atmospheric seeing is commonly estimated by examining unsaturated stars in a deep-sky image. One of the most common metrics is the Full Width at Half Maximum (FWHM) measurement — the width of the star's brightness profile at half the maximum brightness, expressed in arcseconds. The lower the FWHM value, the better the seeing conditions.

FWHM GRAPH: LEAH TISCIONE / *S&T*

Undersampled or Oversampled? So What?

An astrophoto is said to be *undersampled* when there aren't enough pixels to capture all the detail available. The easiest way to find out if your deep-sky image is undersampled is to simply zoom in and look at the smallest stars. If they are square, you could have obtained more detail with a higher-resolution system — one with a smaller pixel scale.

Conversely, an *oversampled* picture is one that has more pixels than needed to show all the available information. In oversampled images, stars look bloated. Sometimes grossly oversampled images reveal optical aberrations that aren't visible in properly sampled images, particularly when using field flatteners and focal reducers. This happens when your pixel scale is smaller than the spot size produced by your optical system and will show up as distorted stars most often in the corners of the frame.

Due to the affordability of large detectors these days, imagers are often tempted to buy cameras with detectors that have large arrays of very small pixels. When paired with long-focal-length instruments, the resulting images are extremely oversampled. But that same camera can still be useful, particularly if you have a wide range of instruments with both long and short focal lengths. The solution in these scenarios is to *bin* the pixels in the camera, which groups adjacent pixels to act

as a larger, single pixel. This technique makes a camera with, say, 3-µm-square pixels at its native resolution into one with 6-µm pixels when binned 2 × 2 or even 9-µm when binned 3 × 3. However, binning works best with monochrome cameras. One-shot-color cameras require a different approach because of the Bayer filter matrix, which divides the detector into a grid of red, green, and blue pixels. In this case, you should shoot at native resolution and then *downsample* the images after calibration and color conversion during post-processing.

▲ **USEFUL TOOL** Astronomy Tools' CCD Suitability Calculator shows that the author's setup slightly oversamples.

On nights of average seeing, my Celestron 14-inch EDGE HD used at its native focal length with my QHY600M camera in 2 × 2 binning mode (3.76-µm pixels binned 2 × 2 = 7.52 µm) produces slightly oversampled images with a pixel scale of 0.4 arcsecond. But this rig can get every speck of detail that's available on the nights of best seeing, when I can sometimes achieve a FWHM value of 1.5 arcseconds.

If you're after fine detail and your image is slightly undersampled, you can use a special integration technique to recover some of that information. *Drizzle* integration was originally developed by scientists working on Hubble Space Telescope images. The process reconstructs undersampled images using a combination of dithering, upsampling, and stacking to produce a larger, higher-resolution photo.

Dithering is intentional, random pointing offsets between each sub exposure so that stars do not appear on the exact same pixels in each frame. These dithered frames are then *upsampled* or *resampled* using a special mathematical process to increase the overall pixel count in an image. Upsampling itself does not gain any resolution in your image. But use of the Drizzle algorithm will recover additional resolution in the averaged result. Most advanced image-processing software includes a Drizzle stacking option. Drizzle works best if you have a large number of subexposures to combine.

I often use Drizzle stacking on images taken with my Takahashi 60-mm f/6.2 refractor and QHY367C camera with its 4.88-micron pixels, which produces undersampled images

RECOVERING DETAIL A technique originally developed by scientists working with Hubble Space Telescope data, Drizzle is a stacking routine used to improve the resolution of undersampled data in the image at left. It helps to round out the tiniest, square-looking stars in the result at right. Drizzle requires a relatively large number (25 or more) of dithered subexposures.

at a 2.6-arcsecond pixel scale. Using 2× Drizzle processing in *PixInsight*, the resulting pixel scale is boosted to 1.3 arcseconds, and most stars look round when closely examined. I use this imaging system for large objects, like the North America Nebula, NGC 7000, or the Andromeda Galaxy, M31. For wide-field, deep-sky images and for nightscapes, *field of view* (how much sky fits on the camera sensor) is more important than pixel scale, since the intention isn't to see individual stars, galaxies, and nebulae up close. When the vastness of the Milky Way or the foreground in a nightscape shot is most important, image scale doesn't matter much at all.

Optimizing Your System

If you'd like to determine the pixel scale for your optics and cameras, there's a great online tool that does the math for you. The Astronomy Tools website hosts the *CCD Suitability Calculator* (**https://is.gd/CCDsuitability**), which, despite its name, also works with CMOS cameras. It lets you select from many models of cameras and telescopes in dropdown lists or input custom information about your equipment, including camera binning and telescope focal reducers. Simply enter the values in the calculator, choose your typical seeing conditions, and the app immediately determines the pixel scale. It also provides information regarding the suitability of the setup for high-resolution imaging. It's interesting to explore how various kinds of equipment or operational settings affect pixel scale. The documentation includes a discussion of how the Nyquist theorem is used (with slight modifications) to complete the assessment.

Based on my own experience with a wide range of telescopes and cameras, about 0.5 to 2 arcseconds per pixel resolves the majority of small-scale detail that conditions allow on most every clear night, assuming you have accurate collimation, focus, and tracking.

Get the Most from Your Conditions

The quality of the data we acquire depends on things we can control just as much as on things we can't. Local seeing conditions are largely beyond our influence, but we can select equipment to perform reliably given our specific situation. Focusing on image scale when you next upgrade your telescope or camera can help ensure you'll be able to get as much fine detail in your photos as possible. And it will help you pick a combination that can produce round, not square, stars — even the tiny ones.

■ Contributing Editor **RON BRECHER** currently photographs the night sky at 0.4 arcsecond per pixel from his home observatory in Guelph, Ontario. He displays his images at **astrodoc.ca**.

GALACTIC SURFBOARD The spiral galaxy M108 in Ursa Major shows a wealth of detail in this high-resolution portrait recorded at 0.4 arcsecond per pixel. Note the many pinkish HII regions and mottled dust lanes not visible in lower-resolution shots, as well as several much farther galaxies visible in the background.

Celestron's Origin Astrograph

This smart telescope promises to be easy enough for rank beginners and powerful enough for seasoned astroimagers.

CUTTING-EDGE TECHNOLOGY for amateur astronomers has revolutionized the hobby in ways most of us couldn't have imagined a generation ago. In the 1990s, it was Go To telescopes. A decade later, digital cameras were relegating emulsion-based astrophotography to the history books. Today we're being wowed by a proliferation of smart telescopes. Set them down and, with the push of a few buttons, they automatically align themselves to the sky, find celestial targets, and generate remarkable images of those objects in less time than most of us need to set up a Dobsonian for a night of observing.

Celestron's Origin is the company's latest entry in the genre of smart telescopes, though it prefers to call the product an "intelligent home observatory." The Origin's 6-inch f/2.2 Rowe-Ackermann Schmidt Astrograph optical system (popularly known as RASA) is arguably the most advanced astrograph currently available as a smart telescope, and it joins Celestron's impressive family of 8-, 11-, and 14-inch RASA scopes.

It's worth noting that the Origin is foremost a scope for deep-sky imaging. And while there are always exceptional imaging situations, its relatively short 335-mm focal length and 1.27°-by-0.85° field of view have limited value for the Moon and planets.

The Origin borrowed from Celestron for this review arrived in a large box measuring roughly 1.3 meters (50 inches) long and weighing 28 kilograms (63 pounds). Inside, the RASA tube assembly, mount, and tripod were individually packed in robust boxes. I was momentarily startled when I unpacked the "Quick Setup Guide." This large-format, 20-page booklet filled with scores of photos suggested that getting started with the Origin would be anything but "quick" — until I realized it was printed in five languages. Furthermore, three and a half of the four pages in English covered the assembly of the parts, which most amateurs will find so intuitive that no instructions are necessary. And the final section on getting the scope operational essentially said to download and launch the app on your controlling device, turn on the scope, and follow the app's on-screen instructions. Could it really be that simple?

To find out, I made

▲ Celestron's fully assembled Origin weighs just 18 kilograms (40 pounds), with the heaviest individual piece being 7.7 kg. That and features such as well-designed carrying handles, captive thumbscrews, and a no-tool assembly make this smart telescope a breeze to transport and set up.

▶ Launching the *Celestron Origin* app brings up a home screen displaying the observer's real-time sky based on *SkySafari*'s mobile planetarium software as well as basic scope controls and an inset showing the scope's field of view with continuously updated short exposures from the camera.

Celestron Origin Intelligent Home Observatory

U.S. Price: $3,999.00
celestron.com

What We Like

High-performance astrograph for deep-sky imaging

Remarkably easy to use out of the box

Controlling app includes powerful advanced features

What We Don't Like

Relatively slow upload speed of internally stored raw image data

Andromeda Galaxy, 20-minute exposure

a 180° U-turn from my typical product-review process. Rather than download and pore through the scope's 41-page user manual and familiarize myself with the hardware, I simply set up the scope in my backyard observatory and plugged in the power supply to top off its internal battery. Ignoring my own curiosity, I didn't flip on the scope's power switch. Likewise, I downloaded the iOS version of its *Celestron Origin* control app on my iPhone 11 Pro (the app is also available for Android devices) but didn't launch it. Those things would have to wait for a clear night. And wait was the key word here. Clouds, a full Moon, and a seemingly endless river of smoke thick enough to sometimes obscure 2nd-magnitude stars flowing over New England from wildfires thousands of miles away kept my "first light" experience on hold for days. Finally, an evening came that wasn't great, but it was good enough to try out the scope. Here's how it went.

Under a Night Sky

Shortly before astronomical twilight ended, I powered up the scope and launched the app on my iPhone. Within moments a message appeared asking me to connect my phone to the Wi-Fi signal from the telescope. Doing that started the Origin moving while I read through additional on-screen instructions for how I could connect to the scope via a home network or save that option for later. Suddenly a message appeared saying "Ready To Image." Really? Ready to image? How could this be? I don't think three minutes had passed since I powered up the scope.

The app's home screen showed a real-time planetarium view of my sky with the globular star cluster M13 in Hercules high in the west. I tapped on the cluster and touched what I assumed to be the app's Go To symbol. The scope quickly and quietly swung toward the cluster and within seconds I could see a faint smudge centered in the app's small "live" window. Tapping the camera icon on the screen expanded this view, and within seconds a surprisingly good image of the cluster appeared as the first 10-second exposure was automatically downloaded and processed by my phone. Exposures continued to accumulate, with an updated image appearing about every 10 seconds. In less than a minute I found myself staring at a fine color image of the cluster. This would certainly be a "Wow" moment for someone new to astroimaging, and frankly it was one for me, too!

When you stop the exposure sequence, the app downloads a stacked version of the image that's been automatically created and internally stored in the scope's 50+ gigabytes of memory during the imaging sequence, processes it, and saves a copy in your device's photo gallery.

As with any astronomical imaging, the longer the exposure sequence the better the result. But image quality was secondary to my interest in exploring Origin's features, so I kept my exposures to just a few minutes this first night. Nevertheless, by the end of the evening I had a noteworthy collection star clusters, bright nebulae, and galaxies stored on my phone. Fainter nebulae definitely needed longer exposures than I was making, especially given my smoky sky conditions. On subsequent nights when I devoted more imaging time to individual

▲ *Left:* Origin's camera is built around a 6.4-megapixel Sony IMX178 CMOS color sensor with a Bayer BGGR filter pattern. The scope's dew prevention system can be run manually or automatically using sensors that monitor ambient conditions. The author left it in automatic mode and never had a problem with dew despite September in New England being notorious for dewing conditions. *Center and right:* Magnets hold Origin's filter drawer in place. It accepts 1¼- or 2-inch astronomical filters, and the scope comes with 1¼-inch clear and dual-band nebula filters. The filter is a critical part of the optical system, and one must always be in place. There's sufficient room to access the filter drawer when the dew shield is attached.

▲ These 3-minute exposures of the globular cluster M13 (left) and the Dumbbell Nebula, M27 (right), are the author's first two images made with the Origin. Within 15 minutes of powering up the scope for the first time ever, the pair had been captured, automatically processed, and saved on his iPhone. Unless otherwise stated, all celestial images with this review are taken directly from the Origin gallery on the phone, with only the brightness and contrast tweaked using the phone's built-in photo-editing tools.

objects, I was rewarded with an impressive set of images, including nebulae. I was so impressed that I dropped my plans to take the scope to a dark-sky site (well, lousy weather played a role, too) to showcase the RASA's ability. Getting such good results under my suburban skies is, in my opinion, an even better demonstration of the scope's capability.

While I suspect most people are interested in the Origin for its imaging potential, because the scope generates such good on-screen images quickly, I found it fun to use for observing. And it certainly would be a fascinating instrument for public-outreach situations.

Getting Even More

For people who want to take their astrophotography beyond the app's automatic, AI-powered image processing described above, there are several ways to do this. One of the easiest is to tinker with the app's settings for the AI processing rather than using the default settings. Another is to use the post-processing, image-tweaking controls in the app or that are typically available with the device you're running the app on. For example, the images accompanying this article had their brightness and contrast adjusted with the photo-editing tools built into my iPhone. Going further, you can download the stacked TIFF files from the scope's internal memory and process them with any of the myriads of photo-editing computer programs available today.

Lagoon Nebula, 15-minute exposure

Lastly, you can set the Origin to save every individual exposure used by its stacking process as a separate FITS file (along with factory pre-loaded dark, bias, and flat-field calibration files). This is the standard for advanced astronomical image-processing programs. Just be mindful that these 12.2-megabyte FITS files quickly mount up. An hour-long exposure made with the default 10-second subexposures produces 360 FITS files totaling well over 4 gigabytes of data. You can increase the subexposure durations to 15 or 30 seconds to reduce the number of files, but longer exposures do not work well in all parts of the sky due to the inherent image rotation that occurs with an altazimuth-mounted telescope. At the moment, the Origin doesn't work in equatorial mode, but there are rumors that this may be an option in the future.

Software

If reviewing the Origin were just about the hardware, it would be a slam-dunk process. I was truly impressed with the Origin's mechanics and optics. Everything is well designed and well manufactured. I doubt that even a nitpicker could find something to complain about.

But the Origin "experience" is based on more than hardware. Indeed, of the hours I spent with the telescope during my two months of testing, all but a few were devoted to using the app. And reviewing software for a brand-new product can be a bit of a fool's errand,

▲ While the images created by the *Celestron Origin* app are remarkably good, the scope's raw data can also be saved as FITS files and exported to a variety of astronomical programs designed for advanced image processing. This 45-minute exposure of the Horsehead Nebula was made under a very hazy sky. The version from the app is at left, while the other was created from the raw data by the author's colleague Sean Walker, who commented that calibrating and processing the 270 raw files was "a huge amount of work."

since updates and bug fixes are common in the weeks and months following a product's release. I did have one software update during my tests, and for the record everything in this review is based on version 1.0.2 (1164) of the iOS mobile app and version 1.1.4233 of the telescope's internal software.

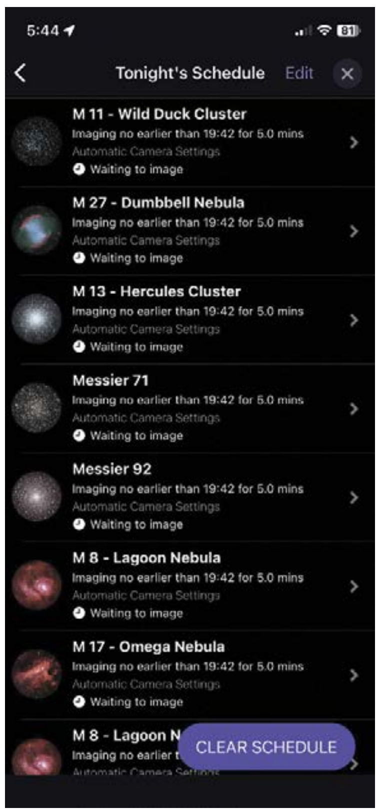
From the get-go, these versions were notably good, especially for the basic operation of the scope. Even the rare appearance of something going wrong often proved to be a false alarm. For example, several times I had the ominous message "Origin has encountered a critical error, please power cycle your Origin" appear on the app screen. But tapping the screen made the message disappear and reveal that the system was working just fine and continuing with the exposure it was making. Likewise, there were occasional messages noting some issue with the Wi-Fi that also never caused a problem.

When it comes to all the good stuff about the app, there's far more than I could ever fit in this review. It's easy to master the basic operation of the scope, but finding some of the less-obvious features can take time. Even after two months I would come across some useful feature that I hadn't discovered before.

Perhaps one of the most powerful advanced features of the app is the ability to create a schedule of objects for the Origin to image unattended (and not even connected to your controlling device). And it's remarkably easy to use. Furthermore, when you add an object to the schedule the app automatically sets default parameters for the exposure, which you can manually modify if desired. The only thing I considered missing from the scheduling feature is an ability to halt the schedule while it's running if you wanted to change the RASA's filter — you must stick with the initial filter installed in the RASA's filter drawer for the duration of the schedule.

I used the ***Schedule*** feature on multiple nights with great success. Several times Origin worked through my schedule to an object not yet clear of local trees. This aborted the exposure when no stars were detected in the image, and Origin moved on to the next object in the schedule. To avoid a missed target like this, you can set a minimum start time to begin shooting an object, but doing this requires some care since it will suspend the schedule until the set time arrives, even if other objects farther down in the schedule list are observable. The trick is to organize the schedule's order and total duration of exposure times for targets such that the next object on the list will be in an observable part of the sky.

Overall, the Origin certainly lived up to its advertised promises, especially in regard to its claim of being easy and virtually foolproof for someone new to astroimaging. Furthermore, given Origin's modular nature, including its camera, and the ever-improving nature of software, I suspect this telescope will remain at the cutting edge of amateur astronomy for quite a while. It's not a piece of technology that will become obsolete anytime soon.



▶ The ***Schedule*** feature of the control app is a powerful tool for programming an automated night of observing. Each object added to the schedule can be recorded with default parameters tailored to the object or with manual exposure settings.

■ As someone whose earliest cutting-edge astrophotography involved a roll of Tri-X film, Senior Contributing Editor **DENNIS DI CICCO** is enjoying the latest revolution.

▲ COMPACT MOUNT

Chinese manufacturer WarpAstron announces the Warpdrive WD-17 mount ($2,399), a dual-axis tracking head for astrophotographers. The mount features fast, servo-direct strain-wave drives in both axes that produce zero backlash slewing and consistent tracking in any part of the sky. The head weighs 4.3 kilograms (9½ pounds) and can carry an instrument load of 13 kg without counterweights. It operates in both equatorial and alt-azimuth modes, and its universal saddle plate accepts both Losmandy-D and Vixen-style dovetail mounting bars. The WD-17 is controlled via an included wireless hand controller or third-party computer and app programs. It also features on-board FRAM memory that records its pointing position when powered off. The mount connects to piers and tripods via a ⅜ center bolt or three M6 bolts. It comes with a DC power cable, USB-C cables, and an aluminum carry case.

WarpAstron
1525 Caoan Road, F1 Floor, Zhineng Bldg., Shanghai, China
www.warpastron.com

▲ ROBOTIC ENCLOSURE

PlaneWave Instruments announces its first foray into observatory design for autonomous, gimbal-mounted telescopes. PlaneWave Enclosures are state-of-the-art, rotating structures with sealed bearings starting with a model 3.3 meters tall and 2.58 meters wide (130 × 102 inches). They protect your equipment from the elements better than traditional observatory domes yet produce similar shielding from wind and solar heating. The enclosure is meant to operate without human occupancy in order to minimize the airspace and better control temperature and humidity, ensuring your telescope is ready to operate at any time. The entire structure turns on an industrial sealed bearing that permits high-velocity rotation to match the speed of the company's gimbal-tracking mounts in alt-azimuth configuration. Its optional aperture window (shown installed above) follows the aim of the housed instrument. Prices yet to be determined.

PlaneWave Instruments
1375 North Main St., Bldg. #1, Adrian, MI 49221
310-639-1662; planewave.com

◀ ECLIPSE GUIDE

Astrophysicist and frequent *Sky & Telescope* contributor Fred Espenak releases *Guide for the Total Solar Eclipse of 2026* ($18.99), detailing everything you'll need to know about the upcoming eclipse. It contains a series of 14 full-color maps of the path of totality across Russia, Greenland, Iceland, Spain, and the western Mediterranean. The large image scale (1 inch = 22 miles) in the map of Spain plots major roads, towns, rivers, lakes, parks, and mountain ranges to help you plan your trip. Its circumstance tables for hundreds of cities provide times for each phase of the eclipse along with its duration and the Sun's altitude. A detailed climatological study identifies areas along the eclipse path with the highest probability of favorable weather. Espenak's guide uses the new elliptical model for Earth's shadow, producing the most accurate predictions to date. A brief summary for all total solar eclipses through 2039 is also included. 8½-by-11 inches, 40 pages, paperback.

AstroPixels Publishing
P.O. Box 16197, Portal, AZ 85632
astropixels.com

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

The Salad Bowl Telescope

An artist builds a Dobsonian . . . sort of.

MOST OF YOU KNOW Cindy Krach for her stunning lunar sketches that illustrated two of my feature articles (*S&T:* Sept. 2022, p. 20 and July 2024, p. 34). She's also the coordinator of the Astronomical League's Sketching Observing Program (**https://is.gd/ALsketching**). You'd probably guess that I met her because of her sketching, but that's not actually the case. It was her enthusiasm for telescope making that initially kindled our friendship.

Cindy is one of only a handful of people I know of who have built a trackball mount for a ball scope. That's how we met, with her asking me for information about my design. Then over the years she became interested in grinding her own mirror and building a scope for it. She chose an 8-inch blank and set to work, using a glass tool to hog it out to f/5 and fine-grind it, then pitch to polish and parabolize it.

Not surprisingly, parabolizing her first mirror proved a challenge. Cindy got close several times and messed it up several times, as almost all new mirror makers do until we learn the nuances of parabolizing. She would gamely take it back to a spherical figure and try again, and she would send me progress reports with Ronchigrams she took through a homemade tester. I watched one series of Ronchigrams draw closer and closer to the ideal pattern until I finally told her, "Stop there and star test."

That meant building a star-testing rig. Cindy first tried to mount the mirror deep inside a longer-focal-ratio commercial scope tube, but that proved too awkward to collimate. Other attempts at building a skeletal OTA proved equally unusable. So she set out to build the actual scope that would house her homemade mirror.

Cindy is an artist, so not surprisingly, she didn't settle for plywood and cardboard. She kept an eye out for more interesting materials that might do, and one of the first things she found was a

▲ *Left:* Cindy used a gorgeous hardwood bowl and cutting boards for the mirror enclosure, its base, the altitude bearings, and the secondary ring. *Right:* The focuser mounts on slotted angle brackets for adjustability.

▲ Cindy Krach built this beautiful as well as functional 8-inch Dobsonian telescope.

deep, laminated-wood salad bowl that was just the right diameter at the bottom to hold the mirror. Not long after, she found laminated cutting boards that she used to make moon-shaped altitude bearings. More cutting boards provided the secondary ring and the base for the mirror bowl and struts to rest on.

Of course, these non-traditional materials meant she had to custom-fit everything, often rethinking things that didn't go right the first time. I got emails like, "I managed to move the bowl by butchering the center hole. I'll probably throw a few screws into the bottom to hold it in place. Can't be seen which is good 'cos it ain't pretty." Many times it felt like she took two steps backward for every step forward. And sure enough, one day I got an email that started with, "Today I almost gave up on the scope." My heart stopped until I read the next sentence: "But after stamping my feet and saying a lot of bad words, I figured it out."

That was pretty much the story all the way to the end, with some surprisingly innovative ideas along the way. Cindy bought a commercial focuser, but rather

▲ The "ain't pretty" end of Cindy's scope, showing the slightly off-center collimation bolts and the truss attachment bolts, is still a work of art.

than mount it on a board, she used slotted angle brackets so she could scoot it up and down, which gave her a lot more leeway in placing the secondary mirror and fine-tuning the focal point.

She settled on a two-truss system, with bolts running into T-nuts in wooden blocks that she glued inside the ends of aluminum box tubing. When the trusses are tightened up against the cutting boards at top and bottom, the structure is surprisingly stable. A planned third truss proved unnecessary. She used a metal ruler to make a curved spider using Gary Seronik's design (*S&T:* Apr. 2002, p. 108) . . . and suddenly she had a scope. A scope built entirely with simple tools.

Cindy was new at star testing. Stars looked sharp, though, and the Moon looked gorgeous through the uncoated mirror. (There's something about bare glass that makes the Moon seem almost ethereal.) Then Cindy mentioned the mirror to Mel Bartels, who had just finished a computer program that turns the Ronchi pattern into a null test (**bbastrodesigns/ronchi.html**). He tested Cindy's mirror and pronounced it "excellent."

Which is what I pronounce the entire scope. Innovation abounds from the salad bowl all the way up.

■ Contributing Editor **JERRY OLTION** appreciates fine art, especially when it's in a telescope.

What Is an Astronomy Club?

IF YOU'VE RECENTLY been bitten by the astronomy bug and have picked up an issue or two of *Sky & Telescope*, you might be feeling a bit overwhelmed at the scientific depth, the wide variety of equipment, or the unfamiliar vocabulary associated with observing activities. Diving into our hobby can be daunting, even with guides such as this magazine (and, specifically, this column) to hand. But there's another resource out there you can dip into for guidance.

Ask most any astronomer what propelled them into the subject, and they'll likely tell you that it was their first view through a telescope of *[insert favorite object, usually Saturn]*. But when you ask an amateur in particular how they progressed in the hobby, they'll probably tell you that they joined an astronomy club.

Among the Like-Minded

The central element of an astronomy club is regular — usually monthly — meetings. These get-togethers often take place in university lecture theaters or science museums or libraries — whatever convenient venue the club has access to. The format of a meeting generally comprises three main parts: a summary of club activities in the previous month, upcoming exciting celestial events to look forward to, and a presentation on a topical subject. Speakers are culled from either the professional or amateur communities and share their knowledge and experience on a variety of subjects, which can range from the latest results from the Event Horizon Telescope to photos from a solar-eclipse-chasing trip.

Note that, post-pandemic, many clubs have adopted a "hybrid" meeting format, whereby those members who can participate in person are welcome to, while those who prefer to attend virtually can do so, which makes attending meetings more convenient than ever. But by far the most important message clubs want to disseminate is that no matter what your level of experience, nor how you prefer to attend, their doors are always open.

Observing Opportunities

One of the more coveted aspects of astronomy-club membership is access to dark-sky sites for quality observing. These sites are usually specific locations in, for example, nearby state or city parks (often in a parking lot) where members can set up their telescopes and imaging equipment. Some clubs have their own observing fields, complete with clubhouse for warming up on cold winter nights, while still others operate their own observatories.

Whatever the location, these specially arranged observing nights are (with sporadic exceptions) exclusively for club members.

What if you don't own a telescope? Not to worry. Fellow observers are generally happy to share the views through their eyepiece (though *always* confirm with them first). But do take advantage of the "loaner-scope" program that many clubs offer — you can get a feel for the observing experience before taking the plunge and buying your own equipment. Most importantly, amateurs generally can't contain their enthusiasm for the night sky and will gladly give you tips — but remember to always check first if it's okay to ask for help.

FIND A CLUB NEAR YOU
Head to **skyandtelescope.org/community** for a listing.

Spreading the Passion

Amateur astronomers are among the most passionate people on the planet, and as an outlet for this enthusiasm, they engage in a wide range of outreach activities, such as participating in local science festivals or Astronomy Day events. In one of the more popular outreach activities, members set up their telescopes at pre-arranged school or library viewing sessions and invite the eager public to peer through eyepieces at a variety of celestial targets.

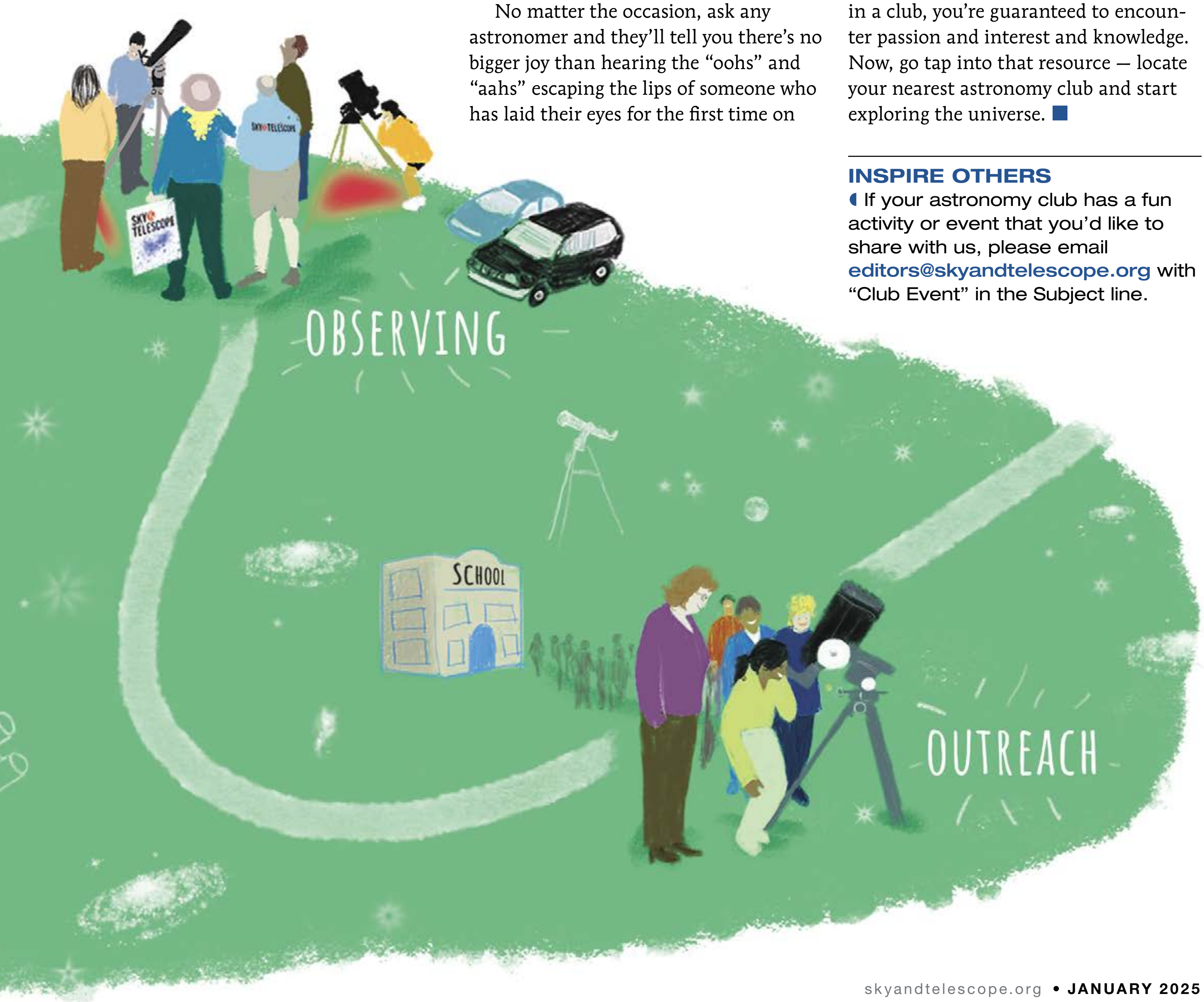
No matter the occasion, ask any astronomer and they'll tell you there's no bigger joy than hearing the "oohs" and "aahs" escaping the lips of someone who has laid their eyes for the first time on Saturn or Jupiter's Great Red Spot or the Andromeda Galaxy. It can get addictive.

And More!

Club activities aren't limited to the above. Social events such as picnics abound. Having trouble collimating your scope? Your club might run workshops dedicated to solving such niggles. Maybe a member who's passionate about combating light pollution will arrange a visit to town officials with suggestions for improving street lighting. Curious about how professional observatories operate? Fellow members might arrange a group trip to just such a facility to get the inside scoop.

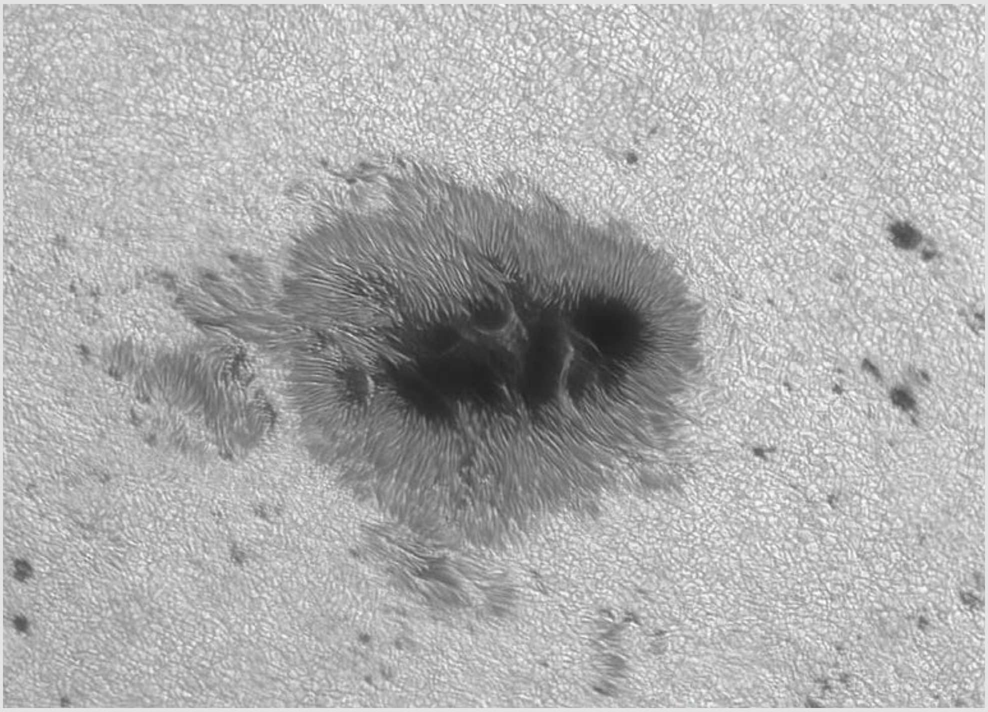
No matter what personalities you find in a club, you're guaranteed to encounter passion and interest and knowledge. Now, go tap into that resource — locate your nearest astronomy club and start exploring the universe. ■

INSPIRE OTHERS
◖ If your astronomy club has a fun activity or event that you'd like to share with us, please email editors@skyandtelescope.org with "Club Event" in the Subject line.



BEATRIZ INGLESSIS / S&T

THE MAJESTIC NORTHERN LIGHTS
Debra Ceravolo
Shimmering curtains of purple, pink, and green dance above Debra and Peter Ceravolo's observatory on Anarchist Mountain in Canada during May 10th's spectacular auroral displays.
DETAILS: *Canon EOS R6 camera and Sigma 20-mm lens. Total exposure: 8 seconds at f/2.2, ISO 1000.*



◁ CHURNING SPOT

Daniel Brousseau

Hundreds of wispy strands of plasma comprising the penumbra of sunspot AR 3780 appear to reach towards the sunspot's dark core. The thousands of solar granules that surround AR 3780 in this sharp, high-resolution image may look small in comparison, but each can be as large as Alaska.

DETAILS: *Sky-Watcher 250PDS Newtonian and ZWO ASI290MM camera. Stack of several video frames through AstroSolar and O III filters.*

LUNAR SKIMMING

Philippe Moussette

This series of images captures the Moon's passage through the edge of Earth's shadow last September 17th. The shadow slowly crept across Mare Frigoris along the north and a portion of Sinus Roris in the northwest (lower right image).

DETAILS: *Canon R3 camera and 600-mm lens. Composite of three images, each less than a second at f/5.6, ISO 100.*

▷ DELICATE SPIRAL

Bob Fera and Eric Coles

The arms of the barred spiral galaxy NGC 2903 in Leo are interwoven with dark dust lanes and pinkish star-forming regions. Farther out, older bluish stars decorate the ends of each arm.

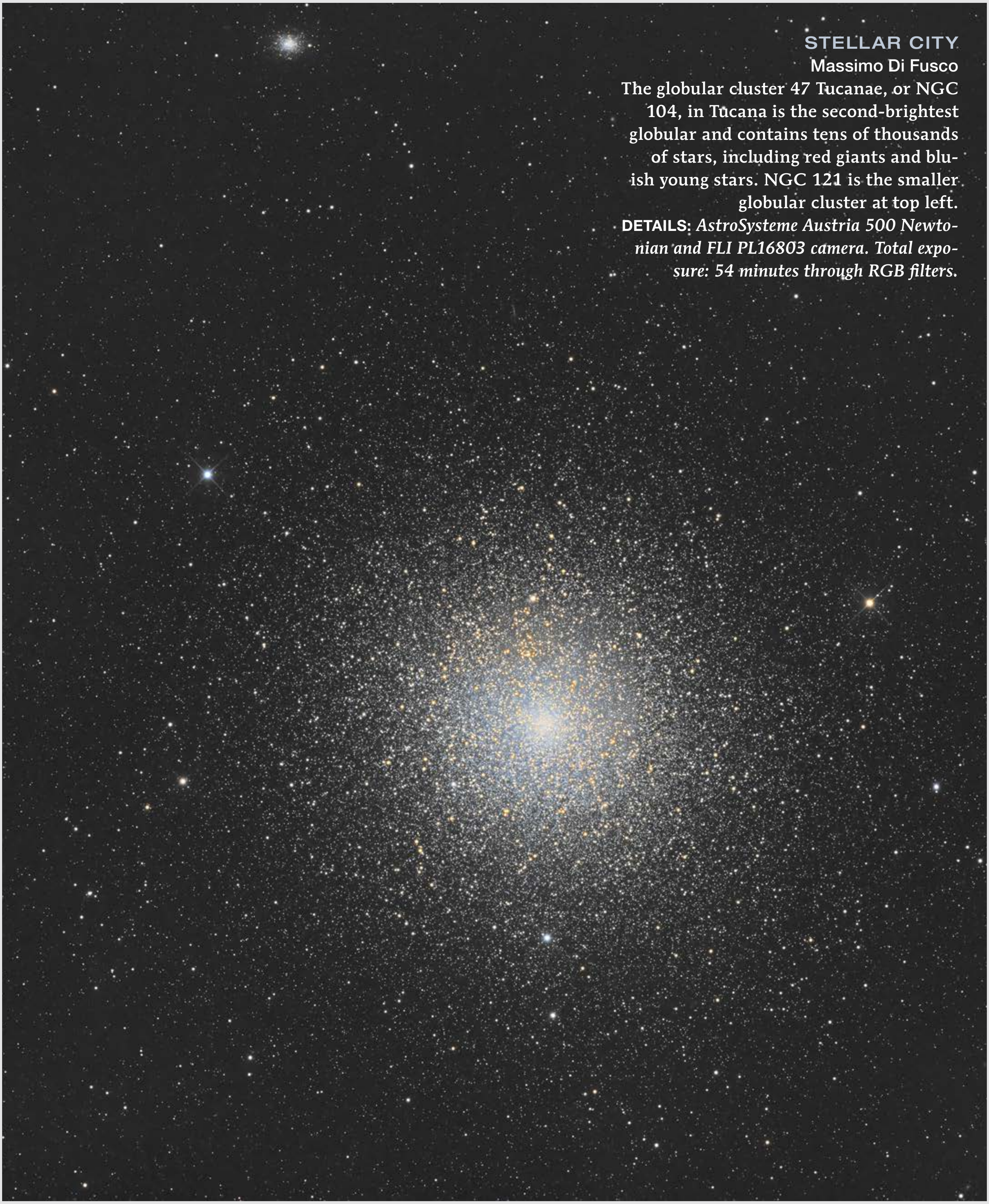
DETAILS: *PlaneWave CDK20 Corrected Dall-Kirkham telescope and Moravian C3-61000 Pro camera. Total exposure: 15.33 hours through LRGB filters.*

▽ SCULPTED DUST

Vikas Chander

Located about one degree east of the third-magnitude star Alfirk, or Beta Cephei (right), this undesignated knot of dust is one of many that permeate the region. The slightly dimmer 11 Cephei illuminates the area near the top of this dusty cloud.

DETAILS: *Takahashi FSQ-106EDX4 quadruplet refractor and ZWO ASI2600MC Pro camera. Total exposure: 21 hours.*



STELLAR CITY

Massimo Di Fusco

The globular cluster 47 Tucanae, or NGC 104, in Tucana is the second-brightest globular and contains tens of thousands of stars, including red giants and bluish young stars. NGC 121 is the smaller globular cluster at top left.

DETAILS: *AstroSysteme Austria 500 Newtonian and FLI PL16803 camera. Total exposure: 54 minutes through RGB filters.*

Gallery showcases the finest astronomical images that our readers submit to us. Send your best shots to gallery@skyandtelescope.org. See **skyandtelescope.org/aboutsky/guidelines**. Visit **skyandtelescope.org/gallery** for more of our readers' astrophotos.

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Ad Index

Event Calendar

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

ERIN WHITTAKER / NPS

January 27–February 2
WINTER STAR PARTY
Scout Key, FL
scas.org/winter-star-party/?y=2025

April 5–6
NORTHEAST ASTRONOMY FORUM
Suffern, NY
neafexpo.com

April 20–27
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

April 23–26
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

May 3
SPRING ASTRONOMY DAY
Everywhere!
astronomyday.astroleague.org

June 19–22
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

June 21–28
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GrandCanyonStarParty

June 25–29
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

July 20–25
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

July 22–26 (tentative)
WASHINGTON STATE STAR PARTY
Jameson Lake, WA
tmspa.com

July 24–27
STELLAFANE CONVENTION
Springfield, VT
stellafane.org

July (date not yet determined)
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

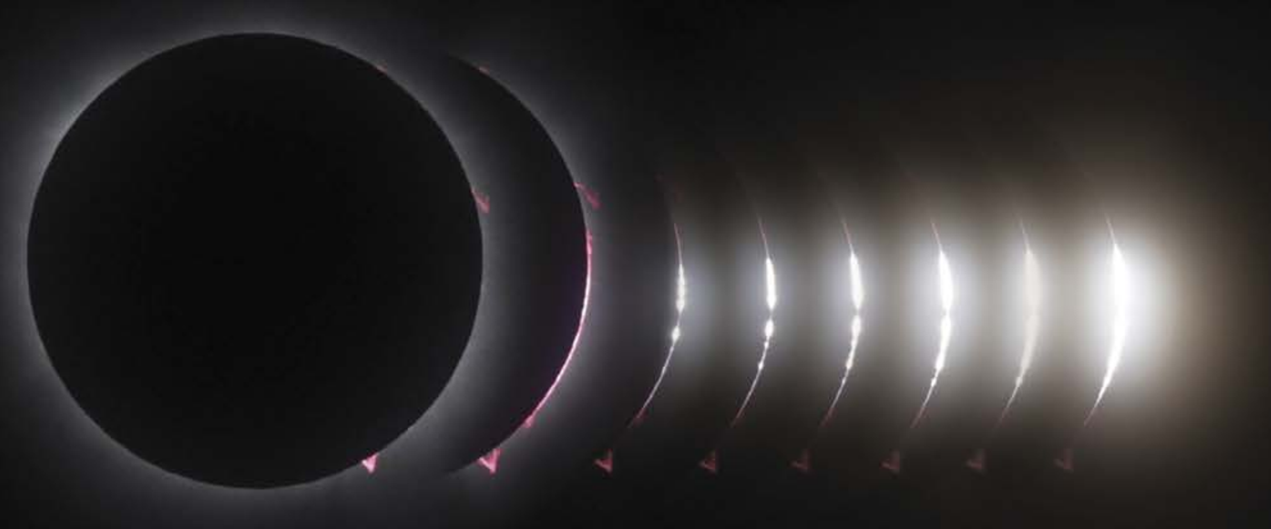
August 22–26
ALMOST HEAVEN STAR PARTY
Spruce Knob, WV
ahsp.org

September 27
AUTUMN ASTRONOMY DAY
Everywhere!
astronomyday.astroleague.org

• For a more complete listing, visit https://is.gd/star_parties.

Blame It on That Darn Corona!

During totality, the Sun's atmospheric halo has the mysterious ability to foil the best-laid plans.



▲ Despite the corona's "deviousness," the author managed to capture this sequence of Baily's Beads on April 8, 2024.

A WELL-WORN MAXIM is that astrophotography can be a frustrating hobby. But let's face it, that statement doesn't go nearly far enough. It seems that where astrophotography is concerned, Murphy of Murphy's Law was a downright optimist.

Those imaging the deep sky often spend hours or days chasing gremlins that dare to sabotage pointing, guiding, or focus, to say nothing of the clouds that Joni Mitchell said got in the way. But solar-eclipse photography condenses all of that agita into a few minutes of sheer terror, as the Sun's bashful but devious corona finds ways to shield itself from the camera. Yes, totality often ruins the best-laid plans of man and machines, turning us both into nonfunctioning nincompoops!

Let's first consider the newbie mistake of forgetting to remove the solar filter as totality begins. What self-respecting *Sky & Telescope* reader would admit to that? Uh, I will, but the corona made me do it. In 2017, I diligently practiced my eclipse routine for weeks, but the sudden appearance of the corona was so (excuse the pun) totally disorienting that it wasn't until about 40 seconds later that I finally realized why my camera's LCD screen showed only black. It could have been worse — I recovered and nailed the corona with a good bracketed sequence.

However, the vindictive corona paid me back with cirrus clouds in 2024, and it also orchestrated the crash of my PC software about 30 seconds after second contact. It was the very software that was supposed to automate my imaging, allowing me to soak in the visual spectacle unfettered by issues of camera management. Facebook groups are replete with similar stories from experienced imagers.

Let's not forget that the corona can trigger battery failure — and don't think you can outsmart it by using an AC cord. A friend of mine discovered this the hard way: The hypnotic corona caused a fellow eclipse participant to trip over my friend's electrical cord, pulling it free from the outlet, with instant shutdown of his camera and PC.

Focus shift, mount slippage, memory-card corruption — all are within the powers of that wispy corona. Amazingly, the corona can even cause the kid standing nearby to accidentally kick your tripod leg. Now, just try reacquiring the Sun in your field of view as totality's seconds tick by . . . with the corona smugly watching over your misfortune.

As I said, the corona almost dashed my plans last April. Between the cirrus clouds and software crash, I initially thought I was cooked. Undeterred, I assumed manual control of the camera, snapping away at a far faster rate than the PC software would have allowed, and I unexpectedly bagged a wonderful sequence of Baily's Beads as we exited totality. The beads may lose a beauty contest to the more elegant corona, but at least I went down with a fight.

Next round of Mazlin vs. Corona: Iceland 2026. Wish me luck!

■ **STEVE MAZLIN** is a neurologist whose retirement plans include chasing totality across the globe (see page 26).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Skygazer's Almanac 30°S 2025

FOR LATITUDES NEAR 30° SOUTH

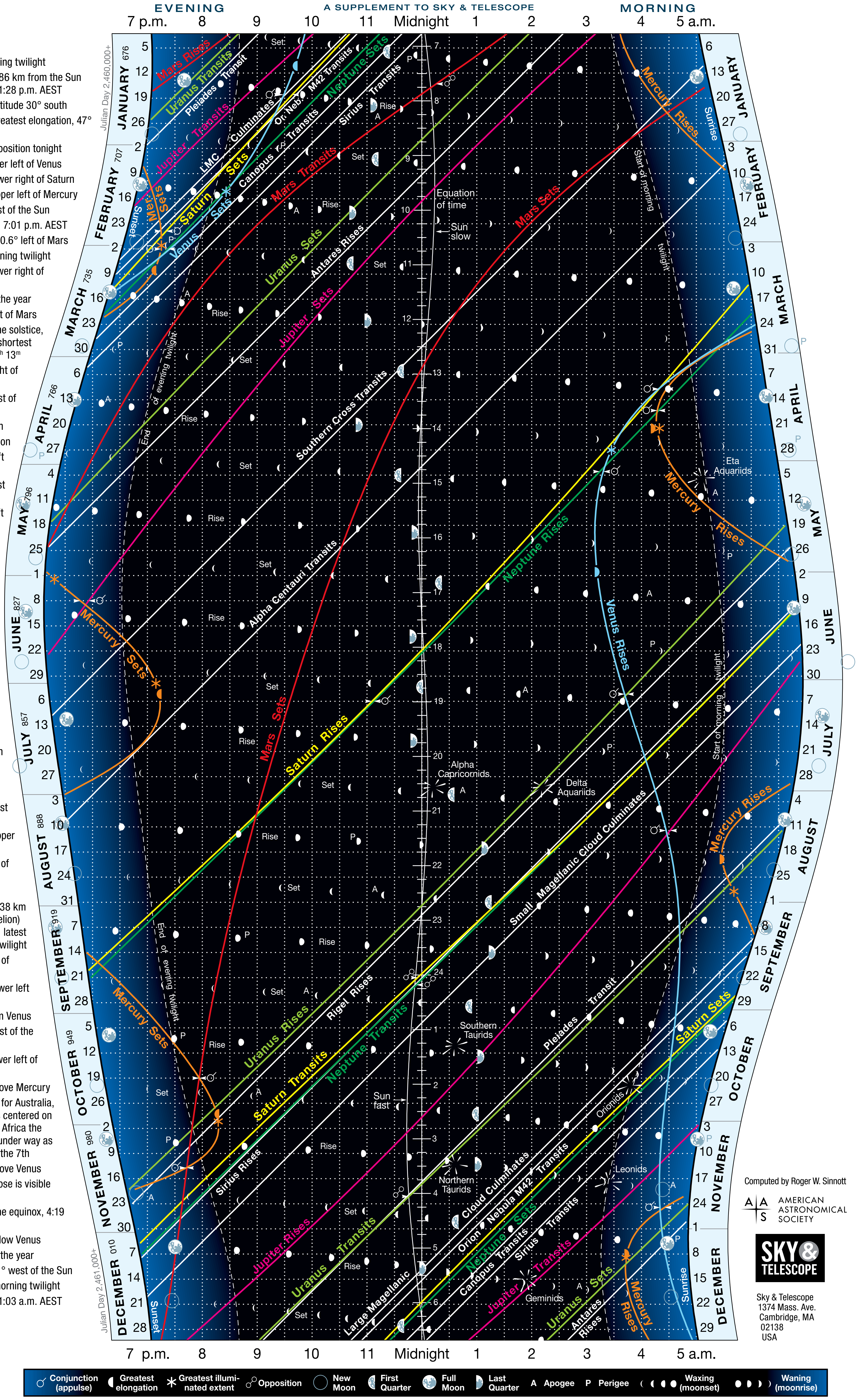
A SUPPLEMENT TO SKY & TELESCOPE

EVENING SKY

Jan 3 Latest end of evening twilight
Jan 4 Earth is 147,103,686 km from the Sun (perihelion) near 11:28 p.m. AEST
Jan 9 Latest sunset at latitude 30° south
Jan 10 Venus stands at greatest elongation, 47° east of the Sun
Jan 15 Mars comes to opposition tonight
Jan 18 Saturn is 2.2° upper left of Venus
Feb 25 Mercury is 1.4° lower right of Saturn
Mar 2 Neptune is 1.8° upper left of Mercury
Mar 8 Mercury is 18° east of the Sun
Mar 20 Autumnal equinox, 7:01 p.m. AEST
May 5 Beehive Cluster is 0.6° left of Mars
Jun 7 Earliest end of evening twilight
Jun 8 Mercury is 2.1° lower right of Jupiter
Jun 10 Earliest sunset of the year
Jun 17 Regulus is 0.7° left of Mars
Jun 21 Winter begins at the solstice, 12:42 p.m. AEST; shortest day of the year, 10h 13m
Jul 3 Beehive is 1.2° right of Mercury
Jul 4 Mercury is 26° east of the Sun
Sep 21 Saturn's opposition
Sep 23 Neptune's opposition
Oct 19 Mercury is 2.0° left of Mars
Oct 29 Mercury is 24° east of the Sun
Nov 13 Mercury is 1.3° left of Mars
Nov 21 Uranus comes to opposition
Dec 21 Longest day of the year, 14h 05m

MORNING SKY

Mar 14 A total eclipse of the Moon, lasting 66 minutes centered on 6:59 UT, may be seen in South America
Mar 29 Partial solar eclipse for Europe
Apr 11 Mercury is 2.0° lower left of Saturn
Apr 17 Neptune is just 0.7° lower left of Mercury
Apr 22 Mercury is 27° west of the Sun
May 4 Neptune is 2.0° upper right of Venus
Jun 1 Venus is 46° west of the Sun
Jul 1 Latest sunrise
Jul 4 Earth is 152,087,738 km from the Sun (aphelion) at 5:55 a.m. AEST; latest onset of morning twilight
Jul 5 Uranus is 2.4° left of Venus
Jul 7 Neptune is 1.0° lower left of Saturn
Aug 12 Jupiter is 1.0° from Venus
Aug 20 Mercury is 19° west of the Sun
Sep 1 Beehive is 1.3° lower left of Venus
Sep 3 Regulus is 1.3° above Mercury
Sep 8 Total lunar eclipse for Australia, lasting 83 minutes centered on 4:12 a.m. AEST; in Africa the eclipse is already under way as the Moon rises on the 7th
Sep 20 Regulus is 0.5° above Venus
Sep 22 A partial solar eclipse is visible from New Zealand
Sep 23 Spring begins at the equinox, 4:19 a.m. AEST
Nov 25 Mercury is 1.1° below Venus
Dec 3 Earliest sunrise of the year
Dec 8 Mercury stands 21° west of the Sun
Dec 9 Earliest onset of morning twilight
Dec 22 Summer solstice, 1:03 a.m. AEST



Computed by Roger W. Sinnott

AMERICAN ASTRONOMICAL SOCIETY

SKY & TELESCOPE

Sky & Telescope
1374 Mass. Ave.
Cambridge, MA
02138
USA

Skygazer's Almanac 30°S 2025

FOR LATITUDES NEAR 30° SOUTH

What's in the sky tonight?

When does the Sun set, and when does twilight end? Which planets are visible? What time is moonrise?

Welcome to the *Skygazer's Almanac 2025*, a handy chart that answers these and many other questions for every night of the year. This version is plotted for skywatchers near latitude 30° south — in Australia, southern Africa, and the southern cone of South America.

For any date, the chart tells the times when astronomical events occur during the night. Dates on the chart run vertically from top to bottom. The time of night runs horizontally, from sunset at left to sunrise at right. Find the date you want on the left side of the chart, and read across toward the right to find the times of events. Times are labeled along the chart's top and bottom.

In exploring the chart, you'll find that its night-to-night patterns offer many insights into the rhythms of the heavens.

The Events of a Single Night

To learn how to use the chart, consider some of the events of one night. We'll pick January 5, 2025.

First find "January" and "5" at the left edge. This is one of the dates for which a string of fine dots crosses the chart horizontally. Each horizontal dotted line represents the night from a Sunday evening to Monday morning. The individual dots are five minutes apart.

Every half hour (six dots), there is a vertical dotted line to aid in reading the hours of night at the chart's top or bottom. On the vertical lines, one dot is equal to one day.

A sweep of the eye shows that the line for the night of January 5–6 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 5–6 begins at the heavy black curve at left, which represents the time of sunset. Reading up to the top of the chart, we find that sunset on January 5th occurs at 7:05 p.m. *Local Mean Time*. (All times read from the chart are Local Mean Time, which can differ from your civil clock time by many minutes. More on this later.)

Continuing rightward on the dotted line for the 5th, we see a *Mars Rises* line crossing it at 8:10 p.m. This lets us know the red planet will be up all night long. Evening twilight doesn't truly end until 8:41, when the Sun is 18° below the horizon (note the dashed line).

At 8:47 the Pleiades star cluster transits the meridian, its high point in the sky. Moving to the right we see that Jupiter transits at 9:44, so it, too, is well situated as an observing target. But brilliant Venus, the fabled "evening star," sets four minutes later.

At about 10:22 the Large Magellanic Cloud culminates (another way of saying it transits). The Great Orion Nebula, Messier 42, transits at 10:35, and the two brightest nighttime stars, Canopus and Sirius, transit at 11:23 and 11:44, respectively. Transit times of such celestial landmarks help us follow the nightly march of constellations.

At about 10:51, notice the tiny Moon symbol on the dotted line. The legend at the bottom of the chart tells us it is at its waxing crescent phase, setting.

Running vertically down the midnight line is a scale of hours. This shows the sidereal time (the right ascension of objects on the meridian) at midnight. On January 5–6 this is $7^h\ 02^m$. To find the sidereal time at any other time and date on the chart, locate the point for the time and date you want, then draw a line through it parallel to the white event lines of stars. See where your line intersects the sidereal-time scale at midnight. (A star's event line enters the top of the chart at the same time of night it leaves the bottom. Sometimes one of these segments is left out to avoid crowding.)

Near the midnight line is a white curve labeled *Equation of time* weaving narrowly right and left down the chart. If you regard the midnight line as the previous noon for a moment, this curve shows when the Sun crosses the meridian and is due north. On January 5th the Sun runs slow, transiting at 12:05 p.m. This deviation, important for reading a sundial, is caused by the tilt of the Earth's axis and the ellipticity of its orbit.

At 1:12 a.m. the red planet Mars transits, the very best time to spot its surface details in a good telescope. As the wee hours continue, Antares, a star we usually associate with later seasons of the year, climbs above the southeastern horizon at 2:19.

The first hint of dawn — the start of morning twilight — comes at 3:31. Elusive Mercury rises at 3:42. The Sun finally peeks above the southeastern horizon at 5:06 on Monday morning, January 6th.

Other Charted Information

Many of the year's most important astronomical events are listed in the

Local Mean Time Corrections

Adelaide	+16	Melbourne	+20
Brisbane	−13	Perth	+18
Canberra	+4	Sydney	−4
Cape Town	+46	Johannesburg	+8
Durban	−3	Port Elizabeth	+18
Harare	−4	Pretoria	+8
Asunción	−10	Rio de Janeiro	−7
Buenos Aires	+54	Santiago	+43
Montevideo	+45	São Paulo	+6

chart's left-hand margin. Some are marked on the chart itself.

Conjunctions (close pairings) of two planets are marked by a ☌ symbol on the planets' event lines. Here, the symbol indicates the night when the planets appear closest in the sky (at appulse), not just when they have the same ecliptic longitude or right ascension.

Opposition of a planet, the date when it is opposite the Sun in the sky and thus visible all night, occurs roughly when its transit line crosses the Equation-of-time line (*not* the line for midnight). Opposition is marked there by a ☍ symbol. For instance, Mars reaches opposition on the night of January 15–16 this year.

Moonrise and *moonset* can be told apart by whether the round limb — the outside edge — of the Moon symbol faces left (waxing Moon sets) or right (waning Moon rises). Or follow the nearly horizontal row of daily Moon symbols across the chart to find the word *Rise* or *Set*. Quarter Moons are indicated by a larger symbol. Full Moon is always a large bright disk whether rising or setting; the circle for new Moon is open. *P* and *A* mark dates when the Moon is at perigee and apogee (nearest and farthest from Earth, respectively).

Mercury and *Venus* never stray far from the twilight bands. Their dates of greatest elongation from the Sun are shown by ◗ symbols on their rising or setting curves. Asterisks mark when their telescopic disks have the greatest illuminated extent in square arcseconds. For example, this occurs for Venus on the evening of February 14th this year.

Meteor showers are marked by a starburst symbol on the date of peak activity and at the time when the shower's radiant (point of origin) is highest in the night sky. This often occurs just as morning twilight begins.

Julian dates can be found from the numbers just after the month names on the chart's left. The Julian Day, a seven-digit number, is a running count of days beginning with January 1, 4713 BC. Its first four digits early this year are 2460, as indicated just off the chart's upper left margin. To find the last three digits for days in January, add 676 to the date. For instance, on January 5th we have 5 + 676 = 681, so the Julian Day is 2,460,681.

Rising or Setting Corrections

South Latitude	Declination (North or South) 0°	5°	10°	15°	20°	25°
10°	0	8	16	24	33	43
15°	0	6	12	19	26	33
20°	0	4	8	13	18	23
25°	0	2	4	7	9	12
30°	0	0	0	0	0	0
35°	0	2	5	7	10	13
40°	0	5	10	16	22	29
45°	1	8	17	26	37	49
50°	1	12	25	39	54	72

Note that the Julian Day does not change to this value until 12:00 Universal Time (UT). In Australia, 12:00 UT falls during the evening of the same day (at 10 p.m. Australian Eastern Standard Time, AEST). Before that time, subtract 1 from the Julian Day number just obtained.

Time Corrections

All events on this southern version of the *Skygazer's Almanac* are plotted for an observer at longitude 135° east and latitude 30° south. However, you need not live near McDouall Peak, South Australia, to use the chart. Simple corrections will allow you to get times accurate to a couple of minutes anywhere in the world's south temperate latitudes.

To convert the charted time of an event into your civil (clock) time, the following corrections must be made. They are given in order of decreasing importance.

- **Daylight-saving time ("summer time").** When this is in effect, add one hour to any time read from the chart.

- **Your longitude.** The chart gives the *Local Mean Time* (LMT) of events, which differs from ordinary clock time by many minutes at most locations. Our civil time zones are standardized on particular longitudes. Examples in Australia are 150°E for the eastern states (which use Australian Eastern Standard Time, AEST), and 142.5°E for the central state and territory (an odd value that puts the minute hands of their clocks 30 minutes out of joint with most of the rest of the world).

If your longitude is very close to your standard time-zone meridian, luck is with you and your LMT correction is zero. Otherwise, to get standard time *add 4 minutes* to times obtained from the chart for each degree of longitude that you are *west* of your time-zone meridian. Or *subtract 4 minutes* for each degree you are *east* of it.

For instance, Melbourne, Australia (longitude 145°), is 5° west of its time-zone meridian (150°). So at Melbourne, add 20 minutes to any time obtained from the chart. The result is standard time.

Find your Local Mean Time correction and memorize it; you will use it always. The table below at left has the corrections, in minutes, for some major cities.

- **Rising and setting.** Times of rising and setting need correction if your latitude differs from 30° south. This effect depends strongly on a star or planet's declination. The declinations of the Sun and planets are listed each month on the Planetary Almanac page of *Sky & Telescope.*

If your site is *south* of latitude 30°S, an object with a south declination stays above the horizon *longer* than the chart shows (it rises earlier and sets later), while one with a north declination spends less time above the horizon. If you are *north* of 30°S, the effect is just the reverse. With these rules in mind, you can gauge the number of minutes for correcting a rise or set time using the table above left.

Finally, the Moon's rapid orbital motion alters lunar rising and setting times slightly if your longitude differs from 135°E. The Moon rises and sets about two minutes earlier than the chart shows for each time zone east of central Australia, and two minutes later for each time zone west of there. Observers in southern Africa can simply shift the Moon symbol a third of the way to that for the following date. Those who live in South America can shift the symbol about halfway there.

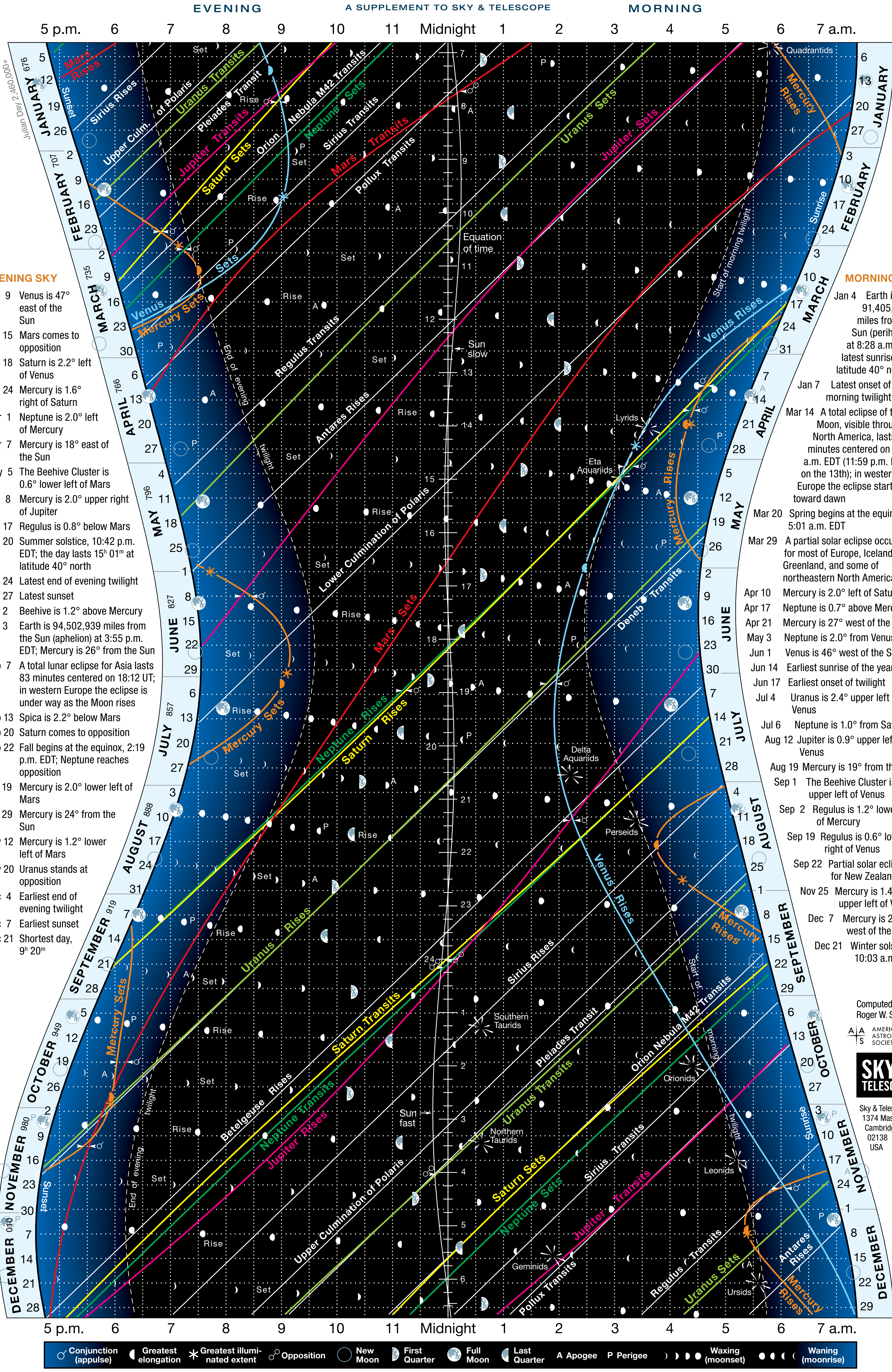
For reprints (item SGA25S) or to order a similar chart for latitude 40° north or 50° north, go to: shopatsky.com/collections/maps-globes/almanacs

Skygazer's Almanac 2025 is a supplement to *Sky & Telescope* Magazine, 1374 Massachusetts Avenue, Cambridge, MA 02138, USA, skyandtelescope.org.

Skygazer's Almanac 40°N 2025

FOR LATITUDES NEAR 40° NORTH

A SUPPLEMENT TO SKY & TELESCOPE



EVENING SKY

- Jan 9 Venus is 47° east of the Sun
- Jan 15 Mars comes to opposition
- Jan 18 Saturn is 2.2° left of Venus
- Feb 24 Mercury is 1.6° right of Saturn
- Mar 1 Neptune is 2.0° left of Mercury
- Mar 7 Mercury is 18° east of the Sun
- May 5 The Beehive Cluster is 0.6° lower left of Mars
- Jun 8 Mercury is 2.0° upper right of Jupiter
- Jun 17 Regulus is 0.8° below Mars
- Jun 20 Summer solstice, 10:42 p.m. EDT; the day lasts 15ʰ 01ᵐ at latitude 40° north
- Jun 24 Latest end of evening twilight
- Jun 27 Latest sunset
- Jul 2 Beehive is 1.2° above Mercury
- Jul 3 Earth is 94,502,939 miles from the Sun (aphelion) at 3:55 p.m. EDT; Mercury is 26° from the Sun
- Sep 7 A total lunar eclipse for Asia lasts 83 minutes centered on 18:12 UT; in western Europe the eclipse is under way as the Moon rises
- Sep 13 Spica is 2.2° below Mars
- Sep 20 Saturn comes to opposition
- Sep 22 Fall begins at the equinox, 2:19 p.m. EDT; Neptune reaches opposition
- Oct 19 Mercury is 2.0° lower left of Mars
- Oct 29 Mercury is 24° from the Sun
- Nov 12 Mercury is 1.2° lower left of Mars
- Nov 20 Uranus stands at opposition
- Dec 4 Earliest end of evening twilight
- Dec 7 Earliest sunset
- Dec 21 Shortest day, 9ʰ 20ᵐ

MORNING SKY

- Jan 4 Earth is 91,405,993 miles from the Sun (perihelion) at 8:28 a.m. EST; latest sunrise at latitude 40° north
- Jan 7 Latest onset of morning twilight
- Mar 14 A total eclipse of the Moon, visible throughout North America, lasts 66 minutes centered on 2:59 a.m. EDT (11:59 p.m. PDT on the 13th); in western Europe the eclipse starts toward dawn
- Mar 20 Spring begins at the equinox, 5:01 a.m. EDT
- Mar 29 A partial solar eclipse occurs for most of Europe, Iceland, Greenland, and some of northeastern North America
- Apr 10 Mercury is 2.0° left of Saturn
- Apr 17 Neptune is 0.7° above Mercury
- Apr 21 Mercury is 27° west of the Sun
- May 3 Neptune is 2.0° from Venus
- Jun 1 Venus is 46° west of the Sun
- Jun 14 Earliest sunrise of the year
- Jun 17 Earliest onset of twilight
- Jul 4 Uranus is 2.4° upper left of Venus
- Jul 6 Neptune is 1.0° from Saturn
- Aug 12 Jupiter is 0.9° upper left of Venus
- Aug 19 Mercury is 19° from the Sun
- Sep 1 The Beehive Cluster is 1.3° upper left of Venus
- Sep 2 Regulus is 1.2° lower right of Mercury
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- Dec 7 Mercury is 21° west of the Sun
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Computed by Roger W. Sinnott

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Sky & Telescope
1374 Mass. Ave.
Cambridge, MA 02138
USA

Skygazer's Almanac 40°N 2025

FOR LATITUDES NEAR 40° NORTH

What's in the sky tonight?

When does the Sun set, and when does twilight end? Which planets are visible? What time does the Moon rise?

Welcome to the *Skygazer's Almanac 2025*, a handy chart that answers these and many other questions for every night of the year. It is plotted for skywatchers near latitude 40° north — in the United States, the Mediterranean countries, Japan, and much of China.

For any date, the chart tells the times when astronomical events occur during the night. Dates on the chart run vertically from top to bottom. The time of night runs horizontally, from sunset at left to sunrise at right. Find the date you want on the left side of the chart, and read across toward the right to find the times of events. Times are labeled along the chart's top and bottom.

In exploring the chart you'll find that its night-to-night patterns offer many insights into the rhythms of the heavens.

The Events of a Single Night

To learn how to use the chart, consider some of the events of one night. We'll pick January 5, 2025.

First find "January" and "5" at the left edge. This is one of the dates for which a string of fine dots crosses the chart horizontally. Each horizontal dotted line represents the night from a Sunday evening to Monday morning. The individual dots are five minutes apart.

Every half hour (six dots), there is a vertical dotted line to aid in reading the hours of night at the chart's top or bottom. On the vertical lines, one dot is equal to one day.

A sweep of the eye shows that the line for the night of January 5–6 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 5–6 begins at the heavy black curve at left, which represents the time of sunset. Reading up to the top of the chart, we find that sunset on January 5th occurs at 4:49 p.m. *Local Mean Time*. (All times on the chart are Local Mean Time, which can differ from your clock time. More on this later.)

Following the dotted line for the 5th rightward, we see that at 5:38 p.m. the red planet Mars rises, a sign it will become well placed for viewing later on.

The dashed line at 6:26 p.m. tells when evening twilight technically ends. This is when the Sun is 18° below the horizon and the sky becomes fully dark.

At 8:01 Polaris, the North Star, has its upper culmination. It then stands directly above the north celestial pole (by 38′ or r37′ this year), a good time to check the polar alignment of an equatorial telescope mount.

Venus, which has been the brilliant "evening star" up until now, finally sets in the west at 8:42.

At 8:44 the Pleiades transit the meridian, meaning the famous star cluster is due south and highest in the sky. So we know it will be a fine target to enjoy in binoculars or a telescope all evening. The Great Orion Nebula (Messier 42) transits at 10:33, as does Sirius at 11:42. Transit times of such celestial landmarks help us keep track of the march of constellations across the night sky.

Notice the tiny Moon symbol sitting on the January 5–6 dotted line at about 11:26. You can tell from the legend at the bottom of the chart that it is at waxing crescent phase, setting.

Running vertically down the midnight line is a scale of hours. This shows the sidereal time (the right ascension of objects on the meridian) at midnight. On January 5–6 this is $7^h\ 04^m$. To find the sidereal time at any other time and date on the chart, locate that point and draw a line through it parallel to the white event lines of stars. See where your line intersects the sidereal-time scale at midnight. (A star's event line enters the top of the chart at the same time of night it leaves the bottom. Sometimes one of these segments is left out to avoid crowding.)

Near the midnight line is a white curve labeled *Equation of time* weaving narrowly right and left down the chart. If you regard the midnight line as noon for a moment, this curve shows when the Sun crosses the meridian and is due south. On January 5th the Sun runs slow, transiting at 12:06 p.m. This deviation, important for reading a sundial, is caused by the tilt of the Earth's axis and the ellipticity of its orbit.

At 1:08 a.m. Mars finally reaches the meridian, making this the very best time of night to look for surface markings in a good telescope. The wee hours continue, and at 5:02 Jupiter sets just as Antares, a star we normally associate with a later season, rises.

The first hint of dawn — start of morning twilight — comes at 5:45. The Sun finally peeks above the horizon at 7:22 a.m. on January 6th.

Other Charted Information

Many of the year's chief astronomical events are listed in the chart's evening and morning margins. Some are marked on the chart itself.

Conjunctions (close pairings) of two planets are indicated by a ☌ symbol on the planets' event lines. Here, conjunctions are considered to occur when the planets actually appear closest in the sky, not merely when they share the same ecliptic longitude or right ascension.

Opposition of a planet, the date when it is opposite the Sun in the sky and thus visible all night, occurs roughly when its transit line crosses the Equation-of-time line (*not* the line for midnight). Opposition is marked there by a ☍ symbol, as for Mars on the night of January 15–16.

Moonrise and *moonset* can be told apart by whether the round limb — the outside edge — of the Moon symbol faces right (waxing Moon sets) or left (waning Moon rises). Or follow the nearly horizontal row of daily Moon symbols across the chart to find the word *Rise* or *Set*. Quarter Moons are indicated by a larger symbol. Full Moon is always a large bright disk whether rising or setting; the circle for new Moon is open. *P* and *A* mark dates when the Moon is at perigee and apogee (nearest and farthest from Earth, respectively).

Mercury and *Venus* never stray far from the twilight bands. Their dates of greatest elongation from the Sun are shown by ◗ symbols on their rising or setting curves. Asterisks mark their dates of greatest illuminated extent in square arcseconds. For example, this occurs for Venus on the evening of February 14th this year.

Meteor showers are marked by a starburst symbol on the date of peak activity and at the time when the shower's radiant is highest in the night sky. This is often just as morning twilight begins.

Julian dates can be found from the numbers just after the month names on the chart's left. The Julian Day, a seven-digit number, is a running count of days beginning with January 1, 4713 BC. Its first four digits most of this year are 2460, as indicated just off the chart's upper left margin. To find the last three digits for evenings in January, add 676 to the date. For instance, on the evening of January 5th we have 5 + 676 = 681, so the Julian Day is 2,460,681. For North American observers this number applies all night, because the next Julian Day always begins at 12:00 Universal Time (6:00 a.m. Central Standard Time).

Time Corrections

All events on this *Skygazer's Almanac* are plotted for an observer at longitude 90° west and latitude 40° north, near the population center of North America. However, you need not live near Peoria, Illinois, to use the chart. Simple corrections will allow you to get times accurate to a couple of minutes anywhere in the world's north temperate latitudes.

Rising or Setting Corrections

North Latitude	Declination (North or South) 0°	5°	10°	15°	20°	25°
50°	0	7	14	23	32	43
45°	0	3	7	10	14	19
40°	0	0	0	0	0	0
35°	0	3	6	9	12	16
30°	0	5	11	16	23	30
25°	0	8	16	24	32	42

To convert the charted time of an event to your civil (clock) time, the following corrections must be made. They are mentioned in order of decreasing importance:

• **Daylight-saving time.** When this is in effect, add one hour to any time obtained from the chart.

• **Your longitude.** The chart gives the *Local Mean Time* (LMT) of events, which differs from ordinary clock time by a number of minutes at most locations. Our civil time zones are standardized on particular longitudes. Examples in North America are Eastern Time, 75°W; Central, 90°; Mountain, 105°; and Pacific, 120°. If your longitude is very close to one of these (as is true for New Orleans and Denver), luck is with you and this correction is zero. Otherwise, to get standard time *add 4 minutes* to times obtained from the chart for each degree of longitude that you are *west* of your time-zone meridian. Or *subtract 4 minutes* for each degree you are *east* of it.

For instance, Washington, DC (longitude 77°), is 2° west of the Eastern Time meridian. So at Washington, add 8 minutes to any time obtained from the chart. The result is Eastern Standard Time.

Find your time adjustment and memorize it. The table below left shows the corrections from local to standard time, in minutes, for some major cities.

Local Mean Time Corrections

Atlanta	+38	Los Angeles	−7
Boise	+45	Memphis	0
Boston	−16	Miami	+21
Buffalo	+15	Minneapolis	+13
Chicago	−10	New Orleans	0
Cleveland	+27	New York	−4
Dallas	+27	Philadelphia	+1
Denver	0	Phoenix	+28
Detroit	+32	Pittsburgh	+20
El Paso	+6	St. Louis	+1
Helena	+28	Salt Lake City	+28
Honolulu	+31	San Francisco	+10
Houston	+21	Santa Fe	+4
Indianapolis	+44	Seattle	+9
Jacksonville	+27	Tulsa	+24
Kansas City	+18	Washington	+8
Athens	+25	Lisbon	+36
Baghdad	+3	Madrid	+75
Beijing	+14	New Delhi	+21
Belgrade	−22	Rome	+10
Cairo	−8	Seoul	+32
Istanbul	+4	Tehran	+4
Jerusalem	−21	Tokyo	−19

• **Rising and setting.** These times need correction if your latitude differs from 40° north. This effect depends strongly on a star or planet's declination. (The declinations of the Sun and planets are listed monthly on the Planetary Almanac page of *Sky & Telescope*.)

If your site is *north* of latitude 40°, then an object with a north declination stays above the horizon *longer* than the chart shows (it rises earlier and sets later), whereas one with a south declination spends less time above the horizon. At a site *south* of 40°, the effect is just the reverse. Keeping these rules in mind, you can gauge the approximate number of minutes by which to correct a rising or setting time from the table above.

Finally, the Moon's rapid orbital motion affects lunar rising and setting times if your longitude differs from 90° west. The Moon rises and sets about two minutes earlier than the chart shows for each time zone east of Central Time, and two minutes later for each time zone west of it. European observers can simply shift each rising or setting Moon symbol leftward a quarter of the way toward the one for the previous night.

For reprints (item SGA25W) or to order a similar chart for latitude 50° north or 30° south, go to: shopatsky.com/collections/maps-globes/almanacs

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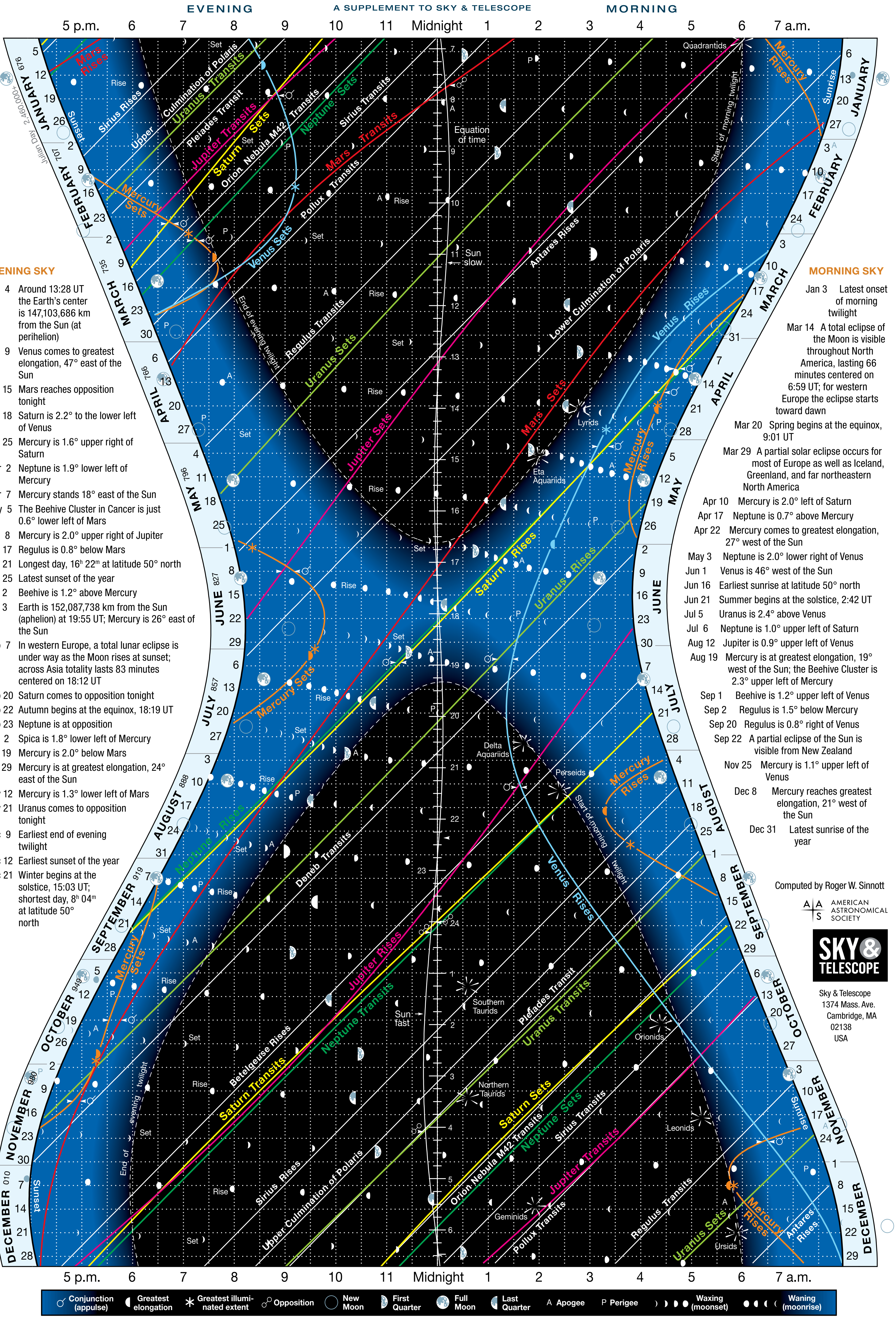
Skygazer's Almanac 50°N 2025

FOR LATITUDES NEAR 50° NORTH

A SUPPLEMENT TO SKY & TELESCOPE



EVENING SKY

Jan 4 Around 13:28 UT the Earth's center is 147,103,686 km from the Sun (at perihelion)

Jan 9 Venus comes to greatest elongation, 47° east of the Sun

Jan 15 Mars reaches opposition tonight

Jan 18 Saturn is 2.2° to the lower left of Venus

Feb 25 Mercury is 1.6° upper right of Saturn

Mar 2 Neptune is 1.9° lower left of Mercury

Mar 7 Mercury stands 18° east of the Sun

May 5 The Beehive Cluster in Cancer is just 0.6° lower left of Mars

Jun 8 Mercury is 2.0° upper right of Jupiter

Jun 17 Regulus is 0.8° below Mars

Jun 21 Longest day, $16^h 22^m$ at latitude 50° north

Jun 25 Latest sunset of the year

Jul 2 Beehive is 1.2° above Mercury

Jul 3 Earth is 152,087,738 km from the Sun (aphelion) at 19:55 UT; Mercury is 26° east of the Sun

Sep 7 In western Europe, a total lunar eclipse is under way as the Moon rises at sunset; across Asia totality lasts 83 minutes centered on 18:12 UT

Sep 20 Saturn comes to opposition tonight

Sep 22 Autumn begins at the equinox, 18:19 UT

Sep 23 Neptune is at opposition

Oct 2 Spica is 1.8° lower left of Mercury

Oct 19 Mercury is 2.0° below Mars

Oct 29 Mercury is at greatest elongation, 24° east of the Sun

Nov 12 Mercury is 1.3° lower left of Mars

Nov 21 Uranus comes to opposition tonight

Dec 9 Earliest end of evening twilight

Dec 12 Earliest sunset of the year

Dec 21 Winter begins at the solstice, 15:03 UT; shortest day, $8^h 04^m$ at latitude 50° north

MORNING SKY

Jan 3 Latest onset of morning twilight

Mar 14 A total eclipse of the Moon is visible throughout North America, lasting 66 minutes centered on 6:59 UT; for western Europe the eclipse starts toward dawn

Mar 20 Spring begins at the equinox, 9:01 UT

Mar 29 A partial solar eclipse occurs for most of Europe as well as Iceland, Greenland, and far northeastern North America

Apr 10 Mercury is 2.0° left of Saturn

Apr 17 Neptune is 0.7° above Mercury

Apr 22 Mercury comes to greatest elongation, 27° west of the Sun

May 3 Neptune is 2.0° lower right of Venus

Jun 1 Venus is 46° west of the Sun

Jun 16 Earliest sunrise at latitude 50° north

Jun 21 Summer begins at the solstice, 2:42 UT

Jul 5 Uranus is 2.4° above Venus

Jul 6 Neptune is 1.0° upper left of Saturn

Aug 12 Jupiter is 0.9° upper left of Venus

Aug 19 Mercury is at greatest elongation, 19° west of the Sun; the Beehive Cluster is 2.3° upper left of Mercury

Sep 1 Beehive is 1.2° upper left of Venus

Sep 2 Regulus is 1.5° below Mercury

Sep 20 Regulus is 0.8° right of Venus

Sep 22 A partial eclipse of the Sun is visible from New Zealand

Nov 25 Mercury is 1.1° upper left of Venus

Dec 8 Mercury reaches greatest elongation, 21° west of the Sun

Dec 31 Latest sunrise of the year

Computed by Roger W. Sinnott

AMERICAN ASTRONOMICAL SOCIETY

SKY & TELESCOPE

Sky & Telescope
1374 Mass. Ave.
Cambridge, MA
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Skygazer's Almanac 50°N 2025

FOR LATITUDES NEAR 50° NORTH

What's in the sky tonight?

When does the Sun set, and when does twilight end? Which planets are visible? What time does the Moon rise?

Welcome to the *Skygazer's Almanac 2025*, a handy chart that answers these and many other questions for every night of the year. This version is plotted for skywatchers near latitude 50° north — in the United Kingdom, northern Europe, Canada, and Russia.

For any date, the chart tells the times when astronomical events occur during the night. Dates on the chart run vertically from top to bottom. The time of night runs horizontally, from sunset at left to sunrise at right. Find the date you want on the left side of the chart, and read across toward the right to find the times of events. Times are labeled along the chart's top and bottom.

In exploring the chart you'll find that its night-to-night patterns offer many insights into the rhythms of the heavens.

The Events of a Single Night

To learn how to use the chart, consider some of the events of one night. We'll pick January 5, 2025.

First find "January" and "5" at the left edge. This is one of the dates for which a string of fine dots crosses the chart horizontally. Each horizontal dotted line represents the night from a Sunday evening to Monday morning. The individual dots are five minutes apart.

Every half hour (six dots), there is a vertical dotted line to aid in reading the hours of night at the chart's top or bottom. On the vertical lines, one dot is equal to one day.

A sweep of the eye shows that the line for the night of January 5–6 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 5–6 begins at the heavy black curve at left, which represents the time of sunset. Reading up to the top of the chart, we can estimate that sunset on January 5th occurs at 4:14 p.m. *Local Mean Time*. (All times on the chart are Local Mean Time, which can differ from your civil clock time by many minutes. More on this later.)

Continuing rightward on the dotted line for the 5th, we see that Mars rises at 4:58 (and Mars, of course, is easy to see in twilight). The dashed line at 6:12 marks the end of evening twilight, the time when the Sun is 18° below the horizon and the sky is fully dark. At 7:04 the brightest nighttime star, Sirius, rises in the southeast.

Polaris, the North Star, reaches upper culmination near 8:02 p.m. This is when Polaris stands directly above the north celestial pole (by 38′ or 37′ this year), a good opportunity to check the polar alignment of a telescope mount.

The ringed planet Saturn sets at 9:31, so we won't see much of it tonight. But Jupiter transits at 9:42, meaning it is then on the meridian and highest in the sky. It will be very well placed for telescopic viewing all evening.

The Pleiades star cluster in Taurus transits the meridian at 8:46, followed by the Great Nebula in Orion (10:33) and Sirius (11:43). Transits of celestial landmarks help remind us where the constellations are during the night.

On the dotted line, notice the tiny Moon symbol at about 11:10. The legend at the bottom of the chart tells us it is at waxing crescent phase, setting.

Running vertically down the midnight line is a scale of hours. This shows the sidereal time (the right ascension of objects on the meridian) at midnight. On January 5–6 this is $7^h\ 03^m$. To find the sidereal time at any other time and date on the chart, locate the point for the time and date you want, then draw a line through it parallel to the white event lines of stars. See where your line intersects the sidereal-time scale at midnight. (A star's event line enters the top of the chart at the same time of night it leaves the bottom. Sometimes one of these segments is left out to avoid crowding.)

Near the midnight line is a white curve labeled *Equation of time* weaving narrowly right and left down the chart. If you regard the midnight line as the previous noon for a moment, this curve shows when the Sun crosses the meridian and is due south. On January 5th the Sun runs slow, transiting at 12:06 p.m. This deviation, important for reading a sundial, is caused by the tilt of the Earth's axis and the ellipticity of its orbit.

The red planet Mars transits at 1:10 a.m., the very best time to study its surface markings with a good telescope. As the wee hours continue, Jupiter finally sets at 5:39. Then at 5:48 Antares, a star we usually associate with later seasons of the year, rises in the southeast.

The first hint of dawn — the start of

Local Mean Time Corrections

Amsterdam	+40	Manchester	+8
Belfast	+24	Montreal	–6
Berlin	+6	Moscow	+26
Bordeaux	+62	Munich	+14
Bremen	+24	Oslo	+17
Brussels	+44	Ottawa	+3
Bucharest	+16	Paris	+51
Budapest	–16	Prague	+2
Calgary	+36	Quebec	–15
Copenhagen	+10	Regina	+58
Dublin	+25	Reykjavík	+88
Geneva	+35	St. John's	+1
Glasgow	+16	Stockholm	–12
Halifax	+14	Toronto	+18
Hamburg	+20	Vancouver	+12
Helsinki	+20	Vienna	–5
Kyiv	–2	Warsaw	–24
London	0	Winnipeg	+29
Lyons	+41	Zurich	+24

morning twilight — comes at 6:00. Elusive Mercury rises at 6:40. The Sun finally peeks above the eastern horizon at 7:58 a.m. on Monday morning, January 6th.

Other Charted Information

Many of the year's chief astronomical events are listed in the chart's evening and morning margins. Some are marked on the chart itself.

Conjunctions (close pairings) of two planets are marked on the chart by a ☌ symbol on the planets' event lines. Here, conjunctions are considered to occur when the planets actually appear closest together in the sky (at appulse), not merely when they share the same ecliptic longitude or right ascension.

Opposition of a planet, the date when it is opposite the Sun in the sky and visible all night, occurs roughly when its transit line crosses the Equation-of-time line (*not* the line for midnight). Opposition is indicated there by a ☍ symbol. For instance, Mars reaches opposition on the night of January 15–16 this year.

Moonrise and *moonset* can be told apart by whether the round limb — the outside edge — of the Moon symbol faces right (waxing Moon sets) or left (waning Moon rises). Or follow the nearly horizontal row of daily Moon symbols across the chart to find the word *Rise* or *Set*. Quarter Moons are indicated by a larger symbol. Full Moon is always a large bright disk whether rising or setting; the circle for new Moon is open. *P* and *A* mark dates when the Moon is at perigee and apogee (nearest and farthest from Earth, respectively).

Mercury and *Venus* never stray far from the twilight bands. Their dates of greatest elongation from the Sun are shown by ◗ symbols on their rising or setting curves. Asterisks mark the dates when their disks in telescopes show the greatest illuminated extent in square arcseconds. For example, during February evenings Venus does so on the 14th and Mercury on 28th.

Meteor showers are marked by a starburst symbol at the date of peak activity and the time when the shower's radiant is highest in the night sky. This is often just as twilight begins before dawn.

Julian dates can be found from the numbers just after the month names on the chart's left. The Julian Day, a seven-digit number, is a running count of days beginning with January 1, 4713 BC. Its first four digits early this year are 2460, as indicated just off the chart's upper left margin. To find the last three digits for evenings in January, add 676 to the date. For instance, on the evening of January 5th we have 5 + 676 = 681, so the Julian Day is 2,460,681. For European observers this number applies all night long, because the next Julian Day always begins at 12:00 Universal Time (noon Greenwich Mean Time).

Rising or Setting Corrections

North Latitude	Declination (North or South) 0°	5°	10°	15°	20°	25°
60°	1	11	23	36	53	80
55°	0	5	10	16	23	32
50°	0	0	0	0	0	0
45°	0	4	8	13	18	24
40°	1	8	15	23	32	43
35°	1	10	20	31	44	68
30°	1	12	25	39	54	72
25°	1	15	30	46	64	84

Time Corrections

All events on this *Skygazer's Almanac* are plotted for an observer at longitude 0° and latitude 50° north, a reasonable compromise for the countries of northern and central Europe. However, you need not be on a boat in the English Channel to use the chart. Simple corrections will allow you to get times accurate to a couple of minutes anywhere in the world's north temperate latitudes.

To convert the charted time of an event into your civil (clock) time, the following corrections must be made. They are given in order of decreasing importance:

• **Daylight-saving time (or "summer time").** When this is in effect, add one hour to any time that you obtain from the chart.

• **Your longitude.** The chart gives the *Local Mean Time* (LMT) of events, which differs from ordinary clock time by a number of minutes at most locations. Our civil time zones are standardized on particular longitudes. Examples in Europe are Greenwich Mean Time (or Universal Time), 0°; Central European Time, 15°E; and Eastern European Time, 30°E. If your longitude is very close to one of these (as is true for London), luck is with you and this correction is zero. Otherwise, to get standard time *add 4 minutes* to times obtained from the chart for each degree of longitude that you are *west* of your time-zone meridian. Or *subtract 4 minutes* for each degree you are *east* of it.

For instance, Copenhagen (longitude 12.5° east) is 2.5° west of the Central European Time meridian. So at Copenhagen, add 10 minutes to any time obtained from the chart. The result is Central European Standard Time.

Find your local-time correction and memorize it. In the table below at left are the corrections from local to standard time, in minutes, for some major cities.

• **Rising and setting.** Times of rising and setting need correction if your latitude differs from 50° north. This effect depends strongly on a star or planet's declination. (The declinations of the Sun and planets are listed in *Sky & Telescope*.)

If your site is north of latitude 50°, then an object with a north declination stays above the horizon longer than the chart shows (it rises earlier and sets later), while one with a south declination spends less time above the horizon. At a site south of 50°, the effect is just the reverse. Keeping these rules in mind, you can gauge roughly the number of minutes by which to correct a rising or setting time from the table above.

Finally, the Moon's rapid orbital motion alters lunar rising and setting times slightly if your longitude differs from 0°. The Moon rises and sets about two minutes earlier than the chart shows for each time zone east of Greenwich Mean Time, and two minutes later for each time zone west.

For reprints (item SGA25E) or to order a similar chart for latitude 40° north or 30° south, go to: shopatsky.com/collections/maps-globes/almanacs

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